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Microwave Journal

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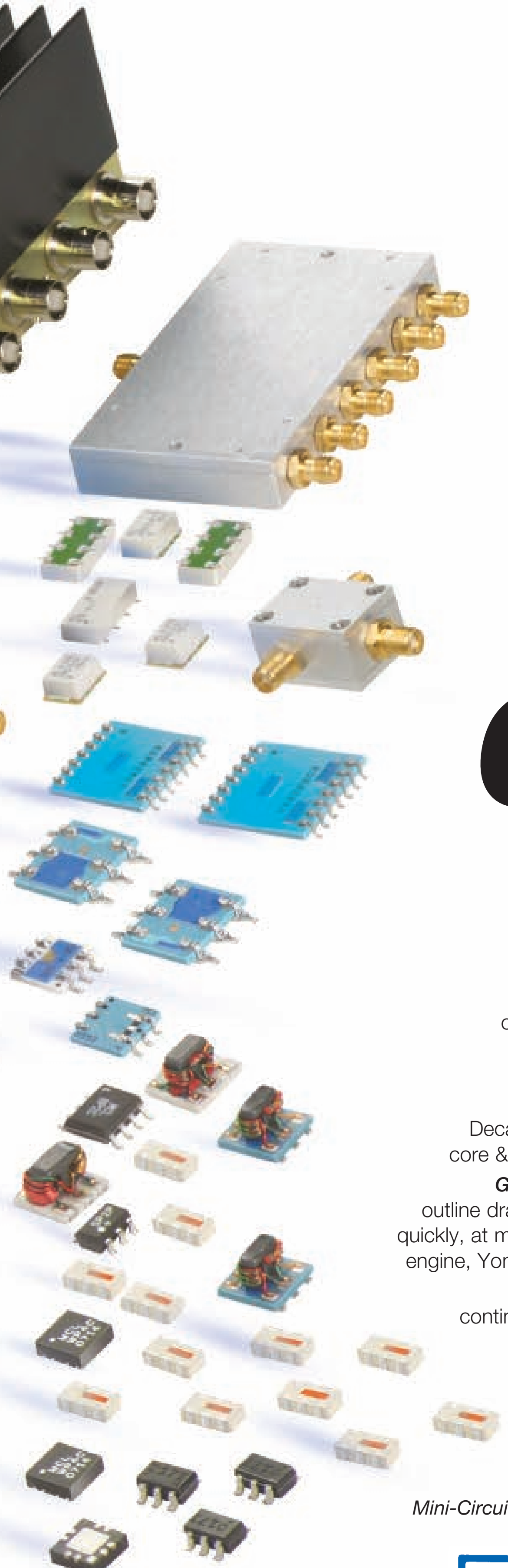

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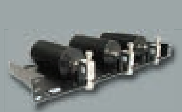

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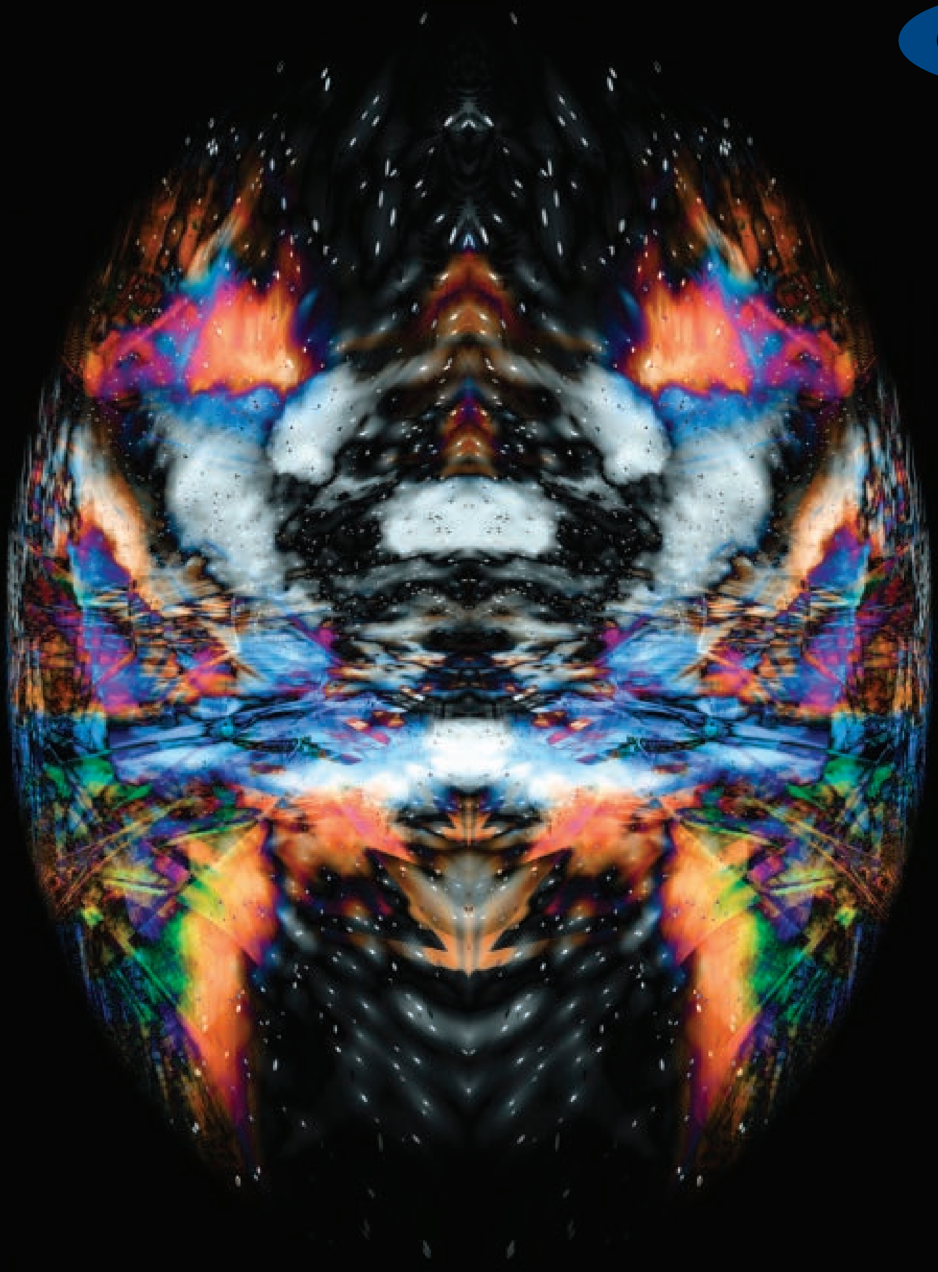

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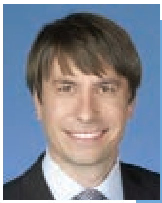

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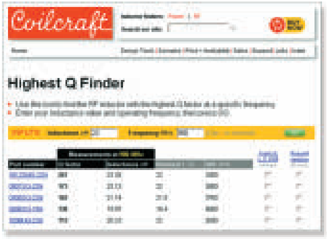

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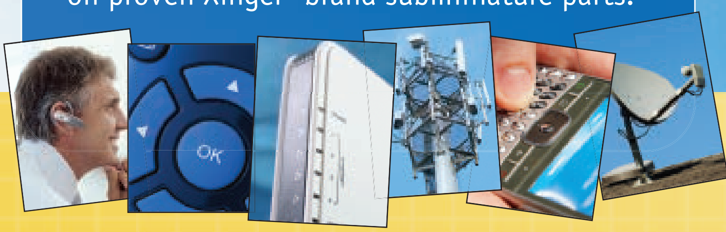

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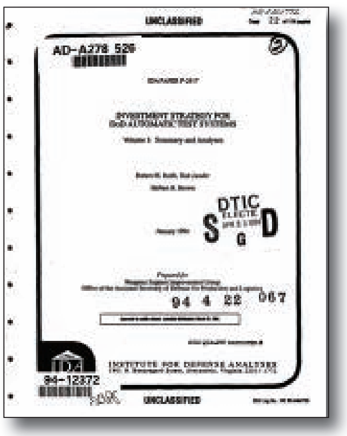
Updating Aerospace and Defense ATS

Commercial R&D and production test equipment is upgraded on a regular basis to keep pace with the short life cycles of commercial wireless products and rapid evolution of communication standards. Many commercial RFIC developers, for instance, typically replace their test systems every five to seven years to achieve optimum measurement speed and accuracy.

In contrast, test systems used for many aerospace and defense applications often have a lifespan of 25 years or more, in keeping with the platforms they support. Maintaining aging measurement equipment over such a long period has many associated costs and disadvantages. This special report looks at the challenges to instrument replacement for legacy testers and the underlying factors behind the Department of Defense's (DoD) long-term system upgrade strategy.



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INVESTMENT STRATEGY FOR DoD AUTOMATIC TEST SYSTEMS

Volume I: Summary and Analyses

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DOD'S ATS EVOLUTION

The DoD employs Automatic Test Systems (ATS) to identify weapon system failures, adjust components to meet specifications and assure that a component or system is ready for issue. An ATS includes the Automatic Test Equipment (ATE) hardware, operating software and associated Test Program Sets (TPS). The DoD spent over $50 billion on ATS procurement between 1980 and 1992. During this period, the standard practice was to develop a single ATS to support a single weapon system, leading to a proliferation of unique and hard to maintain test systems.

Following congressional direction in 1992 and 1993, the Office of the Secretary of Defense (OSD) issued a policy change on ATS acquisitions, stating that DoD components must satisfy all acquisition needs for ATE hardware and software by using "designated ATS families."[1] Faced with a growing number of aging test systems, the OSD wanted to mitigate the impact of ATE obsolescence in future systems through a process of standardization and consolidation.

The memorandum designated the Army's Integrated Family of Test Equipment (IFTE) and the Navy's Consolidated Automated Support System (CASS) as the initial DoD ATS families, and stipulated that commercial off-the-shelf (COTS) testers and components

DAVID VYE
Microwave Journal *Editor*

would be permitted for use at Depot and Factory levels of maintenance. The U.S. Navy was selected as the Executive Agent for developing the "strategic roadmaps to achieve commonality amongst DoD ATS and to ensure conformity with DoD mandates."[2]

In 1994, the DoD released its new policy calling for standardization on DoD ATS families and multiple weapon system support for new ATS acquisitions. Hoping to benefit from an economy of scale, this change was intended to minimize the number of unique ATS in an effort to reduce non-recurring ATS development and maintenance costs, while increasing supportability and equipment reliability.[3]

The DoD ATS Executive Directorate[4] established four main goals including:

- Reduce the total cost of ownership by stopping the proliferation of unique test systems through standardizing on designated ATS families or acquiring "validated" COTS test systems. A cost and benefit analysis over the complete system life cycle would be required for future ATS selections.
- Introduce interoperability – The closed architectures of most legacy DoD Automatic Test Systems prohibited interoperability, yet the flexibility required by the warfighter in modern conflict scenarios requires that the Services move toward interoperability among ATS including functions needed within a given Service and across Services.
- Reduce the logistics footprint to allow rapid deployment and support of weapon systems in the field.
- Reduce the time required to test, repair and return a failed system and component to service by improving the quality of diagnostics and fault isolation. This objective would help reduce the need to stockpile excessive spare parts.

A five-step process toward achieving these objectives was developed. The new guidelines included: 1.) The use of designated DoD ATS families to reduce total ownership costs; 2.) Implementation of a DoD ATS Technical Architecture Framework to serve as the target to which all DoD ATS would evolve; 3.) Joint development of test technologies between Services to leverage each other's investments in ATS-related R&D; 4.) Maintaining periodic system-level demonstrations as a "snapshot in time" of the available technologies; and 5.) Each individual Service would execute their own implementations of the ATS technologies and the ATS Framework through technology insertions or acquisition of new systems.

NAVY'S CASS

As directed, the Navy standardized on CASS to support electronic systems at Intermediate Maintenance Activities (IMA) both ashore and afloat in addition to Navy repair depots by 1994. CASS's modular design consisted of six different configurations including:

- Hybrid – provides the core test capability for general purpose electronics, computers, instruments and flight controls.
- Radio Frequency (RF) – provides ECM, ECCM, EW Support Measures, Fire Control Radar, Navigation Radar, Tracking Radar, Surveillance Radar and Radar Altimeter support capability to Hybrid testers.
- High Power – provides RF station capability plus the capability to test high power RADAR systems such as the APG-65 and APG-73.
- Communications/Navigation/Interrogation (CNI) – provides RF station capability plus communication, navigation, interrogation, and spread spectrum system support capability.
- Electro-Optic (EO) – provides Hybrid station test capability plus support capability for Forward Looking Infrared, Lasers/Designators, Laser Range Finders and Visual Systems.
- Reconfigurable Transportable CASS (RTCASS) – provides a man-portable CASS configuration using COTS hardware and software to meet USMC V-22 and H-1 support requirements as well as to replace mainframe CASS stations at USMC fixed wing aircraft (EA-6B, F/A-18 and AV-8B) support sites.

ARMY'S IFTE

The Army's approach called for developing several different testers known as the IFTE. The IFTE could support automated testing of Army ground vehicle, aviation and missile systems both in theater and out. The IFTE family focused on providing a vertically integrated ATS capability for sustainment and field levels of maintenance. Army planners needed to shift the capabilities of its existing ATS family toward one that was more highly mobile, rapidly deployable and general purposed, while also offering reconfigurable testing, screening and repair capability for its weapon systems and communications.[5]

These capabilities would facilitate the diagnosis and repair of critical components at the unit and sustainment levels of maintenance, supporting future and legacy combat platforms. The new strategy would allow the individual soldier to repair a faulty component with a Line Replaceable Unit (LRU) and return it for issue as needed. Previously, defective equipment was retrograded to a depot or OEM for test and repair.

Originally deployed in the early 1980s, the Army's Direct Support Electrical System Test Set (DSESTS) only supported Abrams and Bradley equipment and was the system-specific ATS that the DoD wanted to migrate away from. In contrast, the IFTE Base Shop Test Facility Version 3 (BSTF(V)3) supported a variety of ground combat systems and limited aviation components. Since its original deployment in the early 1990s, over 150 (V)3 systems have been produced to support various weapons systems including MLRS, Avenger, Paladin, Kiowa Warrior, and ground-based sensors.[6]

The IFTE includes two main categories of ATS, the Off-Platform ATS (OPATS) and At-Platform ATS (APATS). The OPATS consists of the Base Shop Test Station (BSTS) and Base Shop Test Facility (BSTF), the Electronic Repair Shelter (ERS) and the Commercial Equivalent Equipment (CEE). The APATS includes the Maintenance Support Device (MSD). Current and future Army's ATS programs aim to support its Modular Force structure and have evolved significantly over time.

The IFTE BSTF(V)5 with an added Electro-Optics Test Facility (EOTF) is the current field operational Army test station. It provides support to the Kiowa OH-58D Mast Mounted Sights and Apache AH-64D electro-optical

LRUs at field Aviation Intermediate Maintenance (AVIM) levels. EOTS tests laser transmitters, receivers, spot trackers, forward-looking infrared systems (FLIR) and TVs. The EO system uses the Navy-developed Electro-Optical Subsystem (EOSS+) to conform to all DoD standardization objectives. The IFTE BSTF(V)6, also known as the Next Generation ATS (NGATS), will be the newest ATS in the Army's IFTE product line.

THE DOD ATS FAMILY EXPANDS

The Joint Services Electronic Combat System Tester (JSECST) represents a joint USAF-USN procurement program featuring a flight line electronic warfare systems tester for end-to-end functional testing capability of electronic combat systems installed in or on operational aircraft. This tester was not considered a major ATS acquisition and could be approved by the ATS manager in any of the four services since it was built to work with multiple Navy, USAF, Army and Marine platforms.

The JSECST capabilities include threat representative simulations and technique/signal response analysis. Since completion of production in March 2005, JSECST hardware and software is being sustained by WR-ALC to support Air Force, Navy, Army and Marine users. The total DoD acquisition quantity includes 121 Core Test Sets for Air Force and 125 for Navy as well as JSECST core test sets for USMC and Army.

The Marines mostly used the Navy's RT-CASS units while developing their own Third Echelon Test System (TETS) for depot/field repair and diagnostic test support starting in the mid-1990s. TETS would provide the USMC with a capability to test, diagnose and screen a wide variety of electronic and electro-mechanical units at the ground forces organic maintenance levels. TETS would also function as stand-alone General Purpose Electronic Test Equipment (GPETE) to support testing of analog, hybrid and digital technologies with basic RF and EO configurations. Being highly mobile, TETS needed to be man-portable and operable from vehicle power.

In 1998, the DoD ATS Executive Agent approved the USMC's Marine Corps Automatic Test Systems (MCATES) as a new DoD ATS Family with the Third Echelon Test Set (TETS), AN/USM-657, being the basic family member within MCATES. Recently, the TETS capabilities have been expanded with the VXI-based virtual instrument portable equipment repair/test or VIPER/T system.

USAF EMBRACES VDATS

Back in 2003, nearly ten years after the initial call to standardize ATS within the DoD, the US General Accounting Office (GAO) investigating the adoption of the common ATS mandate found a lack of conformity across all the armed services and an unwillingness to comply, especially within the Air Force. The GAO report found a general lack of guidance, support and funding for the mandate. The report also discovered that the Air Force, with its preference to procure and manage unique ATS as part of any parent weapon system, lacked

a service-level ATS standardization policy.

With little substantive data supporting the projected benefits, standardization received little support within the Air Force. While the one tester per weapon approach was wasteful with its redundant procurement and development efforts, procuring common ATS for independent programs was believed to significantly complicate schedules and requirements. As a result, many of the test systems procured during the 1980s remained in service through the mid-2000s. By 2005, the same year that the DoD released a new ATS master plan for reducing proliferation, life-cycle operations and support costs, many of the Air Force's ATS were facing severe aging and obsolescence problems.

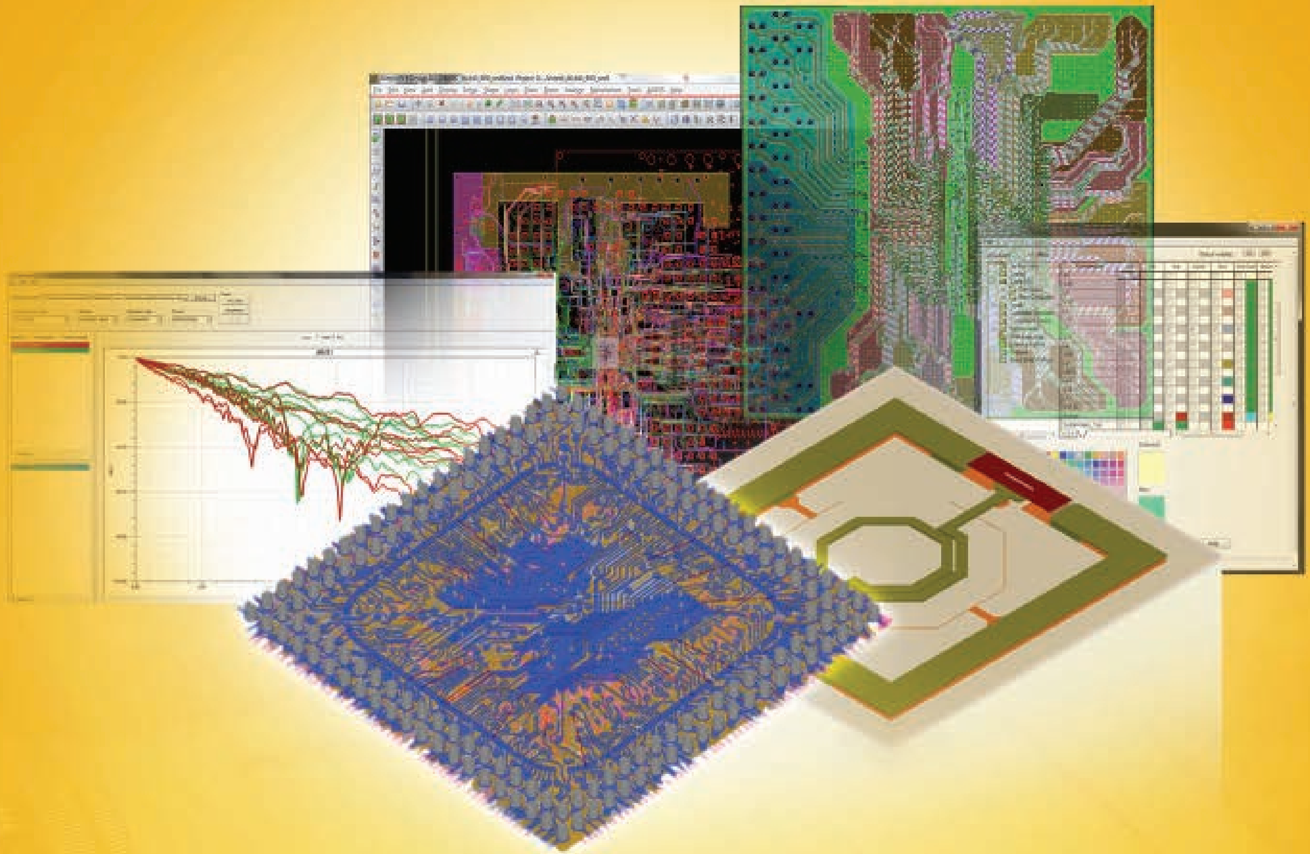
Lack of replacements for obsolete instruments resulted in shortages of spare parts and threatened ATS downtimes. In addition, non-portable Test Program Sets (TPS) impeded legacy system upgrades. The situation was impacting the readiness of military aircraft and weapon systems. Back in 2000, Dempsey Ventress, an engineer support element chief with the 402nd Electronics Maintenance Support Squadron at Warner Robins Air Force Base, devised the concept of a common-core tester. With help from the electronics and software community, Ventress refined his ideas and received funding for $57 million from the Air Force Material Command in 2005.

At the time, Robins Air Force base required 268 legacy testers to support its many weapons systems and aircraft components at the center. The average age of these testers was over 26 years. According to a report by Ventress, there were over 150 different configurations and 100 one-of-a-kind testers. The legacy testers were difficult and expensive to maintain, repair parts were often unavailable, test programs were not transportable and the number of (aging) technicians with a working knowledge of ATS operations was diminishing due to attrition.

In 2006, the new common-core architecture conceived by Ventress and his collaborators officially became known as the Versatile Depot Automatic Test Station (VDATS) – a part of the ATE transformation project. Construction began in January of 2007 and by August, eight VDATS DAs and two RF auxiliary units were completed. In late 2007, VDATS became a member of both the Air Force and DoD family of testers, meaning that any future weapons system development had to first consider utilizing VDATS as the test system (see ***Figure 1***).

The VDATS concept called for a Digital-Analog (DA) tester with a "common-core" set of state-of-the-art instrumentation. The DA tester was designed to provide capability to test 80 percent of the existing depot workload. Shortly after inception, additional RF test capabilities were added to address about 95 percent of the requirements of legacy testers in the Robins Air Logistics Center repair depot inventory.

In its first year of production, VDATS replaced existing test systems such as COMETS, DTS-70, AN/ALM-258, MMTS, WJ1560A/1580 (RF tester) and IFTE (the Army's family of testers). These ATS had



▲ *Fig. 1 Multiple VDATS with RF Auxiliary Unit at Warner Robins Air Force Base.*

been supporting a host of systems including: the avionics in the F-15 all-weather tactical fighter; the AN/ALQ-172 Countermeasures System (CMS) radar warning system; the AN/APR-46A receiving system, a rapid scanning, highly sensitive heterodyne receiver used to detect threats and provide warning of DF radar signals at very long range; and the Lockheed Martin AN/AAS-35(V) Pave Penny laser spot tracker carried by USAF attack aircraft and fighter-bombers (see ***Figure 2***). By 2008, Warner Robins was targeting to build 40 DAs and 18 RF auxiliary units to replace 80 existing testers by 2010 and eliminating 26 different testers this year.

EXTENDING ATS LIFE CYCLE

The DoD is currently in the second phase of system rationalization and ATS consolidation. The first phase allowed the costly proliferation of several hundred different test systems. The next phase, which began in 1994, focused on developing solutions based on major ATS families (VDATS, CASS, TETS, ITFE). Developments over the past 18 years have allowed these systems to cover the bulk of their predecessors testing capabilities with a more flexible solution, making them less vulnerable to equipment obsolescence.

The current generation of ATS families will eventually require either replacement or modernization. The Next Generation Automatic Test Systems (NxTest) Integrated Product Team (IPT) was chartered by the DoD to jointly develop the technologies necessary for implementation in the next generation of ATS. Ultimately, the goal is to have a unified test system across services. Conceived in the late 1990s, this third phase of consolidation is still some years away from being fully realized, but is bearing fruit today.

The IPT group proposed two main thrusts to drive the NxTest activities. First, define the elements in a test system with the most impact on costs and interoperability. The second focus was to develop a generic test system architecture. The open system architecture was needed to support new test needs and permit flexible updates and new technology while minimizing the impact on existing ATS components. This architecture could serve a broad range of commercial applications, helping to garner test industry support. To bring some common terminology between industry participants, the IPT proposed a new architecture based on the concept of "synthetic instrumentation."

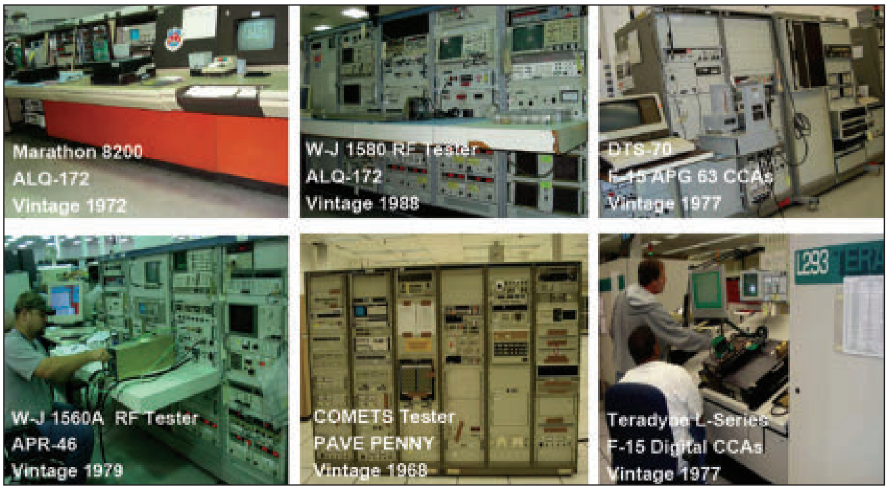
The DoD's Synthetic Instrument Working Group (SIWG) originally defined the SI term in 2004 as elemental hardware and software components with standardized interfaces and measurement software, which yield a smaller footprint and greater flexibility. The SIWG defined synthetic systems as: "A reconfigurable system that links a series of elemental hardware and software components, with standardized interfaces, to generate signals or make measurements using numeric processing techniques."[7]

Once the standard was defined, the group disbanded, and the remaining work moved to IEEE's Automatic Test Markup Language (ATML) Group and the IVI Foundation Synthetic Instrument Groups. IVI Class Drivers provide standardized API functions for test assets and by themselves provide a certain measure of interchangeability. The IVI class driver model fits naturally with the SI hardware model of finer measurement granularity.

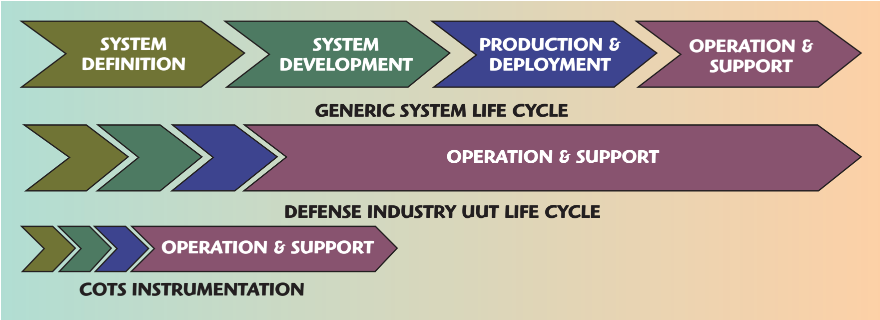
The stimulus or measurement capabilities of traditional RF test instruments could be achieved through a combination of software algorithms and hardware modules based on core instrumentation circuit building blocks. The concept of SI and IVI found its roots in the well-accepted technologies and techniques often found in software-defined radios, mobile phones and other communications systems.

When NxTest was first conceived, modularity was seen as a way to overcome obsolescence, the major downside of COTS hardware. Supporting platforms that will be operational for 25 years and more leads to a significant mismatch between the lifecycles of units under test (UUT) and the lifespan of the ATE (see ***Figure 3***). Because test equipment technology evolves at a rapid pace, individual components of ATE often become obsolete while the overall test system is still in high demand.

An ATS architecture that incorporates a broadly supported modular instrumentation hardware platform greatly minimizes the instrument obsolescence problem; therefore, it is not surprising that VXI and PXI are prominent in the newer AT. The mod-



▲ *Fig. 2 Legacy testers replaced by VDATS.*



▲ *Fig. 3 Defense industry devices feature life cycles significantly longer than commercial-off-the-shelf (COTS) components.*

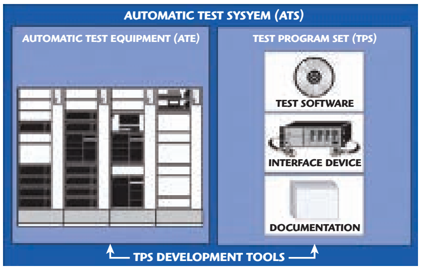
ular form factor increases the possibility of having multiple replacement options from second source suppliers while minimizing the amount of hardware to be replaced since common resources such as computing platforms, power supplies, cooling components and other support infrastructure elements are not integral parts of each instrument.

Replacing instrumentation hardware is just one of the challenges in maintaining ATS support over a long time period. It is also necessary for replacement hardware to perform the existing verified and accepted tests. Existing tests rely on both the instrumentation and the Test Program Set (TPS), which may be unique to each UUT (see ***Figure 4***). Any given TPS, which includes development and integration, support documentation, software and interface components, represents a significant financial investment. For this reason, support organizations prefer to leverage an existing TPS.

Since redevelopment of a TPS is costly, ATS systems designed with an abstraction layer between the TPS and the test station hardware assets offer a significant advantage in reducing the expense of obsolescence. A hardware abstraction layer, sometimes referred to as a software wrapper, makes it possible to develop tests with generic commands for controlling test assets instead of using vendor unique syntax. Separating the commanding functionality from unique syntax protects the TPS investment during an upgrade.

REALIZING NEXT GEN ATS

NGATS is designated as the Army's implementation of the multi-service Agile Rapid Global Combat Support System (ARGCS), a FY04 DoD Advance Concept Technology Demonstration (ACTD) project to develop a



▲ *Fig. 4 Typical ATS showing relationship with TPS development tools, documentation and supporting software.*

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DANL	-155 dBm/Hz	-155 dBm/Hz	-164 dBm/Hz
Sweep time	< 0.9 s	< 0.7 s	< 0.4 s
Weight with battery	3.6 kg (7.9 lbs)	3.6 kg (7.9 lbs)	3.6 kg (7.9 lbs)

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single tester that will incorporate all the test technologies currently maturing to achieve rapidly fieldable, interoperable support capability. Designated as the "Army Standard" ATS, NGATS will be capable of assuming all current and projected ATS missions. The ARGCS integrator contract was awarded to Northrop Grumman Corp. in September 2004.

While meeting all maintenance levels of fault isolation, diagnosis, and repair needs of current and future systems, the NGATS design will allow the ATS to be linked to Automated Information Systems/Networks in order to communicate critical maintenance data. The development schedule calls for backward compatibility, allowing the NGATS to replace DSESTS in FY10, IFTE BSTF(V)3 in FY13 and IFTE BSTF(V)5 in FY15. This evolutionary strategy will yield one common Army ATS, which will be the DoD standard, joint service capable and will be networked within the Army logistics system.

Benefits of NGATS include:

- VME- and VXI-based instrumentation for flexibility and easy modification for future technologies.
- Reconfigurable, modular, single solution.
- Open architecture, Standard COTS instruments, Plug-n-play software.
- Uses the same TPS hardware/software in factory, field or depot.
- Enables isolating LRU faults and screen shop replacement units (SRU) at forward areas for quick LRU turnaround and to minimize the spares pipeline.
- Reconfigurable to adapt to new weapons system technology.
- Reduces maintenance, support training and logistics costs.

Private contractors and ATE vendors will be responsible for integrating all identified TPSs and any TPS software processes and related tools required for DSESTS TPS migration to NGATS. The new test station must be backward compatible with all DSESTS, BSTF(V)3 and BSTF(V)5 station capabilities and interfaces and shall retain all legacy characteristics in order to maintain legacy DSESTS and IFTE TPS performance while taking advantage of the full range of modern test station capabilities.

In March of last year, an Army solicitation (W15QKN-11-X-E007) was posted online stating that the Government was in the process of defining its acquisition strategy to produce and operationally field NGATS test stations to the warfighter, replacing existing mainframe ATE stations starting no later than FY13. A draft RFP was expected for issuance 1st QFY12 with a formal RFP expected to follow during 2nd QFY12. The contract type will be Firm Fixed Priced based on full and open competition. The anticipated production quantities will be 150 NGATS. The production rate is anticipated to be 40 units per year from FY13 thru FY17.[8]

Just a month prior, Northrop Grumman and DRS Technologies announced that they had been awarded a $50 million contract for low rate initial production (LRIP) replacement for the current ITFE and other Army off-platform testers. The system would initially test the electronics and

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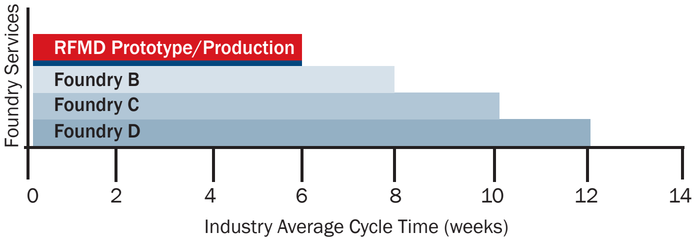

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weapon systems in heavy combat vehicles such as the Abrams/Bradley and will be used for Stryker depot efforts starting in 2012.

Under the terms of a LRIP contract, the Northrop Grumman-led team would deliver a total of eight NGATS plus spares in 2012. In follow-on phases, NGATS will be capable of supporting the Common Remotely Operated Weapon Station, Kiowa Warrior helicopters and missile launchers, as well as a variety of other existing and future weapon systems. DRS Technologies and Northrop Grumman had begun partnering on NGATS over a decade ago, with each company bringing over 25 years of experience developing the DSESTS and ITFE, respectively. This past month, the companies announced the delivery of the first NGATS under the LRIP contract.[9]

NAVY UPDATES ITS ATS

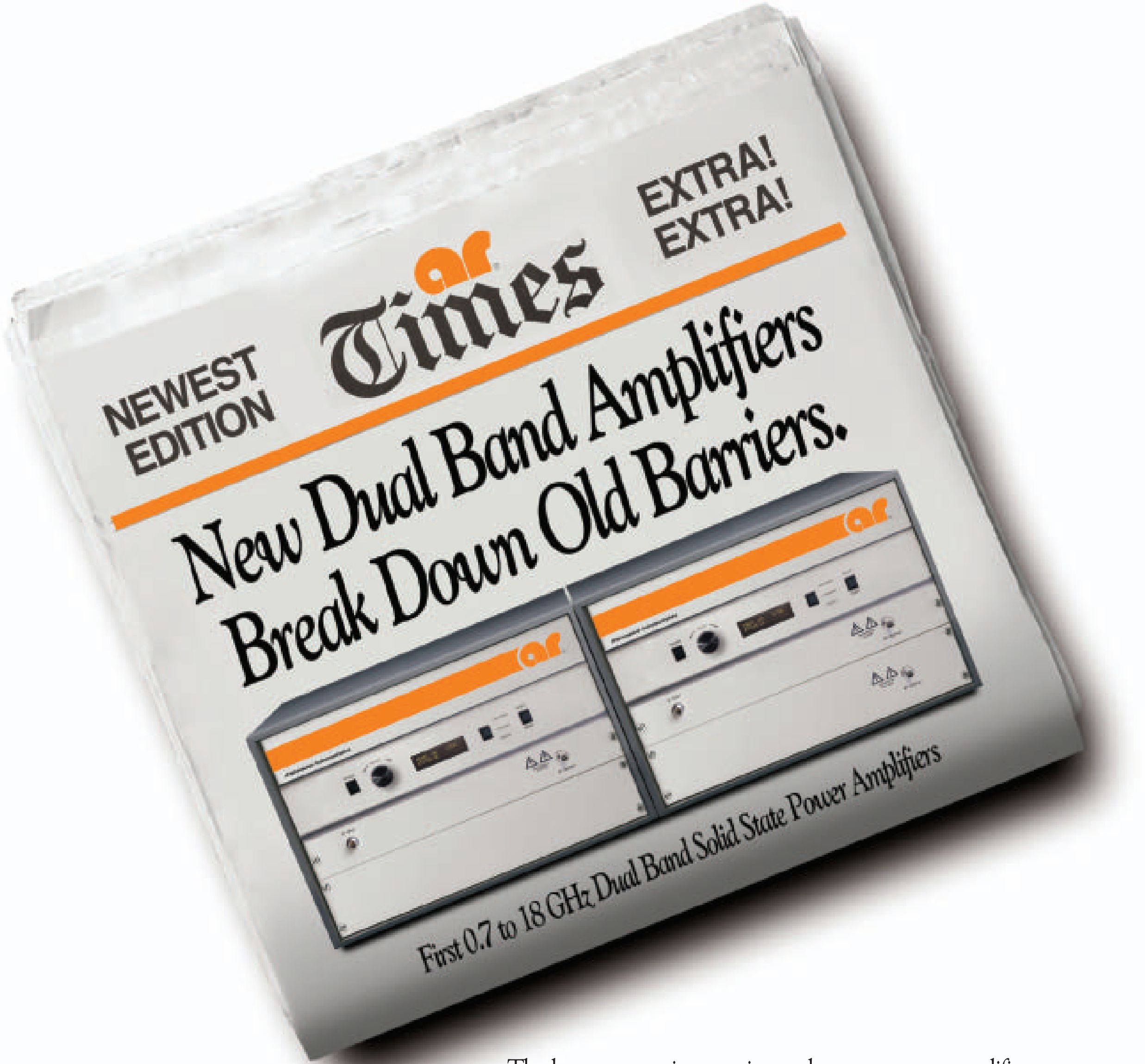
Legacy mainframe CASS systems are approaching the end of their useful service life. The Navy will modernize its ATS needs with the eCASS – the CASS Modernization Program, replacing all five current CASS configurations (Hybrid, RF, CNI, HP and EO). The projected inventory calls for 382 eCASS stations to eventually replace 553 mainframe CASS stations and 160 RTCASS stations. The initial eCASS development contract was awarded in March 2010 to Lockheed Martin Global Training and Logistics with initial operations scheduled to start around 2016 and full operations slated for 2018.[10]

The RFP to replace the legacy CASS mainframe calls for the re-utilization of approximately 750 existing CASS Test Program Sets while maintaining or improving the fidelity of test, run-times and performance. Lockheed Martin will be responsible for any TPS software processes and related tools required for CASS TPS migration to eCASS. The new test station shall have a compatibility mode that will emulate existing CASS station characteristics in order to maintain legacy CASS TPS performance and will also have an eCASS mode that permits taking advantage of the full range of advanced eCASS station capabilities. The program will also develop a set of eCASS TPS development suites, which includes a “CASS to eCASS” TPS conversion toolset.

THE IMPACT OF FUTURE DOD BUDGETS

While the White House has asked for $78 billon in DoD savings over the next five years, the DoD itself has proposed savings initiatives targeting a total of $154 billon ($34 billion AF, $35 billon Navy, Army $29 billon) over the same period in the interest of re-investing the difference ($70 billon) on much needed modernization, including new acquisitions (long range strike family, tankers, T-39 replacement, light attack aerial recon) as well as ongoing procurement (MQ-9 Reaper, Global Hawks, C-130 variants, F-35, F-22, etc.).

A major concern in the overall budget is the amount of duplicate infrastructure among the Services including weapon support (ATS) capabilities.



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As of March 2011, 50 VDATS have been fielded along with over 135 TPSs developed with over 275 more TPSs planned. Near-term ATE opportunities/contact opportunities called for by the Air Force include the B-1B ARTS REW replacement (23 stations, 32 TPS), Cruise Missile tester modifications (potential FY2012 opportunity), A-10 Combined Armament Tester (three-phase procurement – proof of concept, competitive production contract, follow-on TPS demo, production FY12-FY14), VDATS Performance Based Acquisition (to include test stations and ancillary equipment for manufacture/production and parts availability) and the CASS/eCASS/VDATS hybrid interface.[11]

This interface is currently in the analysis phase. The study is strictly focused on these families, looking to identify and produce a consolidated list of their differences, provide tester capability focus, consolidate this information into a design solution and determine if a two-way interface or TPS portability avenue is best. The study, which may result in a contract to undertake the effort, will also look into the potential for a future interface to the Army NGATS.

With the initial operations for eCASS slated for 2016 and a minimum service life of at least 10 years for an ATS platform, the actual merging of an inter-service ATS (among VDATS/eCASS/NGATS) called for in the NxTest initiative should be no sooner than 2026. Expected defense budget cuts will put greater pressure on the DoD to conserve existing test resources into the foreseeable future.

CONCLUSION

Over an extensive period of time, the DoD and individual branches of the Armed Services have done a remarkable job of recognizing and planning for the challenges of maintaining ATS for advanced weapon systems. In doing so, they have been able to address the need for long-term support in the face of constant ATE evolution and obsolescence. By anticipating and leveraging the advances in RF test equipment, digital hardware (i.e. FPGAs, high-speed DACs/ADCs, etc.) and software, combined with the concept of synthetic instruments and a strategic, modular approach to ATS architecture, the DoD has not only addressed its vast testing needs for today and the foreseeable future, defense planners have helped propel the state-of-the-art in test instrument technology for all. ■

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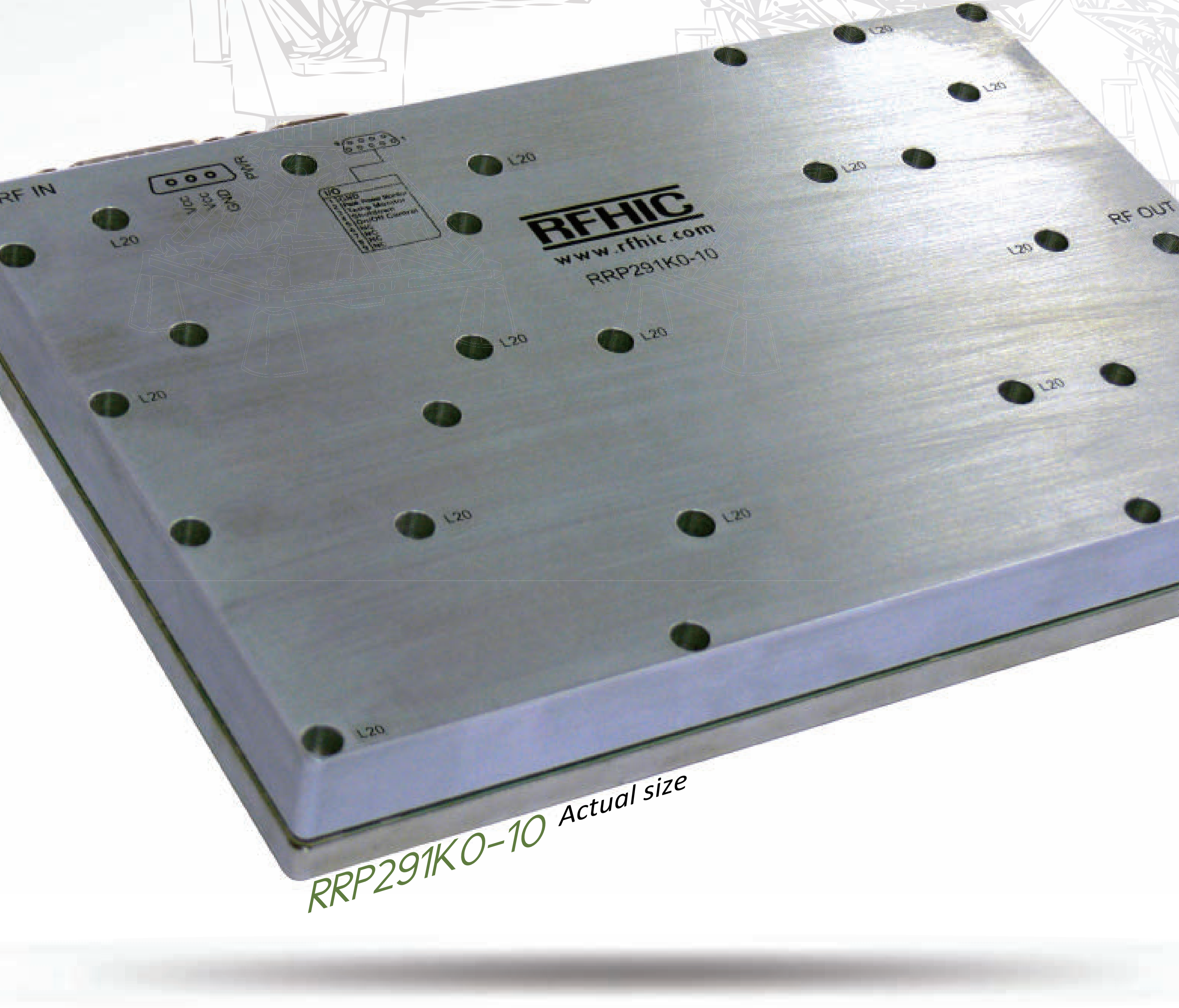

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Defense News

Dan Massé, Associate Technical Editor

Lockheed Martin's Milstar Satellite Surpasses On-Orbit Design Life

The second Milstar II military communications satellite, built by a Lockheed Martin team for the U.S. Air Force, has surpassed its 10-year design life of on-orbit service, providing the nation's warfighters with secure and reliable communications since its successful launch on January 16, 2002.

Designated Milstar II Flight-5, the satellite is the second of three on-orbit Block II spacecraft that offer a full range of enhanced communications for the U.S. military. The satellite is equipped with Ultra High Frequency and Low Data Rate Extremely High Frequency (EHF) payloads as well as a Medium Data Rate EHF payload that processes data at speeds up to 1.5 megabits per second. All Milstar satellites feature radio frequency crosslinks, allowing communication between on-orbit satellites.

The five-satellite Milstar constellation has surpassed 63 years of combined successful operations and provides a protected communication network for the joint forces of the U.S. military. In addition, it can transmit voice, data and imagery, and offers video teleconferencing capabilities.

The system is the principal survivable, endurable communications structure that the President, the Secretary of Defense and the Commander, U.S. Strategic Command, use to maintain positive command and control of the nation's strategic forces.

> *The five-satellite Milstar constellation has surpassed 63 years of combined successful operations…*

In addition to this 10-year milestone for Flight-5, each of the first two Milstar satellites has been on orbit for over 16 years, far exceeding their 10-year design life. The next-generation Lockheed Martin-built Advanced EHF satellites, joining the Milstar constellation, provide five times faster data rates and twice as many connections, permitting transmission of strategic and tactical military communications, such as real-time video, battlefield maps and targeting data. Advanced EHF satellites are designed to be fully interoperable and backward compatible with Milstar.

Raytheon Awarded Airborne Radar Contracts

Raytheon Co. booked $320 million in new contract awards related to its active electronically scanned array (AESA) radar programs for domestic and international customers. With active electronic beam scanning, which allows the radar beam to be steered at nearly the speed of light, Raytheon AESA radars optimize situational awareness and provide superior air-to-air and air-to-surface capability. The agile beam enables the radars to "interleave" in near-real time, so that pilot and crew can use both modes simultaneously.

After designing and building the world's first operational AESA fighter radar, Raytheon has continuously advanced its AESA technology. More than 300 AESA radar systems have been delivered by Raytheon to customers for multiple platforms worldwide and have been in service for more than 250,000 operational flight hours.

"Raytheon's AESA radars continue to set the industry standard for performance and reliability," said Mark Kula, vice president, Tactical Airborne Systems, Raytheon Space and Airborne Systems. "Our solid bookings in 2011 attest to this fact, and we expect to see continued growth in this area."

U.S. Navy Awards Northrop Grumman $37M for Next Phase of CANES

The U.S. Navy has awarded Northrop Grumman Corp. $37 million for the Consolidated Afloat Networks and Enterprise Services (CANES) production and limited deployment phase. The contract includes options that would raise the cumulative value of the contract to $638 millon, if all options are exercised. CANES will consolidate and modernize shipboard network systems to improve operational effectiveness and affordability across the fleet.

"Northrop Grumman is honored to continue our collaboration with the Navy to deploy CANES," said Wes Bush, chairman, chief executive officer and president, Northrop Grumman. "This selection recognizes Northrop Grumman's performance to date and our ongoing commitment to innovative solutions focused on affordability and technical excellence." Consolidation through CANES will eliminate many legacies, standalone networks and provide a common computing environment infrastructure for dozens of command, control, intelligence and logistics applications.

> *"CANES will enable critical C4I capabilities with integrated, flexible cybersecurity capacity…"*

"CANES will enable critical C4I capabilities with integrated, flexible cybersecurity capacity to quickly address evolving threats and missions using our adaptable information technology platform," said Linda Mills, corporate vice president and president of Northrop Grumman Information Systems.

Under the modification to the CANES contract awarded in March 2010, Northrop Grumman will produce the initial CANES shipsets for installation. CANES is planned

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to deploy on a fleet destroyer in late fiscal year 2012. Northrop Grumman uses the Modular Open Systems Approach-Competitive™ process for its CANES solution to achieve the lifecycle benefits of open-systems architecture and commercial off-the-shelf components and software.

CANES will provide an adaptable and responsive information technology platform to rapidly meet changing warfighter needs. The strategy strengthens the network's infrastructure, improves security, reduces the existing hardware footprint and decreases total ownership costs. In addition to providing greater capability, CANES will allow fleet end-users to benefit from reduced operations and sustainment workloads as a result of common equipment, training and logistics.

Harris Receives Contract for AMRAAM Missile Telemetry Modules

Harris Corp. has been awarded a multi-year, $11 million follow-on order for Warhead Replacement Tactical Telemetry Modules (WRTTM), supporting the U.S. Air Force Advanced Medium-Range Air-to-Air Missile. Under this newest order, Harris will deliver WRTTMs to the Tyndall Air Force Base in Florida. The contract brings the overall value of the WRTTM program to Harris to more than $181 million since 1991.

The AIM-120 Advanced Medium-Range Air-to-Air Missile (AMRAAM) is designed to take maximum advantage of the highly accurate, long-range target detection capabilities offered by the advanced radar systems of modern-day warplanes. During live test and training firings at Tyndall Air Force Base in Florida, the Harris WRTTM has provided weapon system evaluators with critical flight and performance information about the AMRAAM, as well as command-destruct capability for the missile — from the time it is launched from F-15, F-16 and F-22 aircraft until impact.

"The proven performance, reliability and availability of Harris telemetry modules are key contributors to the long-standing success of the Air Force's Weapon System Evaluation program," said Sheldon Fox, group president, Harris Government Communications Systems. "The Air Force continues to recognize our delivery performance as WRTTM plays an important role in weapons evaluations and other warfighter initiatives."

... the Harris WRTTM has provided weapon system evaluators with critical flight and performance information...

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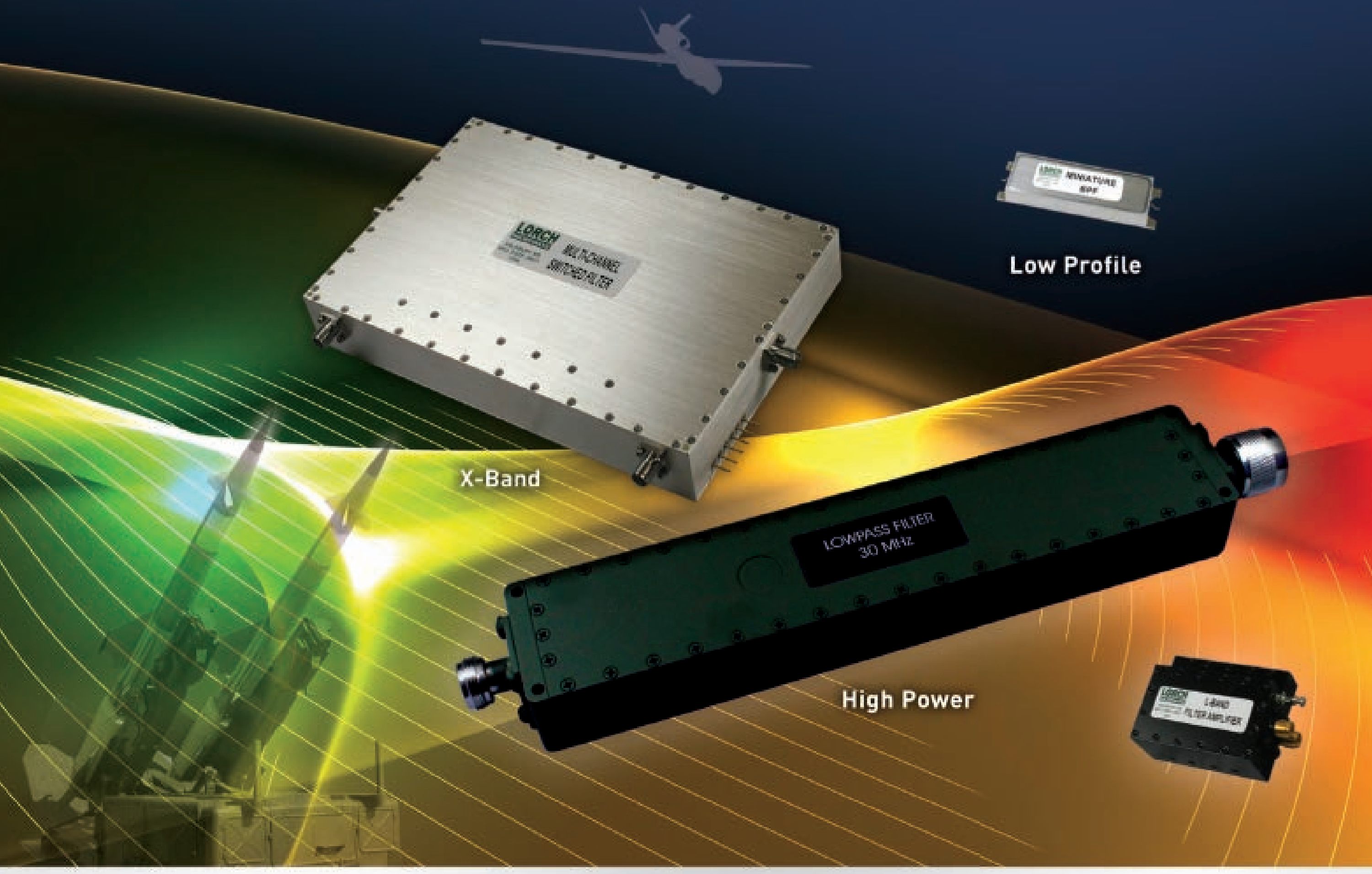

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Major SDOs Act on M2M Standardization

Standards Development Organizations (SDO), including ARIB, ATIS, CCSA, ETSI, TIA, TTA and TTC, have identified the need for a common cost-efficient, easily and widely available M2M Service Layer, which can be readily embedded within various hardware and software. As a result, the SDOs have identified the need for cooperative M2M community standards activity, and have agreed to jointly address the challenge of common standardized solutions by taking initial steps to form a global initiative for M2M Standardization.

This initiative will seek to develop globally agreed upon M2M end to end specifications and reports, with an initial focus on the Service Layer using common use cases and architecture principles across multiple M2M applications.

... the primary goal to support global harmonization and consolidation.

The initiative will develop specifications that will help drive multiple industries towards the goals of lowering operating and capital expenses, shortening time-to-market, creating mass-market economies of scale, simplifying the development of applications, leveraging the worldwide network for enhanced potential of services, expanding and accelerating global business opportunities, and avoiding standardization overlap. In addition, the initiative will focus on cooperative efforts with other standards organizations and fora, including those representing specific aspects of M2M applications.

The SDOs agree that participation in the global initiative will be open to interested organizations and parties to provide opportunities for various levels of participation and provide flexibility for inputs from all market segments. The SDOs will establish a simple and effective operational structure that is responsive to the needs of the various stakeholders. The initiative will seek to balance regional requirements and differences, and to address their respective timeframes, with the primary goal to support global harmonization and consolidation.

EU Research Funding Reaches 15 Percent Target for Businesses

Latest figures show that the European Commission is keeping its promises on research funding for Small and Medium Enterprises (SME). SMEs will receive 15.3 percent (€2.4 billion) of the Cooperation Programme budget of €16.3 billion committed so far under the Seventh Framework Programme (FP7). This surpasses the goal set by the European Parliament and European Council for FP7.

€2.4 billion had already been allocated to almost 8.900 SMEs by 1 January 2012. SME funding under the Cooperation Programme is estimated to remain above 15 percent for the rest of the period of FP7, thereby meeting the commitment taken by the European Commission.

... European Commission is keeping its promises on research funding for Small and Medium Enterprises.

Commissioner for Research, Innovation and Science, Máire Geoghegan-Quinn, said, "The commitment to the 15 percent budget target for SMEs is a commitment to growth and jobs. We have now reached that target and will remain committed to it. Our future research and innovation programme, Horizon 2020, will continue to support the competitiveness of SMEs, which are the bedrock of the European economy."

FP7 provides financial support for transnational research for and by SMEs wishing to innovate and improve their competitiveness in Europe's knowledge-based economy. A focus on SME-friendly measures in the calls of 2011 to encourage SMEs to participate, such as ring-fenced budgets for SMEs or topics highly relevant for SMEs, had a positive impact on achieving the 15 percent target. The last months of 2011 therefore saw a significant increase in the budget share allocated to SMEs and the Commission plans to strengthen such measures further in the future.

UK Invests in Highly Innovative Technology for Aerospace

The UK's aerospace sector is set to benefit from £6M of government investment in collaborative research and development projects that encourage innovative solutions to some of the higher-risk challenges facing the industry. The Highly Innovative Technology Enablers for Aerospace competition for collaborative R&D funding will support and encourage business investment in technology and innovation in high-risk, high-potential approaches that may not be fundable from companies' own resources.

...the industry faces new challenges such as globalisation, new competitors and climate change.

The Technology Strategy Board is to invest up to £5M in the projects and up to a further £1M may be available from the Engineering and Physical Sciences Research Council for projects with a significant, high-quality, academic research component. The projects will develop technology that will grow the sector and give the industry a competitive advantage in the global market.

The UK has the second largest aerospace industry in the world and while this position has been achieved through

UK businesses bringing leading-edge technologies to market, the industry faces new challenges such as globalisation, new competitors and climate change.

The continued growth of global air traffic presents an enormous opportunity for the UK. Meeting this demand sustainably, affordably, reliably and safely depends on continuous and intense research, innovation and technology application.

EU Funding for Aerospace and Defence Systems Project

Together with leading European real-time technology developers, industrial manufacturers and research organisations from France, Germany, Italy and the UK, the European Commission is backing the model-based methods and tools for avionics and surveillance embedded systems' (MADES) project until July 2012. The European Commission has partly funded the project to the tune of €2,450,000 under the Information and Communication Technologies (ICT) Theme of the EU's Seventh Framework Programme (FP7).

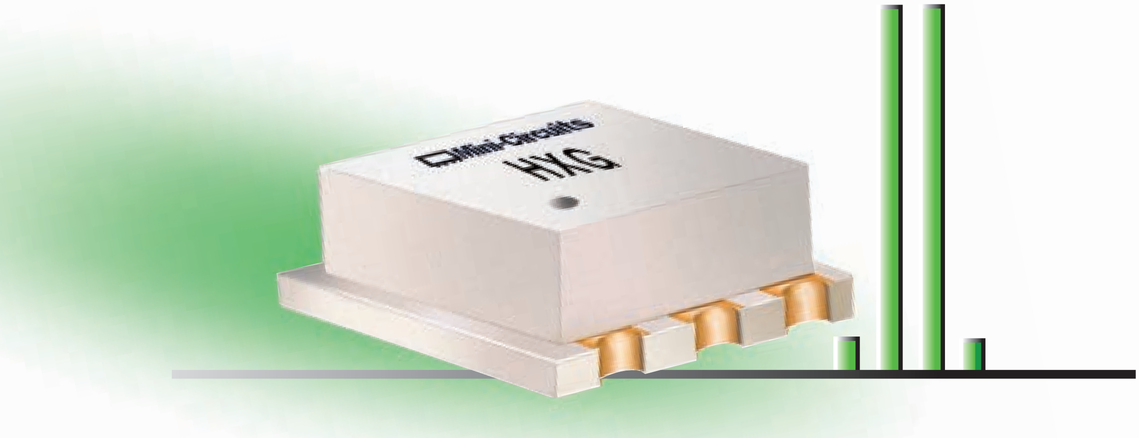
The aim is to develop an advanced framework covering all phases of real-time systems development, from design to code generation and deployment. This platform-independent framework will maintain the robust reliability essential for safety and mission-critical applications while providing improvements in developer productivity and reusability of code, lower costs for maintenance and retargeting to newer multicore platforms.

"This project will bring new innovations to the process of transforming software designs into deployable systems..."

The MADES project applies a comprehensive approach in researching new tools and technologies that support design, validation, simulation and code generation, while providing better support for component reuse. New annotation and verification methods are also being developed to ensure overall system consistency.

"The MADES consortium partners are experts in each phase of model-driven systems development. This project will bring new innovations to the process of transforming software designs into deployable systems that have the required reliability and assurances for safety-critical applications," commented David Lounsbury, chief technical officer at The Open Group in the UK. "We're confident the powerful model-based tools already being evaluated by industrial partners will allow applications developers to be more productive and manage expected increases in system complexity."

INCREDIBLE HXG AMPLIFIERS



IP3 +46 dBm!

P1dB +23 dBm   5V @ 146 mA

50 Ω in/out...no matching required   from $2.75 ea. (qty.1000)

Outstanding IP3, at low DC power. Mini-Circuits HXG amplifiers feature an eye-popping IP3 of +46 dBm, at only 730 mW DC power. A typical gain of 15 dB, output power of 23 dBm, and an IP3/P1dB ratio of 23 dB make them very useful for output stage amplifiers. All this, and surprisingly low noise figures (2.4 dB) extend their usefulness to receiver front-end circuitry! All in all, the HXG family delivers incredible performance with less heat dissipation, for greater reliability and a longer life.

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Mini-Circuits System In Package

0.25 x 0.27 x 0.09"

Model	Freq (GHz)	Gain (typ)	P1dB (typ)	NF (typ)	IP3 (typ)	Price (qty.1000)
HXG-122+	0.5-1.2	15 dB	23 dBm	2.2	47	$ 2.75
HXG-242+	0.7-2.4	15 dB	23 dBm	2.4	46	$ 2.75

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IF/RF MICROWAVE COMPONENTS

492 rev. A

Commercial Market

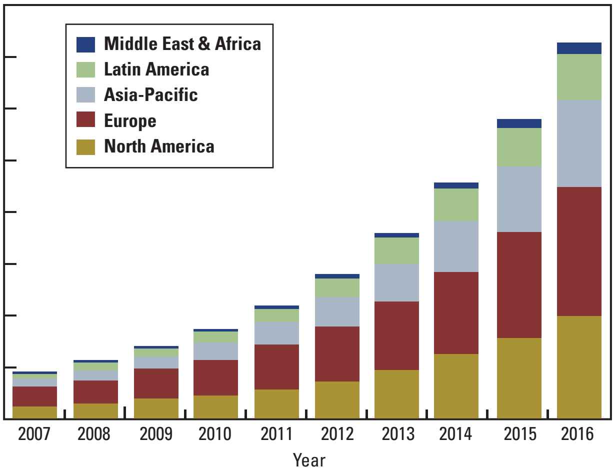
Dan Massé, Associate Technical Editor

Cellular M2M Connectivity Services Market to Rise by 2016

The M2M market has become a fully mainstream segment of the cellular industry. By the end of 2011, most major mobile operators in North America, Europe and the Asia-Pacific region had established M2M business units to focus their efforts in this fast growing market. The market for cumulative cellular M2M connections will rise from about 110 million connections in 2011 to approximately 365 million connections by 2016. This represents a compounded annual growth rate of roughly 27 percent by 2016 and translates to about $35 billion in connectivity services revenue.

ABI Research's new study, "Cellular M2M Connectivity Services," discusses the key trends, technologies and players impacting the cellular M2M connectivity services market.

Total Cellular M2M Connections by Region
World Market, Forecast: 2007 – 2016



Source: ABI Research

Actix Announces Highest Revenues

Actix, a leader in mobile network analytics and optimization solutions, announced record-breaking revenue levels for its fiscal year ending January 31, 2012. During the year, Actix revenues grew 29 percent, resulting in total revenues of over $52 million as the number of active customers surpassed 400. In addition, the company's profit increased by 35 percent, cash increased over 20 percent and more than 50 new employees were added to the company's roster, bringing the total to over 250.

The company's ActixOne Mobile Analytics and Optimization Platform saw revenues grow 71 percent as leading operators worldwide adopted the platform. ActixOne now has over 35 active customers, including six of the top 10 mobile network operators worldwide and strong partnerships with Ericsson, Huawei, NEC and NSN. Actix also announced the release of ActixOne 6.0 at the end of January 2012.

ActixOne now has over 35 active customers, including six of the top 10 mobile network operators…

The company's Analyzer software also recorded an excellent year with revenues growing 10 percent. Analyzer saw particularly strong demand from operators rolling out LTE networks.

"It's been a tremendous year for Actix and these results illustrate how operators worldwide are looking to get the most from their Radio Access Networks (RAN)," said Bill McHale, CEO of Actix.

Global Fixed Broadband Revenue to Generate $191B in 2012

Strong growth in both subscription and service revenue propelled the global fixed broadband market during 2011. Significant subscriber additions last year were made by all fixed platforms: DSL, cable and optical fiber. In some countries with a high penetration of DSL broadband service, the DSL subscriber base declined slightly, but it was offset by the growth in optical fiber subscriptions.

"Fiber broadband adoption has grown rapidly over the past years," says Khin Sandi Lynn, research analyst, broadband, ABI Research. "Consumers are becoming increasingly reliant on a number of data-intensive services such as high-definition online video services, IPTV and online gaming." Broadband operators are upgrading existing networks to meet rising bandwidth demand with some DSL operators going so far as to completely replace existing copper lines with pure optical fiber to offer fiber-to-the-home (FTTH) service, or upgrading copper lines to offer higher-speed services such as VDSL. Nearly five percent of DSL broadband customers worldwide had access to VDSL service in 2011.

At the same time, cable operators are aggressively upgrading networks to DOCSIS 3.0. Adoption of DOCSIS 3.0 service also continues to grow as cable operators race to compete with DSL and fiber operators. As an example, Germany's Kabel Deutschland offers super-fast 100 Mbps DOCSIS 3.0 service as low as €19.9 per month. North American cable operators, such as Comcast and Time Warner, are also rolling out DOCSIS 3.0 to compete against encroaching fiber-optic cable operators. Competitive pressures to offer faster broadband access will spur the upward trend in 2012 with global fixed broadband revenue expected to generate $191 billion and reaching $217 billion in 2016.

At the same time, cable operators are aggressively upgrading networks to DOCSIS 3.0.

Go to www.mwjournal.com for more commercial market news items

ABI Research's "Broadband Carrier Market Data," which is updated quarterly, profiles ARPU and service revenue by operator, by country and by technology. Detailed market trends and market forecast information for key regions and countries around the globe are provided.

M&A Activity Shakes Up Mobile Device Semiconductor Market

2011 marked a big year for mergers and acquisitions (M&A) in the mobile device semiconductor market. From Intel's acquisition of Infineon Technologies AG Wireless Solutions to NVIDIA's purchase of Icera, the mobile device semiconductor market has seen a lot of moving and shaking. Despite all the M&A activity, however, the market is still projected to remain relatively flat, with only 5.6 percent CAGR from 2010 to 2016, pushing the market from $25 billion in 2010 to $35 billion in 2016.

Intel's purchase of Infineon's wireless semiconductor business was a smart move for the company, as Intel previously did not hold any significant share in the handset market, despite attempts to break into it with its processors. Its purchase of Infineon's wireless business, while giving Intel an instant foothold in the market, also appears to be bearing fruit elsewhere. Intel's newfound market share in other areas of the handset IC market assisted in Intel's recent announcement that Motorola and Lenovo will release smartphones based on Intel processors in 2012.

"Most of the major suppliers are spending considerable resources on improving their platform solution capabilities," says Peter Cooney, practice director, semiconductors, ABI Research. "Through acquisitions and internal product developments, suppliers such as ST-Ericsson, Broadcom, NVIDIA, Marvell and Renesas are transitioning to a platform supplier model. Although Qualcomm currently leads the way, many other suppliers are increasing their capabilities and the competition between suppliers will increase significantly over the coming years."

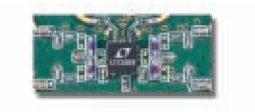
Despite all the M&A activity, however, the market is still projected to remain relatively flat…

Although Qualcomm currently rests easy as the most successful and largest supplier of mobile device semiconductors (holding almost 30 percent of the total market share), the company has partaken in the M&A trend as well, acquiring Atheros Communications to form the subsidiary Qualcomm Atheros, strengthening its wireless connectivity portfolio.

4G 4 U

Dual RF Mixer Needs Only 600mW

Actual Size



LTC5569 Total Solution Size: <220mm^2
Including External Components

300MHz to 4GHz, 26.8dBm IIP3 Dual Active Mixer

The LTC®5569 is the lowest power dual mixer with the highest performance and widest bandwidth. Its small form factor is optimized so you can pack more diversity or MIMO receiver channels in compact Remote Radio Heads. The mixer's wide frequency range allows you to build a wide range of multiband radios cost effectively. With integrated RF and LO balun transformers, the LTC5569 saves cost and precious board space. Each channel can be independently shut down, providing maximum flexibility to efficiently manage energy use.

Dual Mixer Family

Part Number	Frequency Range	IIP3 (dBm)	Conv. Gain (dB)	NF/5dBm Blocking (dB)	Power (mW)	Package
LTC5569	0.3GHz to 4GHz	26.8	2	11.7/17.0	600	4mm x 4mm QFN
LTC5590	0.9GHz to 1.7GHz	26.0	8.7	9.7/15.5	1250	5mm x 5mm QFN
LTC5591	1.3GHz to 2.3GHz	26.2	8.5	9.9/15.5	1260	5mm x 5mm QFN
LTC5592	1.7GHz to 2.7GHz	26.3	8.3	9.8/16.4	1340	5mm x 5mm QFN
LTC5593	2.3GHz to 4.5GHz	26.0	8.5	9.5/15.9	1310	5mm x 5mm QFN

Info & Free Samples

www.linear.com/product/LTC5569

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LINEAR TECHNOLOGY

Around the Circuit

Kerri Germani, Staff Editor

INDUSTRY NEWS

Anaren Inc. announced that it has formed a strategic alliance with **Tesla Controls** to develop and market a unique, streamlined approach to the typical familiarization routine, basic programming and development process of wireless applications for the ZigBee® Standard.

Cassidian and **Rheinmetall** have agreed to pursue Rheinmetall's Unmanned Aerial Systems activities together in a Joint Venture where Cassidian will hold 51 percent and Rheinmetall 49 percent of the shares. The ownership interests are to be assigned to Cassidian by mid-2012 once all the necessary authorizations and antitrust approvals have been granted.

Delta Air Lines announced an exclusive marketing agreement with **OnAsset Intelligence**, a provider of machine-to-machine (M2M) wireless asset tracking solutions, enabling Delta Cargo customers to view GPS location information on www.deltacargo.com. The agreement offers exclusive features and enables a seamless user experience for tracking and tracing cargo in transit on a customized web page. The service will be available for all cargo shipments across the Delta and Delta Connection fleet, which operates more than 5,000 daily flights to more than 340 destinations, 61 countries and six continents.

Linear Technology Corp. announced the acquisition of **Dust Networks Inc.**, a provider of low power wireless sensor network technology. The acquisition of Dust Networks, based in Hayward, Calif., will enable Linear to offer a complete high-performance wireless sensor networking solution. Dust Networks' low power radio and software technology complements Linear's strengths in industrial instrumentation, power management and energy harvesting technology.

Microsemi Corp. announced the company's RF Integrated Solutions facility in Folsom, Calif. achieved compliance with new AS9100:2009 (Rev C) quality system requirements for aviation, space and defense markets.

Molex Inc. has initiated several strategic business developments to further demonstrate its commitment to developing innovative interconnect technologies for next-generation healthcare devices. Molex has been delivering proven solutions to medical device manufacturers since 2005, and recently formed the new Medical Connector and Cable Assembly Business Unit to directly address the increasing demand for advanced interconnect products in this market. The acquisition of **Temp-Flex**, a manufacturer of micro-miniature wire, cable and continuous coils using biomedical coating and medical grade base metals, supports the company's goal of developing technologies that provide medical device manufacturers with the maximum in product efficiency, reliability and flexibility for the ultimate in patient care.

Murata Electronics North America announced that it has expanded its distribution agreement with **Future Electronics Inc.** to include the company's power solutions offerings. Future Electronics has significant experience in the industrial applications, lighting and energy markets, which is coupled with sales training, logistical resources and solutions support. This agreement builds on a relationship with the distributor that was first established in 1994.

For the 13th consecutive year, FORTUNE magazine has named **National Instruments** to its annual list of 100 Best Companies to Work For. This national recognition is based on an annual survey that randomly polls employees from hundreds of companies regarding the quality of their corporate cultures and filters results through strict criteria to select the best workplaces.

NEC Laboratories Europe's vehicular communication system successfully completed the multi-vendor interoperability tests for Car-to-Car and Car-to-Infrastructure (Car-2-X) communications system and was verified to be a mature implementation by the ETSI Centre for Testing and Interoperability at the first ETSI Cooperative Mobility Services Plugtests™.

TriQuint Semiconductor Inc. announced that it has begun work on Phase II of the Defense Advanced Research Projects Agency (DARPA) multi-year Nitride Electronic NeXt-Generation Technology (NEXT) program as a prime contractor. TriQuint has received $12.67 million in support of the NEXT contract to date. NEXT was created by DARPA to research and develop devices suitable for complex, high dynamic range mixed-signal circuits for future defense/aerospace applications. Phase II of the NEXT program is contracted to last 18 months.

TRM Microwave has been recognized for "Sustained excellence in product performance and delivery" by BAE's Joint Strike Fighter team. TRM received **BAE**'s award in a presentation ceremony at its South River Bend location in Bedford, N.H.

United Monolithic Semiconductors (UMS) has fully transferred all its activities to a new facility located in Villebon-sur-Yvette, France. A result of the move will be to improve efficiency and better serve the company's customers. Following the transfer back-end production has been resumed and support services are up and running.

Vishay Intertechnology announced the acquisition of **HiRel Systems LLC**, a supplier of high reliability transformers, inductors, coils and power conversion products. The purchase price was approximately $85 million, including repayment of HiRel debt, and subject to customary post-closing adjustments.


SYNERGY
TO THE RESCUE
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Synergy Microwave Innovative Product Highlights

Around the Circuit

CONTRACTS

API Technologies Corp. announced that it has received a $3.5 million new order from the Canadian Government to provide secure communication systems that will be used to satisfy mobile application security requirements. The order was awarded to EMCON Emanation Control, part of API's Secure Systems & Information Assurance division.

Comtech Telecommunications Corp. announced that its Tempe, Ariz.-based subsidiary, Comtech EF Data Corp., was awarded a $3.2 million contract for satellite communications ground equipment. A mobile operator in Latin America will procure equipment against the contract to support satellite-based mobile backhaul network expansion projects.

Kratos Defense & Security Solutions Inc. announced that its Integral Systems subsidiary executed a contract modification with the Air Force Space Command (AFSPC) and Missile Systems Center (SMC) to complete development and fielding of RAIDRS Block 10 (RB-10). The modification resulted in an additional contract value of $9.9 million on the RAIDRS contract.

Micronetics Inc. announced that it has been awarded a contract, valued at approximately $2.0 million, from a U.S. Department of Defense (DoD) prime contractor. The contract is to design, develop and deliver initial quantities of a key microwave subassembly.

ORBIT Communication Ltd., a subsidiary of Orbit Technologies Ltd. announced that it has been selected by STEC.COM LLC, a Russian space company, to supply a commercial ground station solution to support dual communication with Low Earth Orbit and Geostationary Earth Orbit satellites. The total value of the contract is estimated at $800,000.

The French defense ministry's integrated structure for through-life support of aeronautical equipment (SIMMAD) has awarded **Thales** the contract to support its equipment on board the Rafale aircraft in service with the French Air Force and French Navy. Under the terms of the contract, Thales is responsible for supporting Rafale's phased array radar, electronic warfare system, avionics, optronics and communication systems.

PERSONNEL

Innovative Micro Technology Inc. (IMT) announced that **Craig Ensley** has joined IMT as President and Chief Executive Officer effective immediately. He succeeds Dr. John Foster, who is resigning from the company to become CEO of one of IMT's major customers. Most recently before joining IMT, Ensley was CEO of DisplayLink Corp., a video networking IC company. Previously, he served as President and COO of Peregrine Semiconductor where he led the transition of the firm from a research stage to a high volume supplier.

AR RF/Microwave Instrumentation has announced the appointment of **Mike Alferman** to the position of Regional Sales Manager for the Pacific Rim. He joins Alan

Around the Circuit

Melnyk in servicing AR clients in this region. Alferman will provide service to India, Singapore, the Pacific Rim Countries, South America and South Africa. His experience includes working on the development of integrated RF modules that enabled the size reduction and functionality in the cell phones and laptops that are in wide spread use today.


▲ Mike Alferman

Printed circuit board manufacturer, **CC Electronics Europe** (CCEE) has appointed **Kevin Main** as its new software developer. He has seven years' industry experience and joins the company from Human eCreative where he played a key role in designing and establishing the functionality of CCEE's online quoting and order tracking portal. He will continue to develop the portal and will be tasked with taking various software projects forward.


▲ Kevin Main

Former Danish Chief of Defence, **Admiral Tim Sloth Jørgensen** has taken up the post as Senior Advisor in Terma. Based at the company's facility at Herlev, Denmark, he will predominantly focus on international assignments and markets. Terma develops products and systems for defense, civilian authorities and security applications, including command and control systems, radar systems, self-protection systems for aircraft, space technology and advanced aerostructures for the aircraft industry.

REP APPOINTMENTS

MegaPhase announced that **Partner Electronic** has been selected as the most recent addition to the MegaPhase sales team. Partner Electronic will offer a wide range of services, based on its proficient knowledge of test & measurement, EMC and RF technology solutions. Partner Electronic will be responsible for promoting and marketing MegaPhase's interconnect product line in Turkey.

MESL Microwave has appointed **C-LINK Technology Inc.** as the company's representatives in Taiwan. With over 15 years of experience in the RF and microwave markets, C-LINK Technology has a well respected reputation in providing the highest level of support to its military, space and commercial customers in Taiwan.

WEBSITE

CTT Inc. announced the completion of a new and expanded website: www.cttinc.com. The new website includes more than 175 all-new amplifier products and provides ease of use for visitors in search of high-power and low-noise amplifiers and subassemblies, within the frequency spectrum of 10 MHz to 100 GHz. The updated website includes product listings for high and medium power amplifiers including broadband, narrowband, rack-mount and the new line of GaN-based power amplifiers. Mechanical outline drawings are also available in PDF format for download.

THE MASTERS OF MIMO SERIES

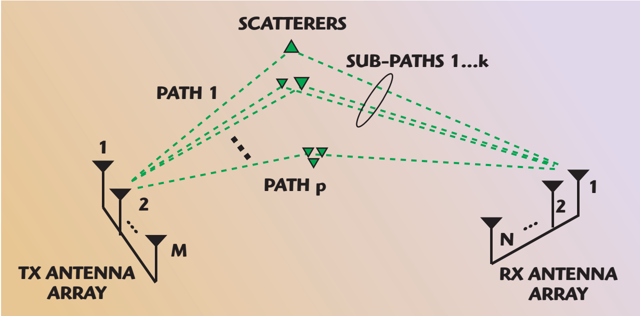
Trends in Wireless Testing

Mobile subscribers increasingly require high data rate applications as the amount of wireless Internet devices continues to rise. Therefore, higher spectrum efficiency and network capacity are required to keep these end-users satisfied and their applications working efficiently. High levels of application data use can be achieved by multi-antenna technologies, adaptive radio links, advanced network and multi-radio technologies. The complexity of user devices and wireless systems is increasing, due to the need for continuous system adaptation to the prevailing multi-dimensional radio channel conditions. One key driver is the multi-antenna technology, multiple-input, multiple-output (MIMO), which comprises spatial multiplexing, spatial diversity and beamforming. The technology development sets challenging requirements for radio channel modeling and emulation as well as for the testing of wireless communication networks, since the MIMO performance depends strongly on radio channel characteristics. Accordingly, the required capacity of radio channel emulators is increasing constantly, as performance verification for more and more complex wireless systems is needed.

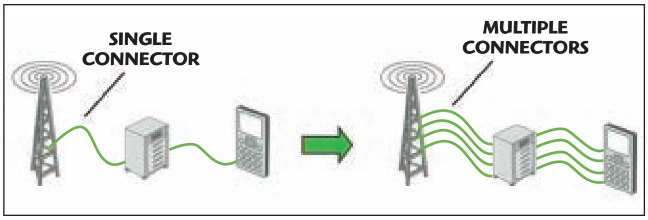
Several trends in wireless testing have been observed during the evolution of mobile technology from 2G to 4G and beyond. Four of them are directly related to radio channel modeling and emulation, namely trends from single-input, single-output (SISO) to MIMO, from conductive to Over-the-Air (OTA), from link to network and from a single network to multiple networks testing. Emulation of realistic channel models is crucial since the state-of-the-art wireless communications systems, such as LTE, adapt both the multi-antenna transmission (TX) and reception (RX) to the continuously changing radio channel. Due to the importance of radio channel emulation in these trends, channel models are reviewed first.

Multi-antenna channel models can be categorized in site-specific geometric models, site-independent stochastic channel models (that is correlation matrix based models) and Geometry-based Stochastic Channel Models (GSCM). Correlation matrix-based models are used in LTE user equipment (UE) conformance tests,[1] and in IEEE 802.11n and 802.11ac specifications.[2,3] The GSCM models rely on the geometry of propagation paths and antenna arrays, which makes it possible to test different antenna constellations with the same propagation model. These include 3GPP/3GPP2 Spatial Channel Models,[4] WINNER[5] and ITU-R IMT-Advanced models.[6]

Tommi Jämsä and Juha Ylitalo
Elektrobit, Oulu, Finland



▲ *Fig. 1 MIMO channel geometry showing TX and RX antenna arrays and propagation paths.*



▲ *Fig. 2 From SISO to MIMO testing.*

GSCM takes into account all four dimensions of the radio channel (frequency, time, space and polarization). It does not explicitly specify the locations of the scatterers, but rather the directions of the paths. The channel parameters for individual snapshots are determined stochastically from statistical distributions extracted from radio channel measurements. Antenna geometries and radiation patterns can be defined separately. Channel realizations are generated by summing contributions of propagation paths with specific small-scale parameters like delay, power, angle-of-arrival (AoA) and angle-of-departure (AoD). Superposition of paths results in a correlation between antenna elements and temporal fading with geometry dependent Doppler spectrum.

Elements of the MIMO channel are illustrated in ***Figure 1***, where each path consists of multiple sub-paths. The time variant impulse responses for any TX-RX antenna pair can be calculated in the GSCM model from the geometry as follows:

$$H(t;\tau)=\sum_{p=1}^{P}\sum_{k=1}^{K}F_{rx}(\bar{\varphi}_{p,k})^{T}A_{p,k}F_{tx}(\bar{\phi}_{p,k})\cdot \exp\left(j2\pi\upsilon_{p,k}t\right)\delta\left(\tau-\tau_{p,k}\right) \qquad (1)$$

where t is time, τ is delay, p is the number of paths, k is the number of sub-paths, and F_{rx} and F_{tx} are the element-wise antenna array dual-polarized field patterns for RX and TX, respectively. $A_{p,k}$ is the dual-polarized complex gain matrix of sub-path p, k, $\bar{\phi}_{p,k}$ is the AoD unit vector, $\bar{\varphi}_{p,k}$ is the AoA unit vector and $v_{p,k}$ is the Doppler frequency component of sub-path p, k. For more details, see references 5 and 6. All the parameters of Equation 1 can be based on measurements or theory. Equation 1 indicates that radio channel models are becoming more accurate. Testing of wireless systems with multi-dimensional channel models is essential in each of the four trends described below.

TREND 1: FROM SISO TO MIMO

The first trend in wireless testing is from a single-antenna SISO radio to multi-antenna MIMO radios (see ***Figure 2***). The capacity requirements of a MIMO channel emulator grow significantly along with the number of TX/RX antennas involved in the system. Conventional testing has focused on SISO devices with test instruments connected to antenna connectors. Such tests include conformance tests, which verify that a product meets the minimum requirements of a certain radio technology. For example, the 3GPP has defined product conformance tests for LTE devices. These tests specify radio channel models that are typically relatively simple tapped delay line models, in which the received signal y(t) is calculated via the convolution of a transmitted signal x(t) and a time variant impulse response h(t,τ) as follows:

$$y(t)=x(t)*h(t,\tau) \qquad (2)$$

where * denotes convolution. The processing requirement (number of multiplications per second) C for the SISO case can be calculated as

$$C=4BLD \qquad (3)$$

where B is the bandwidth and L is the number of taps. D denotes duplexing

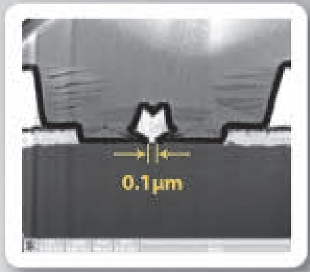
WIN SEMICONDUCTORS

Leading Global Communications

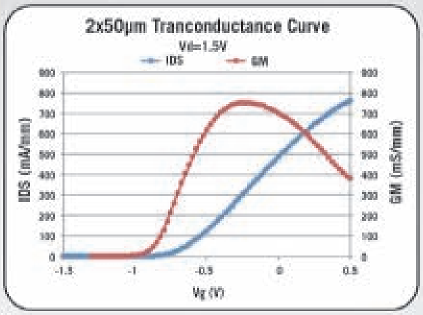
New 0.1μm pHEMT Technology

WIN is the world's largest and leading 6" GaAs foundry

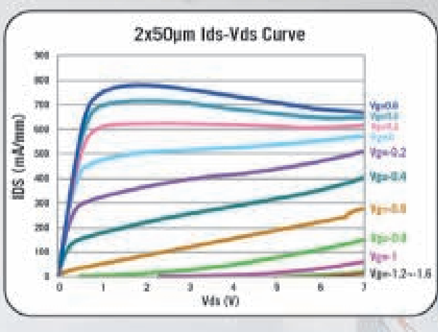
- 0.1μm gate length pHEMT technology
- 9V off-state breakdown voltage for power application
- Wafer thickness options of 50um (PP10-10) and 100um (PP10-11) available
- 860 mW/mm P_{sat} at 29GHz with Vd=4V
- 400 mF/mm^2 capacitor for design flexibility



PP10-10, 11 Tranconductance Curve



PP10-10, 11 I-V Curves



Comparison of WIN's millimeter wave pHEMT technologies

	PP25-21	PP15-50/51	PP10-10/11
Gate length	0.25μm	0.15μm	0.1μm
Operating Frequency	Up to 20GHz	Up to 30 GHz	Up to 90GHz
Max Drain Bias	8V	6V	4V
Max Id (Vg=0.5V)	490 mA/mm	630 mA/mm	760 mA/mm
IDSS (Vg=0V)	340 mA/mm	470 mA/mm	520 mA/mm
Max Gm	410 mS/mm	460 mS/mm	725 mS/mm
Vto	-1.15 V	-1.35 V	-0.95 V
Von (Diode turn on)	0.8 V	0.8 V	0.9 V
BVGD	20V (18V min)	16V (14V min)	9V (8V min)
f_T	65 GHz	90 GHz	130 GHz
f_{max}	190 GHz	185 GHz	180 GHz
Power Density (2x75μm)	1100 mW/mm @ 8V, 10GHz	870 mW/mm @ 6V, 29GHz	860 mW/mm @4V, 29GHz (2x50μm)

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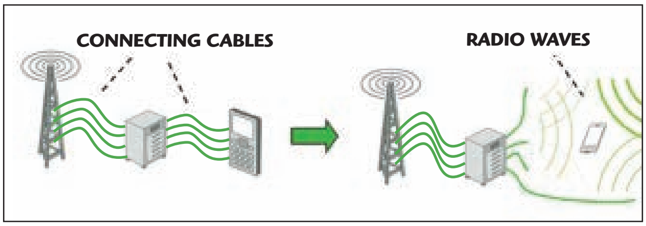


▲ *Fig. 3 From conductive to OTA testing.*

(D = 1: no duplexing, D = 2: duplexing) and the multiplier 4 comes from complex multiplication.

In MIMO testing, the number of fading channels is N × M, where N and M are the number of RX and TX antennas in the system. The LTE supports up to 4 × 4 MIMO mode (Rel. 8) and up to eight TX-antennas in beamforming-MIMO mode (Rel. 9). In the future, the LTE-Advanced (Rel. 10) defines an 8 × 8 MIMO mode, increasing the testing capacity requirements further. The number of multiplications per second in MIMO tests can be calculated from

$$C = 4BLNMD \qquad (4)$$

where the needed testing capacity increases significantly compared to the SISO case.

Another new element in MIMO systems is the correlation between device under test (DUT) antennas. The MIMO performance depends strongly on the correlation of device antenna signals, which necessitates advanced channel models. GSCM channel models apply simulated or measured antenna characteristics and therefore are capable of producing realistic correlations. This is important when modeling:

- Delay spread (frequency diversity)
- Doppler spread (time diversity)
- Angle spread/antenna separation (space diversity)
- Polarization (polarization diversity)

The MIMO radio channel changes dynamically at the rate defined by the Doppler characteristics. With this rate, the adaptive radio link adjusts the data transmission to the instantaneous MIMO radio channel state. In the case of high Signal-to-Interference-and-Noise Ratio (SINR) at a receiver, the transmitter can maximize the data rate by applying parallel data streams (spatial multiplexing), together with high-order modulation. This is possible only with favorable MIMO channel conditions. Obviously, in real life, the optimum channel conditions are rarely available, which underlines the importance of testing the MIMO performance in various radio channel conditions. GSCM models are well suited for this.

Advanced performance testing is needed to verify the actual MIMO device performance. By validating products with reliable performance tests, vendors and operators can gain a competitive advantage on the market by achieving better product quality with shorter development time and lower costs.

MIMO conductive testing is important for radio product development covering several essential aspects such as the baseband chipset, radio module and system testing in R&D. However, ultimate testing also requires accurate models of the base station (BS) and mobile terminal (MT) antennas and RF characteristics. The need for authentic RF modeling with the actual device antennas leads to MIMO OTA testing, which together with conductive testing, increases test effectiveness and validity.

TREND 2: FROM CONDUCTIVE TO OTA TESTING

The second trend is toward OTA testing (see ***Figure 3***). OTA testing employs radio waves, revealing the performance of the DUT with its final antenna and RF design. MIMO OTA testing reveals the end-to-end performance of the entire DUT, while conductive testing totally omits the antenna impact. OTA testing offers a very realistic testing solution to speed-up the development process and to verify the DUT performance in normal operation. Most MTs have integrated antennas, which cannot be separated without affecting the RF performance. This is the main reason why OTA testing is widely applied in SISO systems. However, it is even more important for MIMO systems, since the system performance is dictated largely by the correlation between antenna signals. This correlation depends on actual RF/antenna design and can be defined by the equation:[7]

$$\rho = \frac{\int \left(F_{u\theta}(\Omega) F^{*}_{v\theta}(\Omega) P_{\theta}(\Omega) + F_{u\varphi}(\Omega) F^{*}_{v\varphi}(\Omega) P_{\varphi}(\Omega) \right) d\Omega}{\sqrt{\int \left(\left| F_{u\theta}(\Omega) \right|^{2} P_{\theta}(\Omega) + \left| F_{u\varphi}(\Omega) \right|^{2} P_{\varphi}(\Omega) \right) d\Omega \int \left(\left| F_{v\theta}(\Omega) \right|^{2} P_{\theta}(\Omega) + \left| F_{v\varphi}(\Omega) \right|^{2} P_{\varphi}(\Omega) \right) d\Omega}} \quad (5)$$

where F denotes the antenna pattern and P the power angular spectrum of radio waves, Ω the angle variable, u,v to the antenna indexes and φ, θ to the polarization directions. This equation indicates that antenna and propagation effects have to be tested jointly.

The number of multiplications per second in MIMO OTA tests can be calculated from

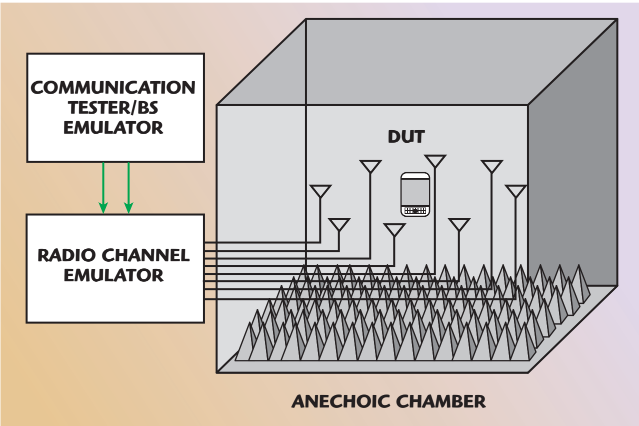
$$C = 4BLN_{OTA}MD \quad (6)$$

where N_{OTA} is the number of probe antennas (typically much larger than the number of the DUT antennas, N).

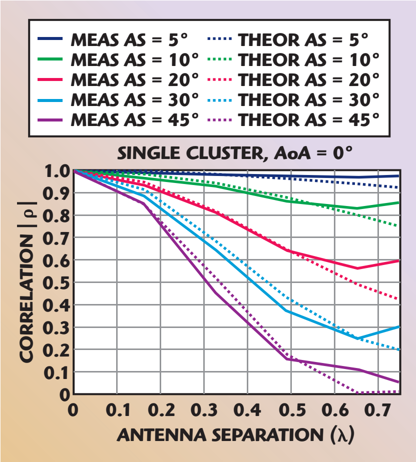
In MIMO OTA testing, the DUT is located in an anechoic chamber and the propagation environment is created by a number of probe antennas and a radio channel emulator (see ***Figure 4***). The setup enables the creation of a predefined radio environment that can be repeatedly applied. A measurement-based GSCM model can be used to create the desired propagation environment. OTA requires mapping of the channel model to the probe antenna constellation. Additionally, the antenna weights are optimized for the desired AoA distribution after calibrating for the effects of cabling, RF and probe antennas. The test setup can be optimized according to the size of the DUT.

The accuracy of the MIMO OTA technique has been verified via measurements. The most important parameter in MIMO testing is the antenna signal correlation, which can be verified by dipole antenna measurements. ***Figure 5*** shows the measured correlation for several different angle spreads (AS) using eight probe antennas. The correlation depends strongly on the antenna separation and the angular spread of impinging radio signals. The result is well in line with the theoretical one. Accordingly, the MIMO OTA is able to generate a wide variety of radio environments with large, medium or low correlation. Figure 5 shows that the accuracy is degrading as the DUT size is growing. However, if the number of probe antennas is increased to 16, the DUT size can be doubled. More validation results are available.[8]

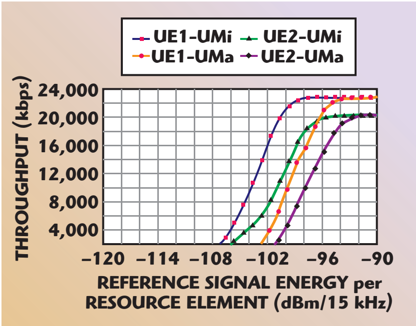
MIMO OTA testing allows performance comparison of commercial off-the-shelf devices giving the actual end-user experience with specific user applications. As an example, commercial LTE terminals have been tested showing the throughput dependence on the actual radio channel environment and on the MT itself (see ***Figure 6***). UE1 clearly performs better. It achieves a peak throughput at 4 dB smaller signal level in UMi than in UMa, due to lower antenna signal correlation (AS is larger in UMi). Single link testing focuses mainly on the physical layer testing of a single BS and a single MT. A more complete picture of the overall system performance is obtained only when the test setup includes multiple BSs and MTs.



▲ *Fig. 4 Anechoic chamber-based MIMO OTA.*



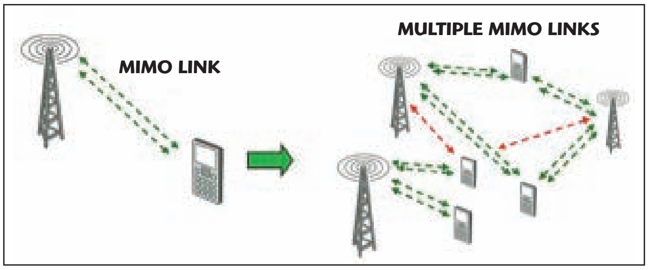
▲ *Fig. 5 Measured spatial correlation.*



▲ *Fig. 6 Throughput measurements in urban micro (UMi) and macro (UMa) cells using two different MTs (UE1 and UE2).*

TREND 3: FROM LINK TO NETWORK

Single link to multi-link (from link to network level) is the third trend in wireless testing (see ***Figure 7***). The complexity of a MIMO channel emulator grows exponentially with the number of BSs and the MTs. The importance of multilink testing is growing due to the need for maximizing the overall system performance (throughput, spectral efficiency and latency). Optimizing only the link level performance is not sufficient, since interference is a major limiting factor in a multi-cell and multi-user environment. In advanced wireless IP networks (such as in LTE), the system performance relies strongly on cross-layer algorithms such as the Medium Access Control (MAC) and Radio Link Control (RLC) layers, which coordinate the efficient utilization of physical layer radio resources. The MAC and RLC layers have a key role in scheduling data packets to each MT during their best possible MIMO radio channel state and, at the same time, minimizing multiuser and multi-cell interference. Wide-



▲ *Fig. 7 From link to network.*

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SKY67102-396LF	Cellular Infrastructure	2000–3000	2600	17.2	0.8	34	15	4 (3.3–5.0)	50 (20–90)	DFN 8L 2 x 2 x 0.75
SKY67001-396LF	Cellular Infrastructure	700–1000	900	17.5	0.6	40.5	21	5 (3.3–5.0)	100 (50–120)	DFN 8L 2 x 2 x 0.75
SKY67002-396LF	Cellular Infrastructure	1600–2100	1950	17.5	0.65	39.5	20	5 (3.3–5.0)	95 (50–120)	DFN 8L 2 x 2 x 0.75
SKY67003-396LF	Cellular Infrastructure	2000–3000	2600	17.5	0.88	39	19.7	5 (3.3–5.0)	100 (50–120)	DFN 8L 2 x 2 x 0.75
SKY67105-306LF	Cellular Infrastructure	600–1100	850	37	0.7	41	26	5 (3.5–5.0)	140 (120–155)	QFN 16L 4 x 4 x 0.90
SKY67106-306LF	Cellular Infrastructure	1500–3000	1950	35	0.65	37	24	5 (3.5–5.0)	100 (80–125)	QFN 16L 4 x 4 x 0.90
SKY67107-306LF	Cellular Infrastructure	2300–2800	2600	32	0.85	37.5	18.5	5 (3.5–5.0)	125 (50–145)	QFN 16L 4 x 4 x 0.90
SKY67012-396LF	General Purpose	300–600	450	16.5	0.85	24	14	3.3 (1.8–5.0)	15 (5–30)	DFN 8L 2 x 2 x 0.75
SKY67013-396LF	General Purpose	600–1500	900	14	0.85	26	15.5	3.3 (1.8–5.0)	15 (5–30)	DFN 8L 2 x 2 x 0.75
SKY67014-396LF	General Purpose	1500–3000	2450	13	0.95	26	15	3.3 (1.8–5.0)	15 (5–30)	DFN 8L 2 x 2 x 0.75
SKY65404-31	5.8 GHz WLAN and ISM Band	4900–5900	5800	13	1.2	20	9	3.3 (2.8–5.0)	11 (10–15)	DFN 6L 1.5 x 1.5 x 0.45
SKY65405-21	2.4 GHz WLAN and ISM Band	2400–2500	2450	15	1.1	24	15	3.3 (2.8–5.0)	12 (10–16)	DFN 6L 1.5 x 1.5 x 0.45

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band MIMO technology enables dynamic scheduling in space, time and frequency domains, which provides additional freedom in system performance enhancement.

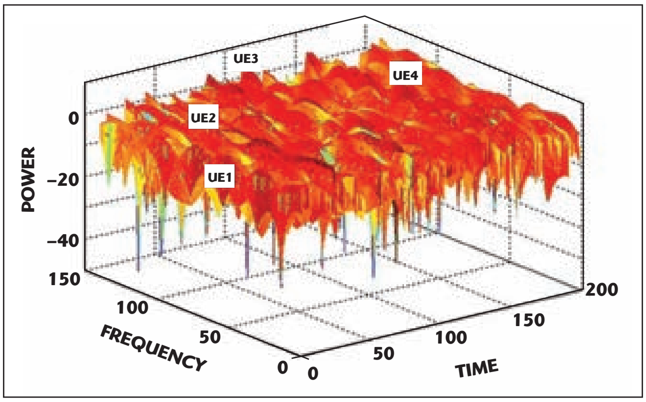
Figure 8 shows an exemplary allocation of four MTs at their preferred time-frequency resource block scheduled by the BS on one physical cell at one time instant. Each of them is given such a time-frequency block, which provides good link performance. In LTE downlink the smallest schedulable resource block corresponds to a bandwidth-time unit of 180 kHz by 1 ms consisting of 12 × 14 OFDMA subcarriers. High spectral efficiency of LTE is based on adaptive MIMO radio with advanced cross-layer algorithms, such as the packet scheduling in BSs. The scheduler implementation is vendor specific, so that the system performance may vary significantly among different products depending on, for instance, radio channel environments and system load scenarios. To assist scheduling, each terminal reports its multidimensional radio channel state information to the serving BS, including Channel Quality Indicator, Precoding Matrix Indicators and Channel Rank Indicators.[9] Based on this information and on the intra- and inter-cell interference condition, each BS is able to coordinate the use of dynamic multiuser MIMO radio channel, using best possible MIMO modes. Clearly, the LTE system performance is directly proportional to instantaneously and continuously changing MIMO channel characteristics as well as on prevailing system interference. This type of multiuser MIMO system optimization is extremely challenging.

Realistic system level testing in laboratory requires complete MTs and BSs with all functionalities. ***Figure 9*** illustrates such a multi-user and multi-cell MIMO test scenario, where the radio channel emulator produces numerous real-time MIMO channels. The system performance of a multi-cell, multi-user network can be evaluated using realistic radio channel environments. Due to the dynamic radio link techniques, it is important that the link adaptation can be repeatedly tested in desired MIMO scenarios with predefined radio channel environments, such as in application level testing.[10] One interesting topic is the coordination of inter-cell and intra-cell interference.

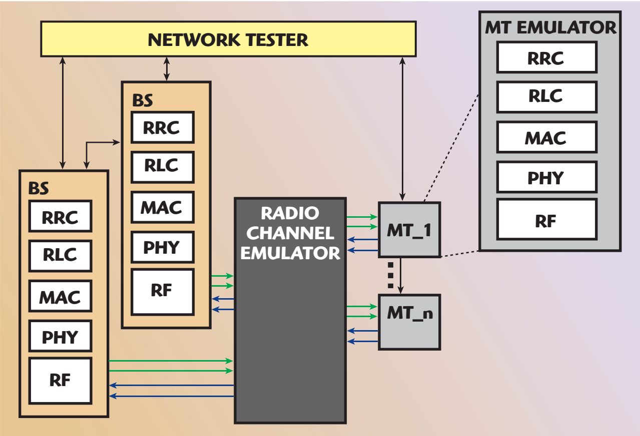
GSCM channel models are suitable also for network level performance testing in laboratory conditions, since they support features such as location, antenna height, antenna tilt and mobile route. However, the number of multiplications per second in network emulation grows with the number of radio links R in the network:

$$C = 4BLNMDR \tag{7}$$

For example, modeling of eight BS



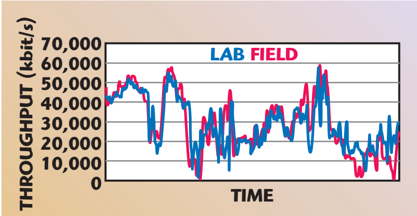
▲ *Fig. 8 Example of shared radio allocation for four users in one cell area.*



▲ *Fig. 9 Test scenario for multiuser system performance evaluation.*

cells and eight independent mobile users requires a 16 × 16 MIMO channel emulator, if a basic LTE with a 2 × 2 MIMO scheme is assumed. Assuming eight users with 4 × 4 MIMO and eight BS cells, a 32 × 32 emulator is required. Alternatively, this would allow the model of 16 BS cells and 16 users with a 2 × 2 MIMO mode.

For a site and multi-site specific performance evaluation, a Virtual Drive Testing (VDT)[11] can be performed in laboratory. In VDT, the actual radio channel conditions and network configuration are recorded and taken from field to the laboratory. The recorded channel data are replayed with the radio channel emulator to study handover and throughput performance in an area covering known cells (see ***Figure 10***). The field test can be repeated in laboratory if the radio channel and network configuration data are recorded along the test route. The VDT approach enables laboratory tests to run using measured radio environments



▲ *Fig. 10 Site specific LTE throughput test in field and laboratory.*

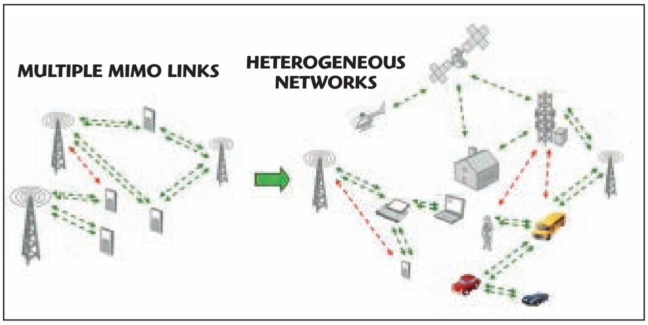
of problematic cells, for example. The testing requirements increase further when moving from a single wireless communication network to multiple networks, which deploy the available radio spectrum in different ways.

TREND 4: FROM SINGLE NETWORK TO MULTIPLE NETWORKS

The fourth trend is from single network to multiple networks testing. As new technology generations develop, they become available as new additional networks (see ***Figure 11***). Testing heterogeneous networks represents the ultimate challenge from the view point of system testing. Current cell phones are typically equipped with multiband 2G, 3G and WiFi connections – in the near future with LTE. From the beginning LTE networks will be deployed for data traffic, whereas the underlying 2G/3G will provide basic voice services and seamless mobility for wide area coverage. Looking at the future, ITU-R has defined guidelines for IMT-Advanced, which indicate that future, wireless systems should encompass new requirements.[12]

- High spectral efficiency
- High degree of common functionalities worldwide
- Service compatibility with legacy IMT systems and fixed networks
- Interworking capability with existing wireless systems

Coordinated use of available radio access systems becomes essential when heterogeneous networks develop further. For efficient use of the limited radio spectrum higher order MIMO, co-operative MIMO, interference coordination and adaptive antenna techniques are used at single network level. In parallel to that, the heterogeneous networks will provide additional methods for balancing the network load. One way is to utilize unlicensed radio access systems such as WiFi, where available, and added features such as device-to-device communications and relaying.



▲ *Fig. 11 From single network to multiple networks.*

This indicates that cognitive radios become important in exploiting the limited radio resources regardless of their location.[13] At the same time, it implies the highest complexity of test systems. There is a need for test system simplification and integration as the demand for testing of heterogeneous networks in realistic conditions is growing. Test systems with multiple frequency bands, dynamic radio channel conditions and propagation models with very wide bandwidths are required. Moreover, hybrid systems bring new challenges to testing (one example being the long propagation delays in satellite radio channels). The GSCM model is a good candidate also for multi-network testing, since it enables adjusting the model accuracy versus complexity.

SUMMARY

The above four trends set high requirements for testing wireless systems in the laboratory and especially for the modeling of the radio channels for complete wireless networks. Test systems will become more advanced due to higher bandwidths, increased number of antennas and multiple radio systems. This requires models with a high number of radio channels. This development indicates also that a higher degree of integration is crucial in advanced test systems. In each trend, the required number of radio channels increases in a multiplicative manner. In addition to the high number of channels, reliability, automation, configurability, usability and versatility of test systems will be also crucial in the future. ■

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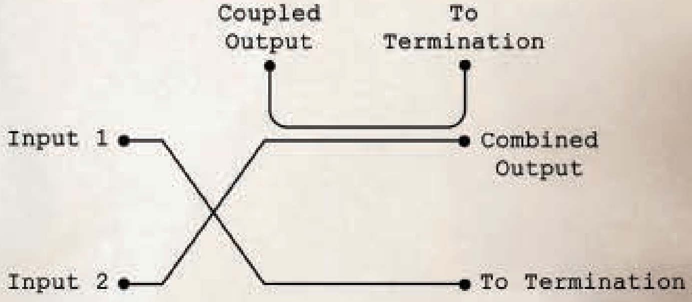

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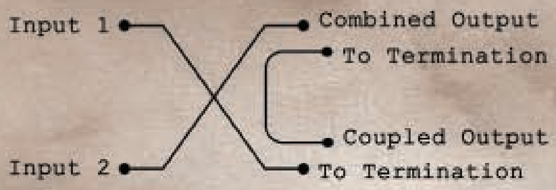

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DHDL20F	1805 - 1880 MHz	3-dB Hybrid	20-dB Directional	Available Now
DDDP30F	2500 - 2700 MHz	Doherty Combiner	30-dB Directional	April 2012
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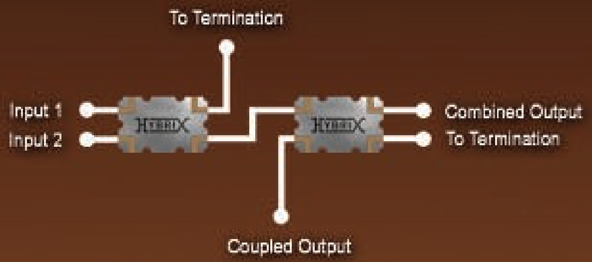

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Compact Transistor Models: The Roadmap to First-Pass Amplifier Design Success

Amplifier designers have been making use of modern transistor models since their first appearance in the mid-1970s. Models have allowed engineers to create advanced designs with first-pass success, without the need for multiple prototypes and design iterations. But with so many different modeling techniques, how does one select which one to use? The three most common types of models used in industry today are: physical models, compact models and behavioral models.

Physical models, as their name suggests, are based on the physics of the device technology. These models are dedicated to the transistor itself and not the overall circuit. Due to the nature of the model, complex model equations have to be used, which can lead to time-consuming simulations. The advantage of the physical model is that it can be successfully used over the largest operating range, compared to alternate methods, since equations are used to describe complex physical rules rather than actual measurement results.

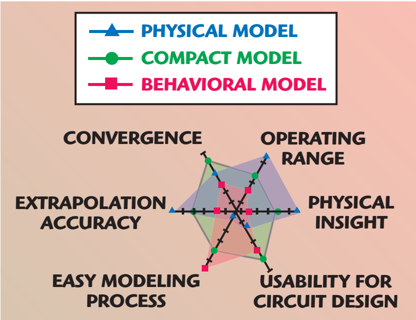

Fig. 1 Type of large-signal models.

Compact transistor models, based on measured IV and S-parameters, allow designers to shift focus from transistor designs to circuit designs. Extracted from quasi-isothermal pulsed IV and pulsed S-parameter data and validated with load-pull characterization, compact transistor models contain a reduced set of parameters. Unlike other model types, compact models take into account complex phenomena, such as electro-thermal and trapping effects. For simulations under nonlinear operating conditions, responses to complex modulated signals (such as EVM or ACPR) are accurately predicted as low-frequency and high-frequency memory effects are taken into account. Compact transistor models are ideal for die-level applications, as developing such a model from IV and S-parameters is straightforward and relatively quick. Packaged-transistor models need to include a die-level model as well as a bonding model and package model, and consequently can be time consuming and costly.

Behavioral models, based on frequency domain measurements, are far less flexible than physical or compact transistor models, but can be easily developed for any type of component (including die-level or packaged transistors). Behavioral models are considered "black-box" models, where only the responses of the com-

Tony Gasseling
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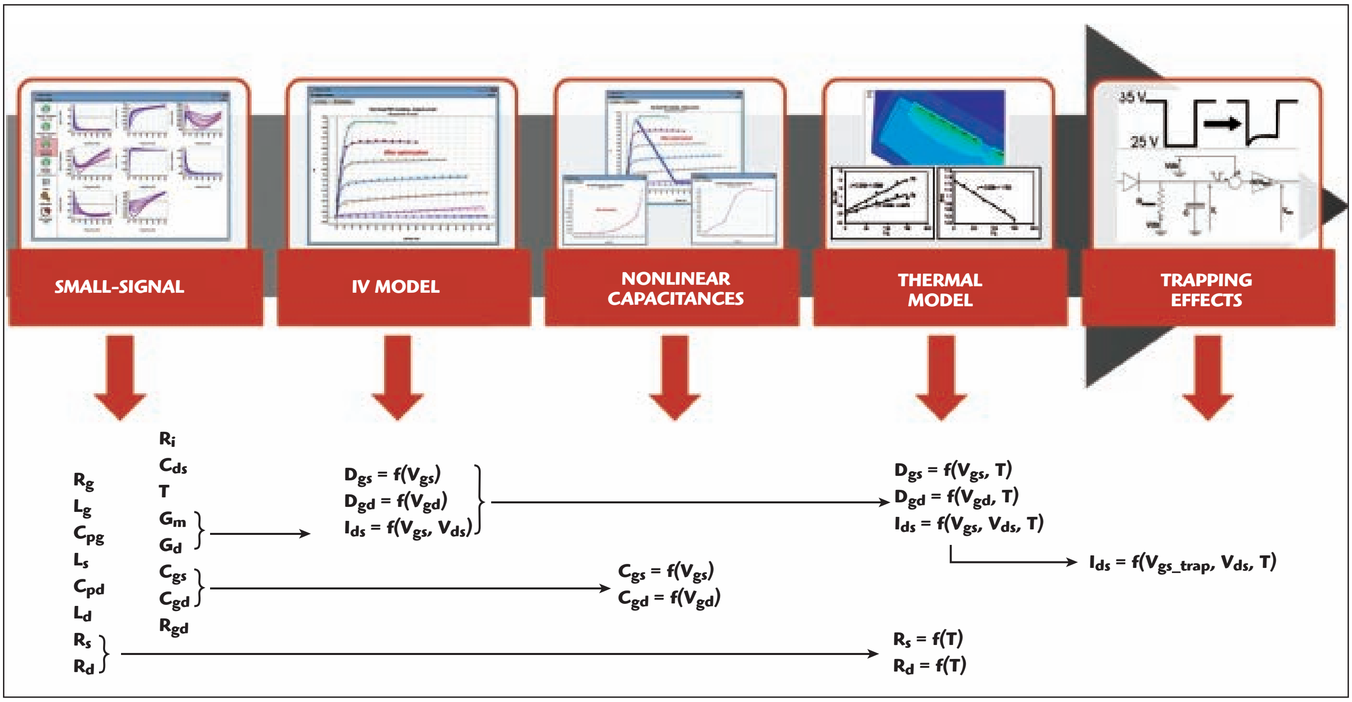
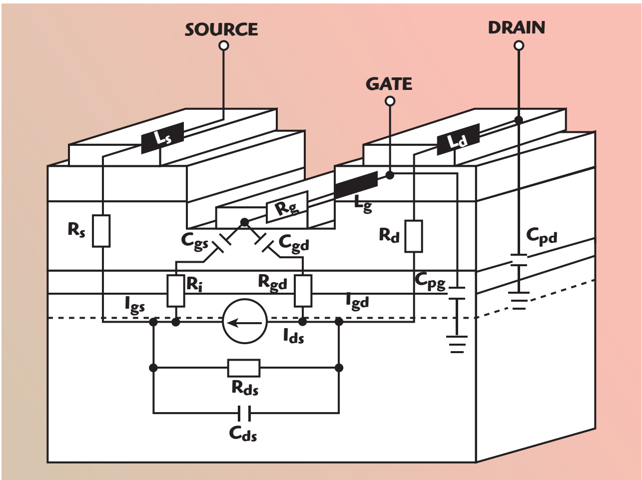
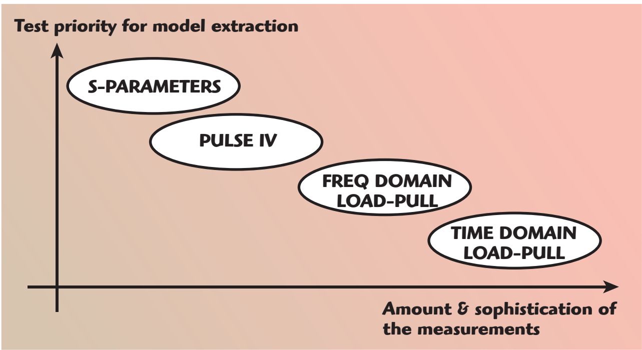


▲ *Fig. 2 Compact FET model extraction flow.*



▲ *Fig. 3 Compact FET model schematic.*



▲ *Fig. 4 Measurements for compact model.*

ponent to some controlled stimuli are known, and are consequently only valid under the operating conditions measured. This model type is actively under development and has been recently improved to take into account memory effects,[1,2] however, as a table-based model, it cannot be as complete as a formula-based model.

It is clear that each model type, physical, compact and behavioral, has unique advantages and disadvantages, as illustrated in ***Figure 1***. While there is no one-size-fits-all model, compact transistor models offer the shortest development time for maximum flexibility with regard to die-level transistors.

Research and development of compact transistor models has been, and continues to be, an important topic for universities and institutes across the globe.[3-9] As such, an abundance of literature and documentation exists on the background R&D of compact models. This discussion will concentrate on the main topics involved with model extraction of wide band gap (WBG) field effect transistors (FET) such as gallium nitride (GaN) FETs. The perfect GaN compact transistor model needs to be accurate for device operation over temperature, bias and RF power. The design flow of a GaN FET compact transistor model, shown in ***Figure 2***, consists of:

- Linear model extraction through small-signal S-parameters
- Nonlinear model extraction through pulsed IV measurements
- Nonlinear capacitance modeling through synchronized pulsed IV/RF
- Electro-thermal modeling through temperature control
- Trapping effect modeling

Additionally, the compact transistor model can be validated through load-pull measurements.

LINEAR MODEL EXTRACTION

The first step in linear model extraction is to use S-parameters to determine the transistor's extrinsic parasitic elements (R_g, L_g, C_{pg}, R_d, L_d, C_{pd}, R_s and L_s), as sketched in ***Figures 3*** and ***4***. By defining a set of extrinsic elements, the S-parameter data can be de-embedded to the intrinsic reference plane and a set of intrinsic parameters (C_{gs}, C_{gd}, G_m, G_d, C_{ds}, R_i, T_{au}, R_{gd}) can be extract-

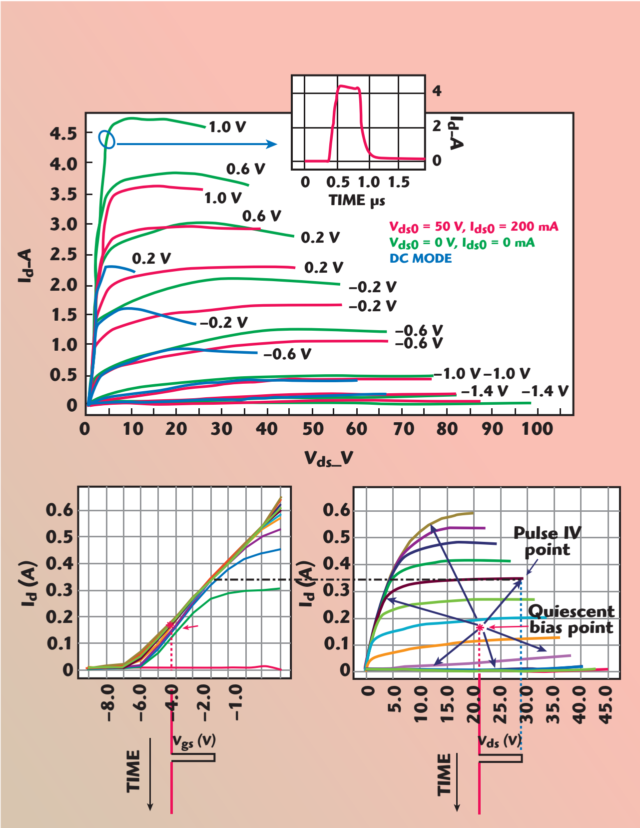
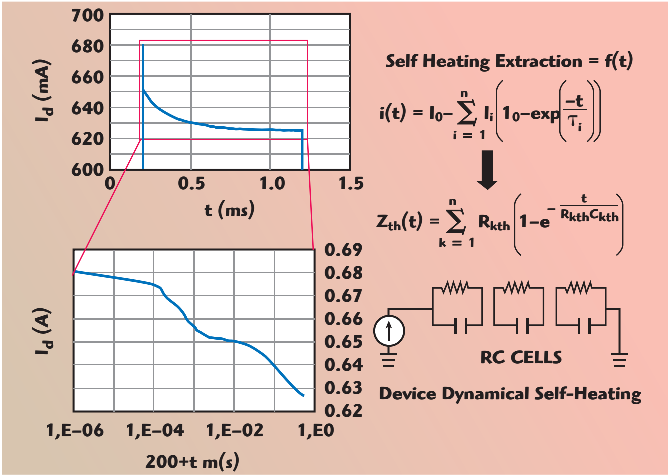


Fig. 5 DC and pulsed IV characteristics.



$$i(t) = I_0 - \sum_{i=1}^{n} I_i \left(1_0 - \exp\left(\frac{-t}{T_i}\right)\right)$$

$$Z_{th}(t) = \sum_{k=1}^{n} R_{kth} \left(1 - e^{-\frac{t}{R_{kth}C_{kth}}}\right)$$

Fig. 6 Thermal model extraction.

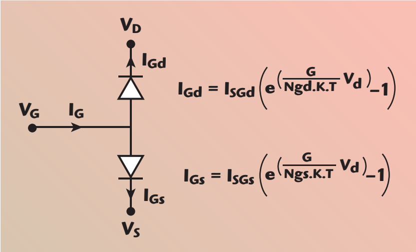
ed using explicit equations.[10-11] During the optimization process, the goal of the linear modeling step is to determine values for the extrinsic parameters, which in turn provides a set of intrinsic parameters with a fixed value versus frequency. During the modeling optimization, measured and modeled S-parameters are compared over the entire RF bandwidth. The measured S-parameters are converted to the corresponding [Y] and [Z] parameters, so that both [Y] and [Z] parameters can be compared at both intrinsic and extrinsic reference planes.

NONLINEAR MODEL EXTRACTION WITH PULSED IV

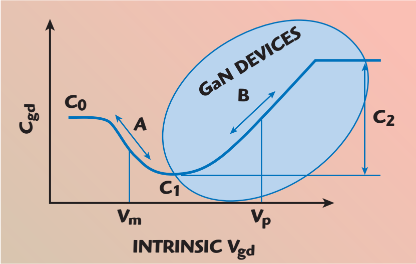
Nonlinear model extraction uses pulsed IV measurements to study the effects of temperature-dependent performance (including self-heating) in safe operating regions and to study the breakdown area of the transistor (see ***Figure 5***).[12] Pulse widths are kept sufficiently short in order to avoid a strong temperature variation during the pulse duration and the duty cycle is kept sufficiently low in order to avoid a mean variation of the temperature, so that the transistor's pulsed IV measurements are obtained under quasi-isothermal operating conditions.

It is necessary to determine the transistor's thermal impedance in order to complete an electro-thermal model that can dynamically predict performance as a function of device temperature (chuck temperature) and self-heating.[9,13] To extract the thermal impedance, two sets of measurements are performed.

First, IV measurements are performed under both continuous (DC) and short-pulsed conditions in order to extract the thermal resistance. As shown in ***Figure 6***, longer pulses are



▲ *Fig. 7 Gate current model.*



▲ *Fig. 8 C_{gd} nonlinear capacitance.*

then applied in order to study the current decrease with time and extract the thermal capacitance. How the temperature (and therefore performance) varies with time is related to the transistor's design, number of layers, type of carrier, heat sink, etc.; the thermal impedance can be modeled by a combination of several thermal resistances and several thermal capacitances representing various time constants. This thermal circuit provides the equivalent transistor junction temperature as a function of DC power and is used in the various sub-circuit models (resistances, current source, diodes and breakdown circuits) that are linked to voltages, currents and temperatures.

In the example shown in ***Figure 7***, the input current diodes must be modeled by equivalent nonlinear current sources that are able to generate a positive gate current when the transistor is biased in forward model with low V_{ds} and high V_{gs} values, and able to generate a negative current for high V_{ds} and pinch-off V_{gs} values. To ensure convergence, the output current source model has to be continuous at n-order for any V_{gs} and V_{ds} values. The AMCAD-FET model uses a current source model that can be formulated using the following equations:

$$I_{ds} = U\tanh(\alpha V_{ds}) \quad (1)$$

$$\alpha = \frac{1}{2}\cdot\left((\alpha_1-\alpha_2)\tanh\left(-V_{gs}+V_{g1}\right)+\left(\alpha_1+\alpha_2\right)\right) \quad (2)$$

$$U = Fa\cdot\left(I_1\left(V_1+\lambda\right)+\frac{\left(V_{ds}-V_{dsp}\right)}{R_{ds0}}, R_u, U_0\right) \quad (3)$$

$$V_1 = F_p\left(V_{gs}, V_{ds}\right) \quad (4)$$

where α_1, α_2, V_{gs1}, I_1, λ, V_{dsp} and R_{ds0} are parameters. The "Fa" function defines a lower limit to a related function from an arbitrary value U_0 with an adjustable smooth transition parameter R_u. The "F_p" function is an n-order polynomial with two variables (V_{gs}, V_{ds}). Additionally, measurements can be repeated at various chuck temperatures when measuring on-wafer. This allows a temperature-dependence variable to be determined and applied to the model.

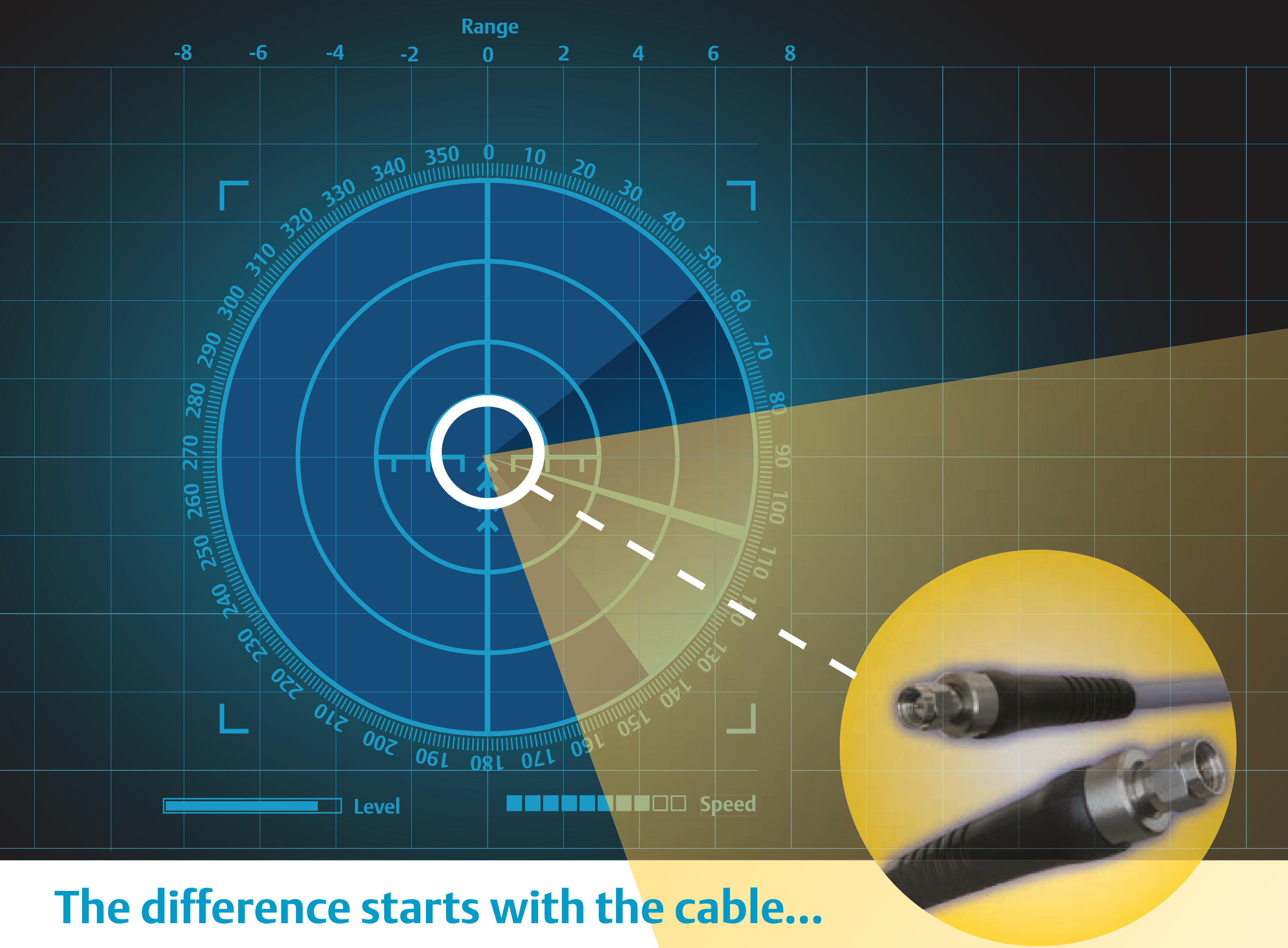
NONLINEAR MODEL EXTRACTION WITH PULSED IV/ PULSED RF

Nonlinear capacitance modeling, determining C_{gd} and C_{gs} models, is achieved through synchronized pulsed RF (Pulsed S-parameters) and pulsed bias (Pulsed IV) measurements along with the predicted RF load line. While nonlinear capacitances can be modeled by equations that depend on both V_{gd} and V_{gs} voltages concurrently (referred to as two-dimensional models), it has been shown that one-dimension capacitance models are more robust regarding convergence without sacrificing accuracy.[14] The C_{gd} capacitance model is therefore linked with V_{gd} while the C_{gs} capacitance model relies on V_{gs}.

The feedback capacitance C_{gd} depends heavily on the drain voltage; therefore, it must be included to fit large-signal operating conditions. The C_{gd} capacitance model is defined by the equation

$$C_{gd} = C_{gd0} + \frac{C_{gd1}-C_{gd0}}{2}\cdot\left[1+\tanh\left(c\left(V_{gd}+V_n\right)\right)\right] - \frac{C_{gd2}}{2}\left[1+\tanh\left(d\left(V_{gd}+V_q\right)\right)\right] \quad (5)$$

This one-dimension C_{gd} capacitance model, shown in ***Figure 8***, was



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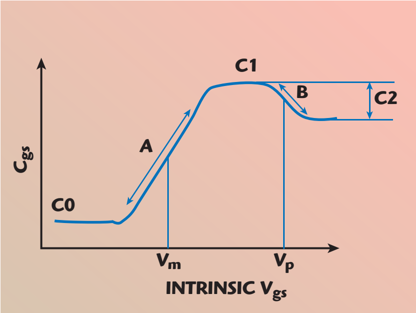
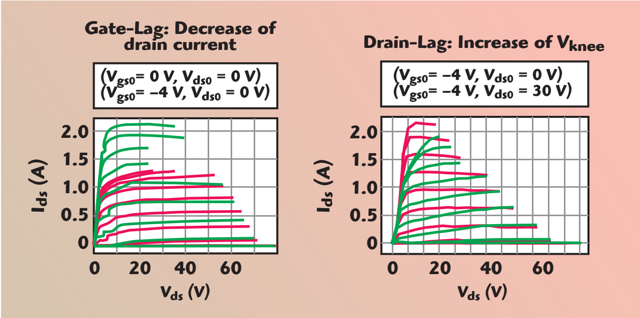


▲ *Fig. 9 C_{gs} nonlinear capacitance.*

initially optimized for gallium arsenide (GaAs) transistors, but has been updated for GaN technologies. Along the same RF load line, the one-dimension input capacitance model C_{gs}, shown in ***Figure 9***, depends heavily on gate voltage. The gate voltage's nonlinearity greatly affects the model's harmonic response. The capacitance can be modeled by the equation

$$C_{gs} = C_{gs0} + \frac{C_{gs1} - C_{gs0}}{2} \cdot \left[1 + \tanh\left(a\left(V_{gs} + V_m\right)\right)\right] - \frac{C_{gs2}}{2}\left[1 + \tanh\left(b\left(V_{gs} + V_p\right)\right)\right] \qquad (6)$$



▲ *Fig. 10 Trapping effects.*

The output capacitance C_{ds} is linear; no voltage dependence is taken into account due to the weak influence for amplification purposes.

TRAPPING EFFECTS

Nonlinear model extraction also takes advantage of pulsed IV measurements to isolate the trapping effects as a function of quiescent bias condition. Trapping effects are parasitic effects that reduce the maximum output current; the charging and discharging of traps influences I_{ds} and leads to current collapse. Trapping corresponds to the existence of energy states, which can be occupied by holes or electrons in the gap. These holes or electrons are trapped at these levels over a time period and cannot take part in conduction, hence the term trap. Trapping is the result of impurities or defects in the crystalline network of the material from which the transistor is composed, and alters the electric behavior of the transistor at microwave frequencies.

Pulsed IV measurements are used to study the individual trapping effects and differentiate between surface trapping (gate-lag) and buffer trapping (drain-lag). When performing pulsed IV measurements, it is important to ensure the IV pulses are shorter than the emission time constant of the traps. It is also important to maintain a constant temperature throughout the measurement to be certain that the device changes are due to trapping effects and not temperature changes.

Gate-lag is mainly attributed to surface trapping effects. In order to isolate these effects, two series of measurements are made with identical dissipated powers equal to zero. When performing pulsed IV measurements, the two quiescent bias points chosen are:

QP1 : $V_{gs0} = V_p$, $V_{ds0} = 0$ V
QP2 : $V_{gs0} = 0$ V, $V_{ds0} = 0$ V

V_p is the pinch-off voltage applied on the gate. Because both dissipated powers are zero, any difference between IV characteristics can be attributed to the presence of gate lags.

Drain-lag is mainly attributed to buffer trapping effects. In order to isolate these effects, two series of measurements are made with identical dissipated powers equal to zero. When performing pulsed IV measurements, the two quiescent bias points chosen are:

QP1 : $V_{gs0} = V_p$, $V_{ds0} = 0$ V
QP3 : $V_{gs0} = 0$ V, $V_{ds0} >> 0$ V

Examples of typical gate-lag and drain-lag IV curves are shown in ***Figure 10***.

These parasitic phenomena can be modeled by a trapping circuit composed of gate- and drain-lag sub-

Product Brochure

Anritsu

Spectrum Analysis Solutions

Research and Development, Manufacturing, Installation and Maintenance

Fast, Efficient, Reliable Solutions for RF & Microwave and Mobile Wireless Communications

Research & Development

Whether you are making RF measurements or performing signal characterization for research and development, manufacturing or installation & maintenance applications, the Anritsu family of spectrum analyzers has everything you require to solve all your measurement needs. These instruments deliver the features and performance you need to operate in both field and lab environments. Their range of capabilities (e.g., high-speed, wide resolution bandwidth, high dynamic range, support for multi-functionality and affordability) ensure fast, efficient and reliable measurement results. With the Anritsu family of spectrum analyzers, signal analysis will never be the same again.

Performance and Capabilities to Support a Range of Applications

The availability of high-performance benchtop instruments, as well as handheld instruments, that combine powerful measurement capabilities with support for a range of frequencies and bandwidths, make Anritsu's spectrum analyzer family ideal for a range of applications.

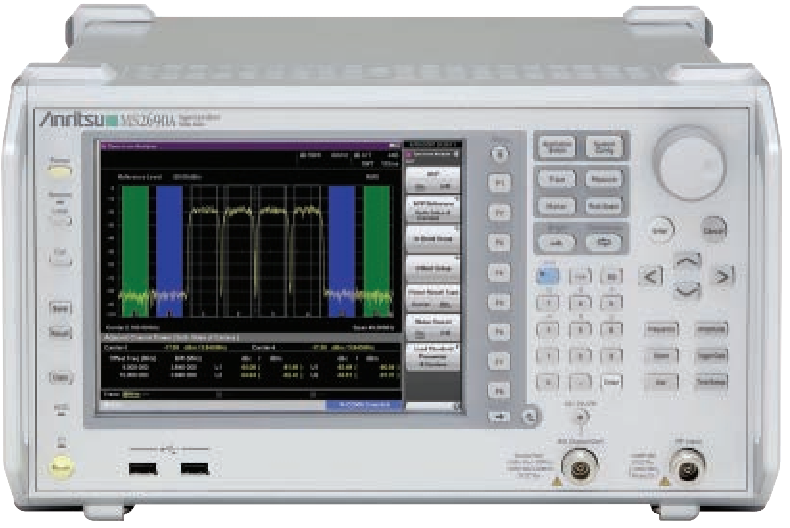
The Challenge

During R&D, next-generation communications applications like Base Transceiver Station (BTS) test, User Equipment (UE) transmitter testing, and mobile backhaul testing (e.g., for 3GPP including TDD LTE, EDGE evolution, and HSPA+) can prove especially difficult. Today's increasingly data-intensive applications are driving wireless communications devices to use wider bandwidths and higher frequencies (above 3 GHz). With greater bandwidth usage, the ability to discriminate between different signals becomes more challenging. Without accurate measurements, the transition into manufacturing also poses an obstacle, even resulting in increased cost when problems are not found early in the design cycle. Overcoming these test challenges requires a fast and accurate spectrum analyzer that is able to measure above 3 GHz.

The Solution

The MS269xA Series Signal Analyzers offer the level accuracy (± 0.3 dB typical), wide dynamic range, high performance and flexibility necessary to quickly, easily and cost-effectively test next-generation communication applications for even the most demanding R&D environment. Because of its accuracy, the MS269xA Series is able to measure the widest signals and, using the latest technology, make measurements faster than ever before. Three different models provide frequency coverage to 6 GHz (MS2690A), 13.5 GHz (MS2691A), and 26.5 GHz (MS2692A), and can be used to perform swept spectrum analysis and fast Fourier transform (FFT) signal analysis. The wideband FFT signal analyzer supports high-speed continuous measurements including CCDF, frequency vs. time, spectrum, and power vs. time analysis. All three models feature a precision digitizer function that enables waveform capture. The addition of an optional signal generator turns the MS269xA Series analyzers into a cost-effective one box solution that dramatically reduces footprint and total average cycle time for device evaluation, and allows the instrument to easily scale as measurement requirements change.

For more information go to MS2690A Signal Analyzer product page.



Benefits

- ► One-Box Tester with the addition of the Signal Generator option
- ► Batch Capture Measurements for the fastest analysis time
- ► XGA-color LCD Display at 1024 x 768 resolution, 213 mm (8.4 in)
- ► Lightweight at 13.5 kg (29.7 lbs)
- ► Size: 340 mm x 200 mm x 350 mm (13.4 in x 7.8 in x 13.8 in)

MS269xA Signal Analyzer Highlights

Frequency Ranges	50 Hz to 6 GHz (MS2690A) 50 Hz to 13.5 GHz (MS2691A) 50 Hz to 26.5 GHz (MS2692A)
Dynamic Range	177 dB
DANL	-155 dBm/Hz
Analysis bandwidth	31.25 MHz (Std.), 125 MHz (with optional hardware)
Third-Order Intercept (TOI)	≥ +22 dBm
Total Level Accuracy	± 0.3 dB (typical)
SSB Phase Noise	-116 dBc/Hz @ 100 kHz offset -137 dBc/Hz @ 1 MHz offset)

Manufacturing

The Challenge

Manufacturing wireless components and devices (e.g., cell phones) and BTS chipsets can be a daunting task. An especially critical challenge is verifying product performance prior to delivery to the customer. The increasing complexity of today's emerging wireless communications standards means that more testing is required and that testing often requires more time. Test time is directly related to cost—something that manufacturers are continually looking to reduce. Running tests using a fast spectrum analyzer is one way to cut test time and in turn, cost. Test accuracy is also critical since it allows engineers to optimize their test budgets for manufacturing variances rather than test instrument uncertainties, thereby increasing yield, maximizing productivity and minimizing cost. Overcoming these test challenges requires use of an economically-priced signal analysis solution with exceptional speed and measurement accuracy.

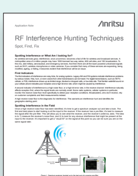
The Solution

As a high-speed, high-performance, cost-effective solution, the MS2830A Series Spectrum Analyzer/ Signal Analyzer is well suited to addressing the challenges facing today's manufacturer. It captures wideband signals and, with its FFT technology, supports multifunction signal analysis in both the time and frequency domains. Behavior in the time domain that cannot be handled by a sweep type spectrum analyzer can be checked in the frequency domain. A wide frequency can be analyzed using sweep type spectrum analysis functions, while detailed signal analysis of a specific frequency band is also supported. Moreover, a built-in signal generator function outputs both continuous wave (CW) and modulated signals for use as a reference signal source for evaluating Rx characteristics.

The MS2830A-040/041/043 is well suited for Tx test, offering the excellent dynamic range performance necessary for spurious test and a wide range of modulation analysis software (e.g., LTE FDD/TDD, WiMAX, GSM/EDGE, and W-CDMA/HSPA/HSPA Evolution). The MS2830A-044/045 is best suited for the development and manufacture of microwave products, featuring both spectrum and signal analysis capabilities.

The MS2830A-044/045 Signal Analyzer includes a spectrum analyzer function for measuring up to 110 GHz using an external mixer based on the 26.5 GHz/43 GHz upper frequency limit. Installing the 10 MHz/31.25 MHz bandwidth analysis option adds signal analyzer functions for checking phenomena that are hard to check using a spectrum analyzer, such as frequency vs. time, phase vs. time, spectrogram, and CCDF. Optional measurement software supports modulation analysis. The MS2830A-044/045 can be customized to support a range of application-specific measurements, such as measurement of weaker signals and catching the instant change of the frequency/phase/amplitude/spectrum of microwave signals.

For more information go to MS2830A Signal Analyzer product page.



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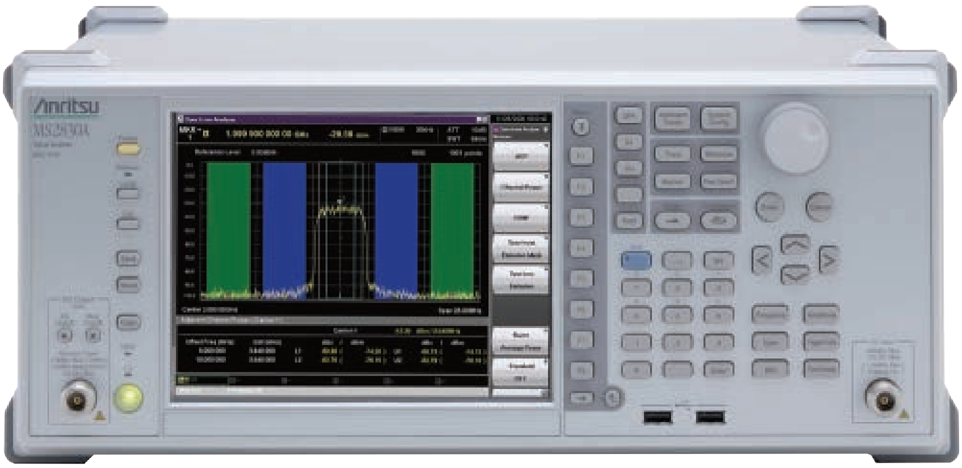


Benefits

- ► Top-class spectrum analyzer measurement speed
- ► Best-of-class dynamic range at medium-class price
- ► XGA-color LCD Display at 1024 x 768 resolution, 213 mm (8.4 in)
- ► Lightweight at ≤ 15 kg (6.8 lbs)
- ► Size: 426 mm x 177 mm x 390 mm (16.7 in x 6.9 in x 15.3 in)

MS2830A Signal Analyzer Highlights

Frequency Ranges	9 kHz to 3.6 GHz (MS2830A-040) 9 kHz to 6 GHz (MS2830A-041) 9 kHz to 13.5 GHz (MS2830A-043) 9 kHz to 26.5 GHz (MS2830A-044) 9 kHz to 43 GHz (MS2830A-045)
Dynamic Range	168 dB (MS2830A-040/041/043) 159 dB @ 25 GHz (MS2830A-044/045)
DANL	-153 dBm/Hz (MS2830A-040/041/043) -146 dBm/Hz (MS2830A-044/045)
Third-Order Intercept (TOI)	≥ +15 dBm (MS2830A-040/041/043) +13 dBm (MS2830A-044/045)
SSB Phase Noise	-133 dBc/Hz @ 100 kHz offset with Option 062 (MS2830A-040/041/043) -115 dBc/Hz @ 100 kHz offset (MS2830A-044/045)

Installation & Maintenance

The Challenge

Properly installing and maintaining wireless networks is critical to ensuring best-in-class network reliability and good Quality of Service (QoS). Consequently, routinely testing a base station's cables, filters, antennas, and amplifiers, and troubleshooting internal and external interference is critical. Difficulties arise due to increasingly complex wireless networks and soaring operating frequencies. Additionally, with more and more wireless communications systems being deployed, interference from both indoor and outdoor transmissions becomes problematic. Moreover, many of these deployments are now in remote locations and sometimes in harsh environments, making testing more difficult. Overcoming these challenges and optimizing network reliability requires the right spectrum analyzer for the task at hand.

The Solutions

Anritsu offers a number of spectrum analyzers to address your installation and maintenance needs. Instruments are available in both the mid-performance and high-performance range and come with a wide variation of features and capabilities to address specific measurement needs.

The MS2711E Spectrum Master™

Use: Installing, provisioning, maintaining, and troubleshooting wireless systems and RF frequency spectrum interference issues. It is particularly well suited for cellular providers and land mobile operators conducting interference analysis and military spectrum analysis.

The MS2711E is designed to handle the most punishing field conditions and monitor wireless systems with the greatest ease. Convenient operating procedures, high sensitivity and excellent repeatability enable it to pinpoint the smallest system performance degradation and allow for easy verification of system compliance.

Additionally, the MS2711E can locate and identify out-of-band spurious signals when analyzing a wireless base station transmitter. When in field strength mode, it allows users to measure propagation and coverage, or to pinpoint electromagnetic (EM) leakage in broadcast systems. Measurement of carrier to interference (C/I) ratio and spectral emission mask is also included.

The MS2712E/13E Spectrum Master™

Use: Monitoring, locating, identifying, and analyzing a broad range of cellular, 2G/3G/4G, land mobile radio, Wi-Fi, and broadcast signals.

The MS2712E/13E Spectrum Master features a field-proven design that can handle even the most challenging field conditions. As a multi-functional instrument, it incorporates a spectrum analyzer, interference analyzer with interference mapping, and a high-accuracy power meter for 2-port transmission measurements. This multi-function capability eliminates the need to learn and carry multiple instruments when locating and identifying signals over wide frequency ranges.

For more information go to MS2711E, MS2712E or MS2713E Spectrum Master product pages.

Mid-Performance Handheld Instruments

Benefits

- Easy to use handheld compact spectrum analyzer for fast reliable measurements
- Field-proven design, rugged, compact with daylight viewable display
- Intuitive menu-driven touchscreen user interface
- 3 hour battery operation time
- Lightweight at 7.6 lbs
- Size: 273 mm x 199 mm x 91 mm (10.7 in x 7.8 in x 3.6 in)

MS271xE Spectrum Analyzer Highlights

Frequency Ranges	100 kHz to 3 GHz (MS2711E) 100 kHz to 4 GHz (MS2712E) 100 kHz to 6 GHz (MS2713E)
Dynamic Range	> 85 dB in 100 Hz RBW (MS2711E) > 102 dB in 1 Hz RBW (MS2712E/13E)
Interference Analyzer	Spectrogram, Signal Strength, RSSI
DANL	-142 dBm in 100 Hz RBW (MS2711E) with preamp option 0008 -162 dBm in 1 Hz RBW (MS2712E/13E)
Phase Noise	-90 dBc/Hz max @ 10 kHz offset at 1 GHz (MS2711E) -100 dBc/Hz max @ 10 kHz offset at 1 GHz (MS2712E/13E)
Frequency Accuracy	< ± 50 ppb with GPS On

Installation & Maintenance

The Solutions

Some in field measurement applications require a spectrum analyzer with benchtop performance, features and bandwidth. Anritsu's high-performance handheld spectrum analyzers meet this need. These instruments include:

The MS2721B Spectrum Master™

Use: Highly accurate analysis of wireless LAN and cellular signals, including 802.11a, 3G, ultra-wideband, WiMAX, and wireless medical patient monitoring systems.

The MS2721B has the fastest sweep speeds of any spectrum analyzer in its class. Its wide dynamic range and low phase noise make NRSC measurements on analog and IBOC signals easy, with no need for an external carrier notch filter. As a result, the MS2721B is well suited for AM and FM broadcast proofing.

With the MS2721B, demodulated signals can be monitored using an internal speaker or by using a universal 2.5 mm 3-wire headset, such as used with many cellular telephones. The use of compact flash memory modules or USB flash drives up to 32 GB allow an unlimited number of traces and setups to be stored.

For more information go to MS2721B Spectrum Master product page.

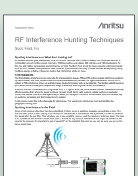
The MS2722C/23C/24C/25C/26C Spectrum Master™

Use: Spectrum monitoring, hidden signal detection, RF and microwave signal measurements, microwave backhaul testing and cellular signal measurements.

The MS272xC Spectrum Master features over 30 analyzers in one, to meet virtually every measurement need. It offers the industry's best sweeps speed to 43 GHz, three sweep modes, resolution bandwidths from 1 Hz to 10 MHz, zero-span capabilities that include 10 MHz resolution bandwidth and video bandwidth, and an enhanced spectrum analyzer graphical user interface. Collected data can be post processed on the MS272xC using the embedded Anritsu Master Software Tools. The Remote Access Tool allows the user to see and control the instrument over a LAN connection.

In addition to spectrum analysis, the user can select optional capabilities and analyzers such as a high accuracy power meter, interference analyzer, channel scanner, or GPS receiver, and 3GPP, 3GPP2 or IEEE 802.16 signal analyzers. Secure data operation, 140 MHz zero-span IF output, 30 MHz bandwidth and geo-tag data collection capabilities are also available.

For more information go to MS2722C/23C/24C/25C/26C Spectrum Master product pages.



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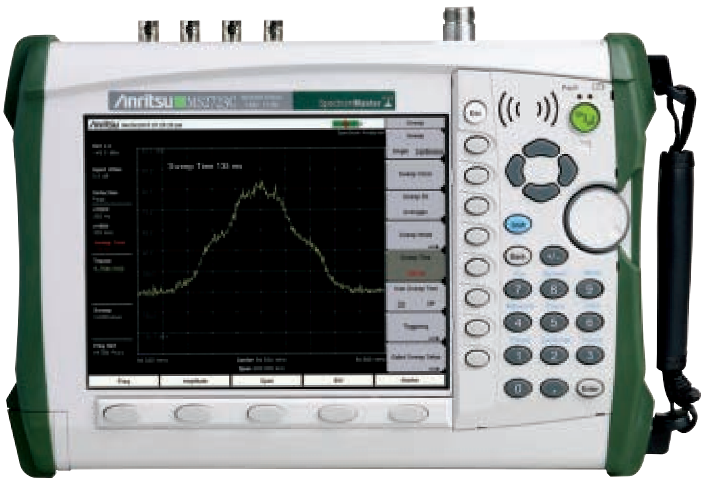
Benefits

- ► Easy to use portable spectrum analyzer
- ► Handheld, battery-operated design
- ► Weighing in at less than 7 lbs, it's equally at home on the engineering bench and in the field
- ► Size: 315 mm x 211 mm x 77 mm (12.4 in x 8.3 in x 3 in)

MS2721B Spectrum and Interference Analyzer Highlights

Frequency Ranges	9 kHz to 7.1 GHz
Measure	Occupied Bandwidth, Channel Power, ACPR, C/I
Interference Analyzer	Spectrogram, Signal Strength, RSSI
DANL	-163 dBm in 1 Hz RBW
Phase Noise	-100 dBc/Hz @ 10 kHz offset at 1 GHz



Benefits

- ► Easy to use portable spectrum analyzer
- ► Handheld, battery-operated design
- ► Weighing about 8 lbs fully loaded, it's light enough to take anywhere, including up a tower.
- ► Size: 315 mm x 211 mm x 77 mm (12.4 in x 8.3 in x 3 in)

MS272xC Spectrum and Interference Analyzer Highlights

Frequency Ranges	9 kHz to 9 GHz (22C), 9 kHz to 13 GHz (23C), 9 kHz to 20 GHz (24C), 9 kHz to 32 GHz (25C), 9 kHz to 43 GHz (26C)
Measure	Occupied Bandwidth, Channel Power, ACPR, C/I, Emission Masks
Interference Analyzer	Spectrogram, Signal Strength, RSSI, Mapping
DANL	-160 dBm in 1 Hz RBW @ 1 GHz preamp on
Phase Noise	-100 dBc/Hz @ 10 kHz offset at 1 GHz

Installation & Maintenance

Our field installation and maintenance spectrum analyzers feature a full range of measurements and signal analysis options for all of the global standards around the world. Measurements provide answers to your toughest network and spectrum challenges.

Measurements

- Field Strength (uses antenna calibration tables to measure dBm/m^2 or dBmV/m)
- Occupied Bandwidth (measures 99% to 1% power channel of a signal)
- Channel Power (measures the total power in a specified bandwidth)
- ACPR (adjacent channel power ratio)
- AM/FM/SSB Demodulation (wide/narrow FM, upper/lower SSB), (audio out only)
- C/I (carrier-to-interference ratio)

Optional Capabilities

Interference Analysis (Option 25)	MS2712/13E, MS2721B and MS272xC
Channel Scanners (Option 27)	MS2712/13E, MS2721B and MS272xC
Power Meter (Option 29)	MS2712/13E, MS2721B and MS272xC
CW Generator (Option 28)*	MS2712/13E
High Accuracy Power Meters** (Option 19)	MS2721B and MS272xC
Zero Span IF Output (Option 89)	MS272xC
Tracking Generator (Option 25)	MS2721B
I/Q Waveform Capture*** (Option 24)	MS272xC

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GSM/EDGE (Option 40)
CDMA, EV-DO (Option 42)
TD-SCDMA/HSPA+ (Option 60)
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Digital TV Signal Analysis (MS2712/13E and MS2721B)

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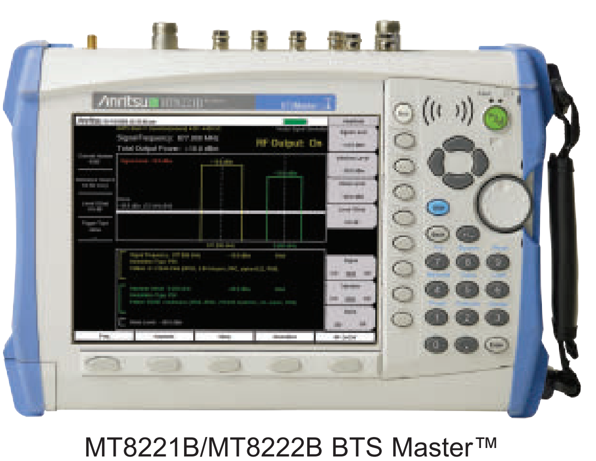

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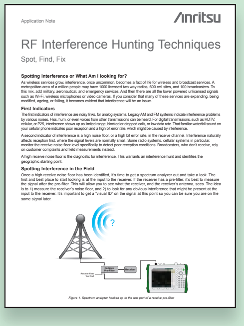

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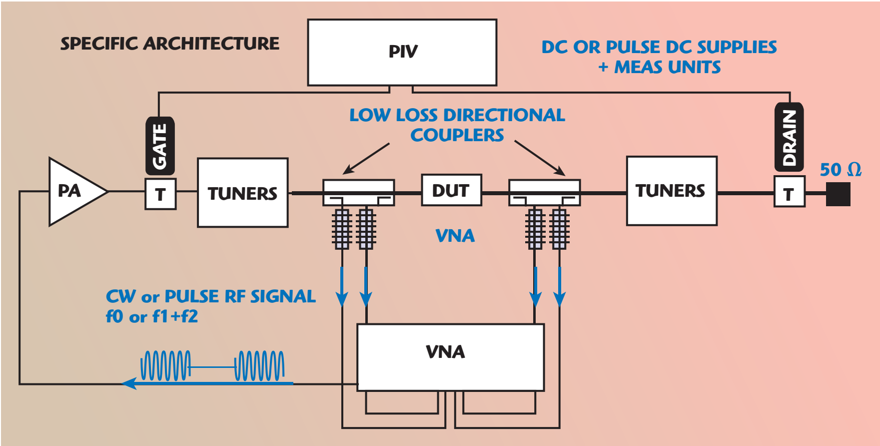
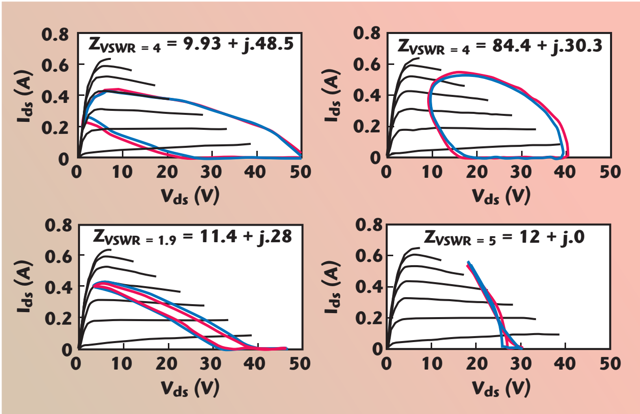


▲ *Fig. 11 VNA-based load pull setup.*

circuits that are connected to the gate command[15] in order to drive the output current as a parasitic phenomenon. The lagging hysteresis can be modeled by a circuit that contains a diode element that will reproduce the dissymmetry between the capture and emission times.[16]



▲ *Fig. 12 Model validation.*

LOAD-PULL FOR MODEL VALIDATION

Load-pull measurements are used to validate compact transistor models beyond 50 Ω by varying the impedances presented to the transistor and comparing measured and modeled parameters. In order to achieve a good correlation between measured and modeled results, it is important to use a vector-receiver (real-time) load-pull system, as shown in ***Figure 11***. Vector-receiver load-pull systems make use of a vector receiver calibrated at the device-under-test (DUT) reference plane to measure the transistor's large signal input impedance.[17] Knowledge of the transistor input impedance removes the mismatch effect between the source impedance and the device impedance, allowing for a true power gain comparison. Power gain is directly related to the intrinsic transistor's performance contained within the model, whereas transducer gain is only an indicator of how the transistor is matched. The mismatch between the source impedance and the transistor's input impedance can hide unstable operating conditions where the transistor's input impedance has negative values for certain load impedances,[18] as the input impedance varies with power delivered to the input of the transistor. This input impedance measurement is important for model validation; during simulations, a model's effectiveness is judged by its ability to accurately predict power gain expansion and/or compression, which plays a major role in linearity.

Time-domain load-pull measurements may also be used for model validation.[19] In addition to the parameters obtained from a frequency-domain system, time domain load-pull allows for the measurement of voltage and current waveforms and load lines. When correctly calibrated and de-embedded to the intrinsic transistor reference plane, the RF load line can be displayed and superimposed onto the transistor's IV characteristics, and a comparison between measured

and modeled results can be made, as shown in ***Figure 12***. Time-domain voltage and current waveforms and load lines can be used to verify whether the transistor is operating close to RF breakdown, or used to confirm class of operation (A, AB, C, E, F, F-1, G…).

CONCLUSION

Amplifier designers are under more stress than ever to release effective products in the least amount of time and maximize profitability; meaning first-pass design success and being first-to-market. Gone are the days when engineers could cut and paste, design by trial and error, and work at their own pace to release innovative products. Compact transistor models are the first and most crucial step in a successful MMIC design flow and, when used in conjunction with circuit simulators, can lead to first-pass design success and first-to-market. ■

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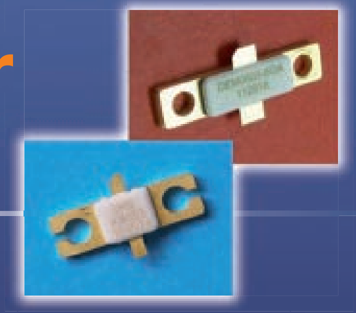

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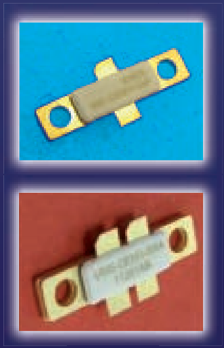
CHK025A-SOA	DC - 4.5	30	14 @ 4	55 @ 4	0.2 / 50	Flange
CHK040A-SOA	DC - 3.5	40 / 55	12/13 @ 3	55/60 @ 3	0.3 / 50	Flange
CHK080A-SRA	DC - 3.5	80 / 100	12/13 @ 3	55/65 @ 3	0.6 / 50	Flange



Flange: screw-down ceramic metal package

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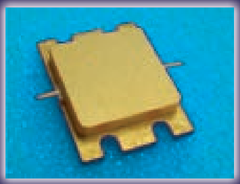

Part Number	Frequency (GHz)	Power (W) Pulse	Assoc. Gain (dB) Pulse	PAE (%) Pulse	Bias (A) / (V)	Case
CHZ050A-SEA	5.2 - 5.9	55	11	40	0.4 / 50	Flange hermetic

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Tackling MIMO Design and Test Challenges for 802.11ac WLAN

The proliferation of wireless LAN into new applications, outside of the traditional email and browsing applications, is driving the need for higher data rate throughput. New applications, such as wireless display, HDTV streaming/distribution and rapid upload/download of data, are driving two new IEEE WLAN standards requirements for very high throughput: 802.11ac for frequencies below 6 GHz and 802.11ad for the 60 GHz band.

A goal of 802.11ac is to support wireless distribution of multiple multimedia/data streams with data rates of at least 1 Gbps in the 5 GHz band. Some key features for increasing data throughput are wider channel bandwidths (that is contiguous 80 and 160 MHz, or non-contiguous 80 + 80 MHz), higher-order modulation with optional support for 256 QAM and multiple-input multiple-output (MIMO) support for multiple spatial streams using multiple antenna techniques. Pre-distortion and beamforming are some further possibilities for high-performance systems.

This challenging combination of wider bandwidths, higher-order modulation and MIMO introduces new design and test challenges for the system engineer. Supporting higher-order modulation formats such as 256 QAM will require better (lower) error vector magnitude (EVM) performance from the transmitter to meet the overall system performance. Achieving a lower EVM can require better linearity from the transmitter's power amplifier (PA), lower phase noise (in dBc/Hz) from the local oscillators (LO) being used for frequency up-conversion in the transmitter, and reducing IQ skew and gain imbalance from the IQ modulator. With these tighter design margins, the system engineer may need to gain insight into predicted performance early in the design cycle to perform system design budget trade-offs. Once in the R&D and prototype testing phase, it is useful to measure the EVM performance at various stages along the transmitter chain to measure error contributions and optimize the overall system EVM performance.

This article shows how the system engineer can use system simulation to help understand the design performance and design requirements needed to achieve transmitter system-level metrics such as EVM. System performance budget trade-offs can quickly and easily be performed with system design simulation

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AML056P4014	0.5 - 6.0	40	37	38	6	28V, 1.0A	20%	EAR99
AML056P4511	0.5 - 6.0	45	39	40	10	28V, 1.3A	25%	EAR99
AML056P4512	0.5 - 6.0	45	43	44	25	40V, 2.7A	23%	EAR99
AML13P5013	1.0 - 3.0	50	46	47	50	28V, 4.8A	25%	EAR99
AML26P4011	2.0 - 6.0	40	40	41	12	28V, 1.5A	30%	EAR99
AML26P4012	2.0 - 6.0	45	43	44	25	28V, 3.0A	30%	EAR99
AML26P4013	2.0 - 6.0	50	46	47	50	28V, 6.0A	30%	EAR99
AML59P4512	5.5 - 9.0	45	45	46	40	28V, 4.0A	35%	3A001.b.4.b
AML59P4513	5.5 - 9.0	45	48	49	80	28V, 8.0A	35%	3A001.b.4.b
AML910P4213	9.9 - 10.7	43	37	38	6	32V, 0.5A	30%	EAR99
AML910P4214	9.9 - 10.7	43	39	40	10	32V, 0.8A	30%	EAR99
AML910P4215	9.9 - 10.7	46	41.5	42	15	32V, 1.3A	30%	EAR99
AML910P4216	9.9 - 10.7	46	42	43	20	32V, 1.3A	30%	3A001.b.4.b
AML811P5011	7.8 - 11.0	45	43	44	25	28V, 2.8A	30%	3A001.b.4.b
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AML218P4011	2.0 - 18.0	40	39	40	10	32V, 2.8A	12%	ITAR
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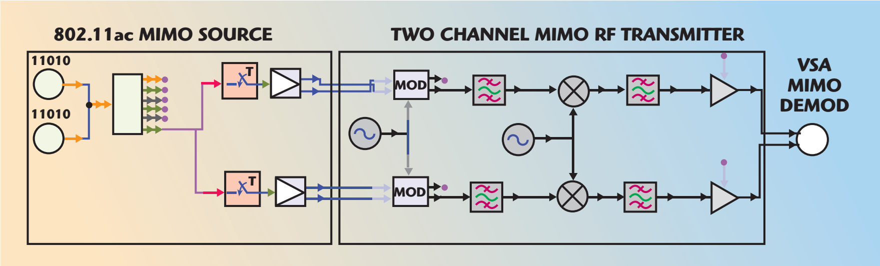

Fig. 1 802.11ac MIMO transmitter simulation design.

tools before designing hardware. Once hardware is available and the prototype R&D testing phase has begun, system simulation tools can then be combined with arbitrary waveform generators (AWG) to generate wide-bandwidth 160 MHz waveforms for MIMO testing. Multi-channel, phase-coherent, high-performance digital oscilloscopes with vector signal analysis (VSA) software are then used to perform the SISO or MIMO demodulation to evaluate the transmitter's performance. In addition, the error contributions along the transmitter chain (IQ, IF, RF) can be measured using a digital oscilloscope with VSA software to help the system engineer optimize the design performance of the prototype hardware.

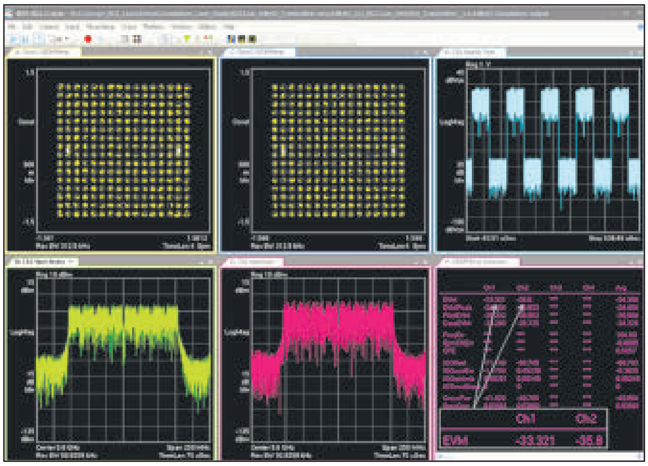

Fig. 2 802.11ac, 160 MHz and 256 QAM MIMO.

802.11AC MIMO SYSTEM SIMULATION

Figure 1 shows an 802.11ac MIMO RF transmitter design modeled in simulation. The spatially multiplexed 802.11ac MIMO source is modeled on the left with complex baseband outputs, a two-channel MIMO RF transmitter with IQ inputs is modeled in the center and a VSA simulation measurement is used at the output of the RF transmitter to measure the simulated MIMO performance of the modeled transmitter. Various transmitter design impairments are being modeled such as IQ modulator phase imbalance, LO phase noise (dBc/Hz vs. frequency offset), impairments from IF/RF filters and PA nonlinearities (1 dB compression point).

The simulation results for a 160 MHz, 256 QAM MIMO simulation are shown in ***Figure 2***. The two constellations are shown on the upper left, the two spectrums centered at 5.8 GHz are shown on the lower left and the EVM is shown on the right. EVM is approximately -33.3 dB for channel 1 and -35.8 dB for channel 2, as a result of the design impairments being modeled. The modeled design impairments are impacting the channel 1 (Ch1) EVM more significantly than the channel 2 (Ch2) EVM for this example.

The system engineer can easily change parameters, such as bandwidth, to evaluate a 20, 40, 80, or 80 + 80 MHz configuration. The modulation order can be changed to evaluate different QAM formats. The various design impairments being modeled in the simulation design (IQ modulator phase imbalance, LO phase noise, IF/RF filter impairments and PA nonlinearities) can easily be evaluated and modified by the system engineer to better understand design requirements and trade-offs to meet the overall system-level EVM metric.

Figure 3 shows the same design as in Figure 1, with parameters configured for 160 MHz, 64 QAM MIMO. Several of the design parameters, such as phase noise and PA 1 dB gain com-

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TEST AND MEASUREMENT

MODULES	SKU	Start (MHz)	Stop (MHz)	Pout (Watt)	Size (Inch)	Gain (dB)
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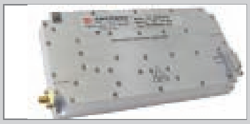
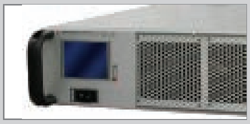
	1067	0.01	500	25	7.0x5.0x1.3	44
	1100	20	1000	80	6.4x3.4x1.1	49
	1141	20	1000	125	6.4x6.7x1.3	51
	1166	20	1000	200	7.2x7.6x1.2	26
	1119	500	2500	50	7.4x3.6x1.1	46
	1189	500	2500	100	7.4x3.6x1.1	50
	1164	800	3000	50	6.4x3.4x1.1	50
	1146	1000	3100	100	6.9x4.5x1.2	10
	1178	2000	6000	35	6.9x3.6x1.1	55
	1138	2500	6000	10	6.0x3.0x1.0	40
	1131	2500	6000	35	6.9x3.6x1.1	48

SYSTEMS	SKU	Start (MHz)	Stop (MHz)	Pout (Watt)	Size	Gain (dB)
	2013	0.15	230	50	R2U	46
	2014	0.15	230	100	R3U	50
	2015	0.15	230	250	R3U	54
	2048	0.15	230	500	R5U	56
	2031	20	500	100	R2U	50
	2034	20	500	300	R3U	54
	2021	20	1000	50	R2U	46
	2108	20	1000	250	R3U	52
	2129	500	2500	50	R2U	46
	2018	1000	3000	50	R3U	46
	2135	300	3800	50	R3U	48
	2153	700	3800	200	R3U	54
	2020	2000	4000	100	R5U	50
	2143	3000	6000	50	R3U	47

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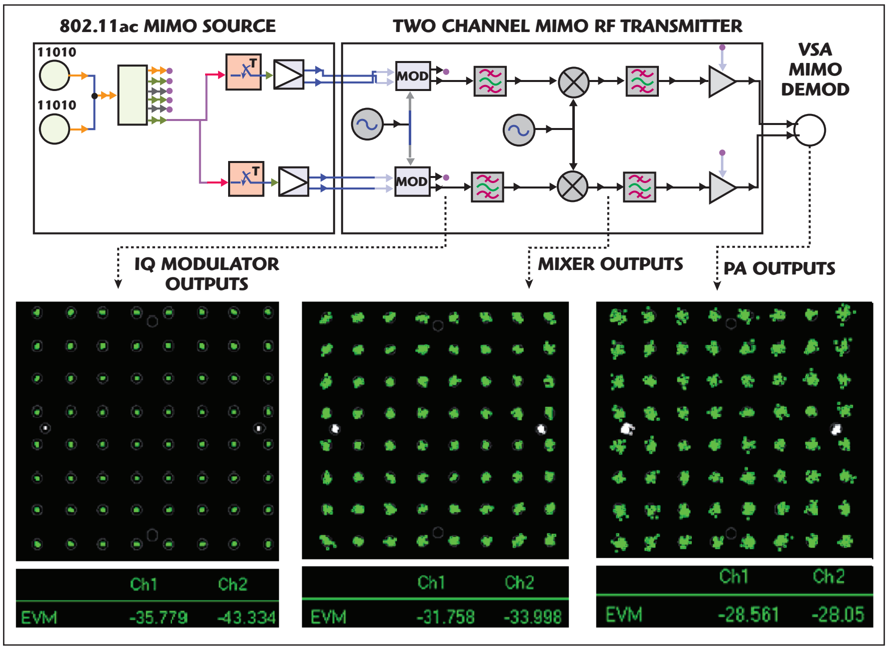
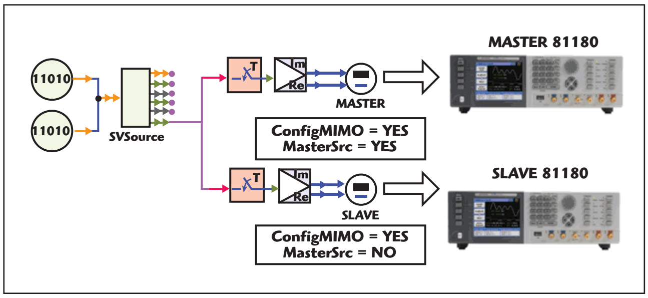


▲ *Fig. 3 Evaluating the system performance budget for 64 QAM MIMO.*

pression, have been modified to meet the EVM design performance metrics. Several VSA simulation measurement elements have been placed along the transmitter design at the IQ modulator outputs, the IF/RF mixer outputs and the PA outputs, to gain insight into the incremental waveform impairments along the transmitter chain.



▲ *Fig. 4 Generate MIMO waveforms in simulation and download to 81180A AWGs.*

The constellations at the IQ modulator outputs are relatively clean and the EVMs are approximately -35.8 dB for Ch1 and -43.3 dB for Ch2 due to the design impairments being modeled. Only one of the two constellations is shown due to space constraints. The Ch1 IQ modulator is introducing more waveform distortion than the Ch2 IQ modulator. The mixer output used to upconvert from IF to RF shows additional waveform distortion from the LO phase noise and other mixer impairments. The EVMs are approximately -31.8 dB for Ch1 and -33.9 dB for Ch2. The PA output shows even more waveform distortion from the PA gain compression. The overall transmitter output EVMs are approximately -28.6 dB for Ch1 and -28 dB for Ch2.

COMBINING SIMULATION AND TEST TO CREATE AND ANALYZE MIMO WAVEFORMS

Simulation can easily be leveraged in the R&D testing phase with test equipment links, which are seamlessly integrated into the simulation tools. The 802.11ac MIMO simulation source used to design the RF transmitter in the previous examples is now used to download MIMO waveforms to two arbitrary waveform generators. The complex IQ simulation waveforms are fed into two signal downloader sinks, which download the simulated IQ waveforms to two AWGs (see ***Figure 4***). In addition, the signal downloader sinks set and configure parameters on the two AWGs, such as the master/slave relationship using parameters on the sink and a math script.

A picture of the 802.11ac MIMO test equipment setup is shown in ***Fig-***

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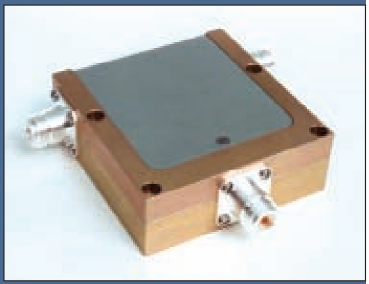

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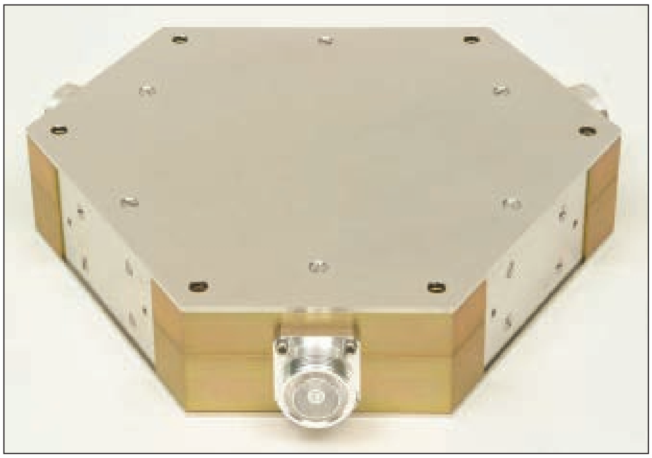

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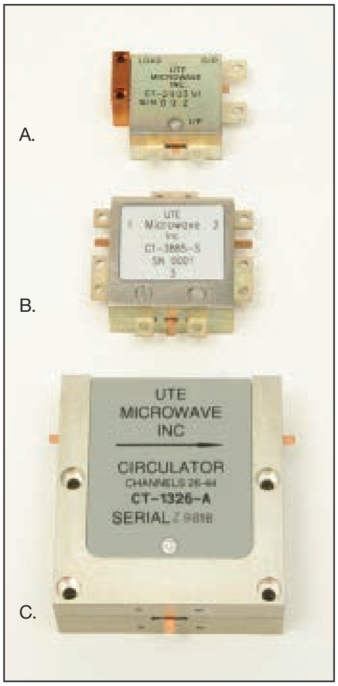

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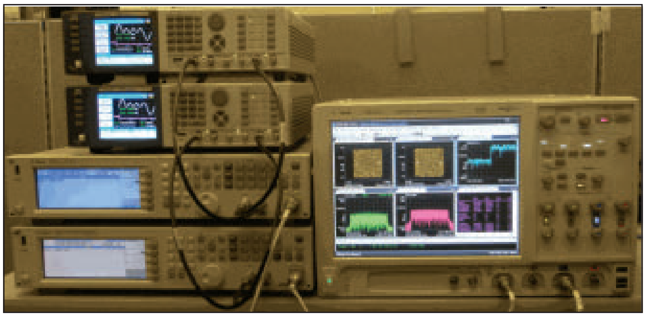

Fig. 5 802.11ac MIMO test equipment.

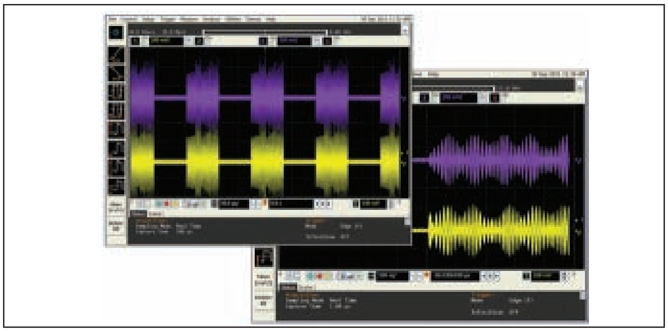

Fig. 6 Time measurement of the master/slave AWG MIMO waveforms.

ure 5. The two master/slave AWGs are shown on the upper-left, two MXG signal generators for converting the baseband signals to RF are shown in the lower-left and a high performance 13 GHz digital oscilloscope with VSA software is shown on the right. A special sync cable is used on the rear panels of the two AWGs to set the master/slave configuration. The two AWGs output analog IQ signals are connected to the external IQ inputs of the RF signal generators to modulate the IQ waveforms on the 5.8 GHz carriers. The two modulated 5.8 GHz carriers are input into two of the four phase coherent channels (Ch1 and Ch3) on the 13 GHz digital oscilloscope to perform the RF MIMO measurement with the VSA software. Proper synchronization of the two MIMO waveforms on the master/slave AWGs is verified using a 13 GHz digital oscilloscope, as shown in ***Figure 6***.

A close-up of the RF MIMO demodulation results at 5.8 GHz is shown in ***Figure 7***, playing back a VSA recording captured on the digital oscilloscope. The two constellations are shown on the upper left, the two spectrums centered at 5.8 GHz are shown on the lower left and the EVM is shown on the right. The EVM is approximately -40.4 dB for Ch1 and -40.6 dB for Ch2 with the equalizer training set to “preamble, pilots and data.”

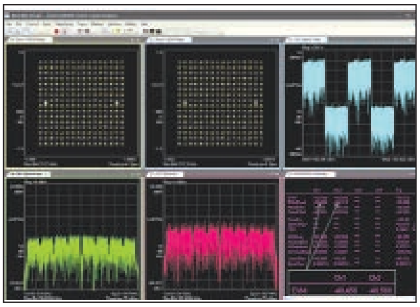

Fig. 7 VSA MIMO demodulation using VSA software on the 13 GHz digital oscilloscope.

With the equalizer training set to "preamble only," the measured EVMs were approximately -36.1 dB for Ch1 and -36.4 dB for Ch2. When the equalizer training is set to "preamble, pilots and data," the equalizer estimate is averaged over all the symbols in the measurement, producing a more accurate and less noisy equalizer estimate. For 802.11ac, the typical change in EVM is between 2 and 4 dB.

The multi-channel, phase-coherent capability of the high-performance digital oscilloscope also enables the system engineer to perform measurements at various stages along a transmitter chain (IQ, IF, RF) to help debug issues that may arise in prototype hardware.

CONCLUSION

Achieving high data rate throughput for the next generation WLAN applications introduces new design and test challenges for the system engineer in terms of wider channel bandwidths, higher-order modulation formats, such as 256 QAM and multi-antenna MIMO support. This article showed how system-level simulation can help to gain insight into performance requirements and design trade-offs needed to address these new design challenges. Once the R&D testing phase has begun, simulation can be combined with test equipment using integrated test equipment links for hardware prototype testing.

A MIMO test example was shown, using simulation to generate the waveforms, which were then downloaded to two master/slave AWGs to turn the simulated IQ waveforms into physical IQ waveforms for hardware prototype testing. Two signal generators were used with the AWGs to create the modulated 5.8 GHz test signals, which were then measured using a high-performance 13 GHz digital oscilloscope and VSA software. MIMO EVM measurements were shown and the impact of equalizer training on EVM was discussed.

The combination of simulation, AWGs, and signal generators provides a flexible waveform and signal generation capability to help the system engineer tackle the next generation WLAN testing challenges. In addition to the basic MIMO signal generation capability shown in this article, waveforms with modeled impairments could have easily been created and downloaded to the AWGs to test "what-if" scenarios and stress-test prototype hardware. Using a high-performance multi-channel phase-coherent digital oscilloscope enables MIMO signal analysis, as well as the ability to measure performance at various stages along a transmitter chain. ■

Reference

"Testing New-Generation Wireless LAN," Agilent Technologies Application Note, http://cp.literature.agilent.com/litweb/pdf/5990-8856EN.pdf.

Greg Jue *is an applications development engineer/scientist in Agilent's High Performance Scopes team. Previously, he was with Agilent EEsof, specializing in SDR, LTE and WiMAX™ applications. Jue wrote the design simulation section in Agilent's new LTE book and has authored numerous articles, presentations and application notes, including Agilent's LTE algorithm reference whitepaper and Agilent's new Cognitive Radio whitepaper. He pioneered combining design and test solutions at Agilent Technologies, and authored the popular application notes 1394 and 1471 on combining simulation and test. Before joining Agilent in 1995, he worked on system design for the Deep Space Network at the Jet Propulsion Laboratory, Caltech University.*

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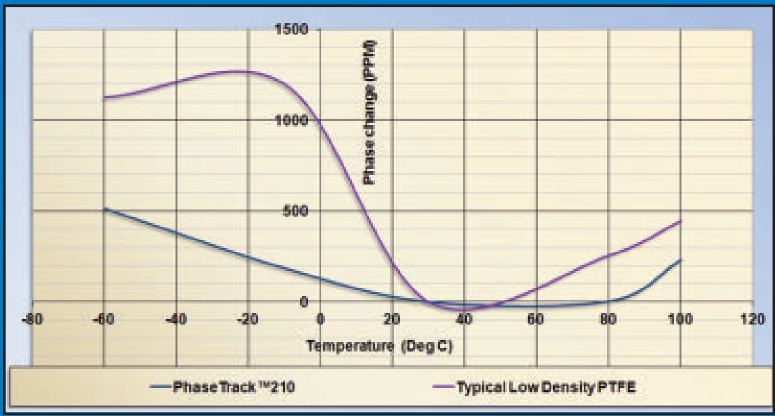

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Compact Antenna for MIMO LTE Mobile Phone Applications

Long-term evolution (LTE) is one of the 4th generation (4G) mobile communication technologies developed at different frequencies ranging from 400 MHz to 4 GHz with bandwidths up to 20 MHz.[1] LTE technology facilitates multiple antennas performing both transmit and receive operations, (such as multiple-input-multiple-output (MIMO) to support high data rate applications. However, integrating several antennas onto a printed circuit board (PCB) becomes progressively more difficult as each new generation of handsets experience miniaturization (that is thin, slim shapes). The closely-spaced antennas produce high mutual coupling, which opposes the relatively low correlation between the received signals as required for effective MIMO performance. High port-to-port isolation is required to achieve the low correlation between closely spaced antennas.

Various techniques to improve the isolation include: placing parasitic elements between driven elements,[2] using suspended inductive wire connecting the array elements at appropriate locations[3] and using a shunt reactive element in combination with certain length of transmission line.[4] The aforementioned methods are unattractive because of the space requirement for the parasitic elements, inductive wire and the transmission line. Orthogonally polarized elements may offer significant port isolation, but the finite-sized ground plane generates high cross-polar components that spoil the polarization purity. Other techniques to achieve port-to-port isolation include using decoupling branch line hybrids.[5] Research has also been conducted to develop diversity antennas by combining the separate antennas into one, thus reducing the space requirement and achieving polarization as well as pattern diversity.

Keeping the modern day miniaturization concept in mind, this article presents a compact antenna design that minimizes the space requirements and still achieves low correlation. The antenna design emerges from orthogonally oriented antennas that can be excited separately as well as together, as introduced by Rao and Wang.[6] A more compact design with a novel feeding structure that suits modern, miniaturized handheld devices is presented. Suitable polarization and pattern diversity can

Gopinath Gampala and C.J. Reddy
EM Software & Systems (USA) Inc., Hampton, VA
Oliver Stäbler and Thomas Hager
AWE Communications GmbH, Boeblingen, Germany

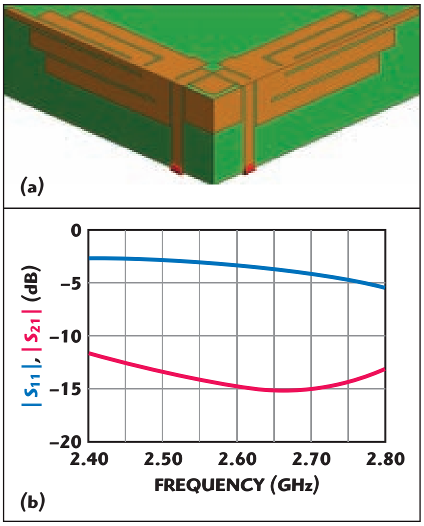
be achieved because of the orthogonal orientation of the antennas.

ANTENNA DESIGN AND OPTIMIZATION

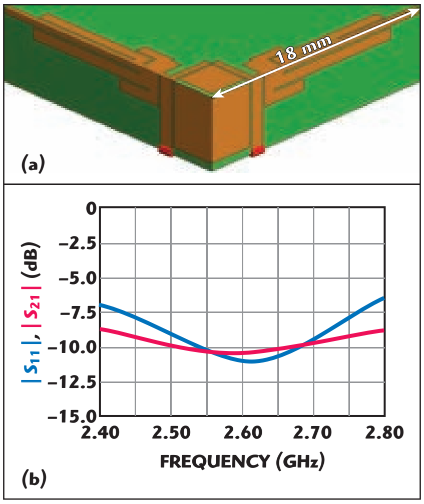
Cell phones and handheld devices are the new media centers, with access to music, photos, games, video and a host of connectivity options. Cellular standards such as High Speed Packet Access (HSPA) are already enabling multi-call capabilities on handsets, but the demand for mobile broadband services continues to rise. Therefore, a technology is needed that will suit the needs of different network operators that have different bandwidth allocations and also allow operators to provide different services based on spectrum. LTE technology with fast, mobile, multimedia data services appears to address critical issues at the optimal time and in a cost-effective manner. The goal of LTE is to increase the capacity and speed of wireless data networks, while exploiting MIMO concepts to achieve ambitious requirements. MIMO employs multiple antennas on both the transmitter and receiver to transmit additional data by utilizing persistent multi-path effects rather than causing interference. However, the challenge faced in a MIMO system is the placement of multiple antennas with low correlation (high isolation) in a finite given space on the platform. In addition, the modern day telecommunications are marching towards smaller, faster and more portable handheld devices and this trend makes the task of the engineer even more challenging.

Incorporating multiple antennas on a handheld device is difficult because of the miniature size, which imposes high correlation if the antennas have poor isolation. Therefore, an electrically small antenna (ESA) that can offer low correlation is needed. An ESA is an antenna that satisfies the condition,[7] $ka < 0.5$, where k is the wave number $2\pi/\lambda$, and a is the radius of the minimum size sphere that encloses the antenna. Keeping in mind the present day miniaturization of the handheld devices, a dual-port ESA has been designed, as shown in ***Figure 1***. Unlike the printed inverted-F antennas (PIFA), the miniaturization is achieved by introducing slots in the radiating elements of the dual-port ESA.

The input impedance of an ESA is characterized by low resistance and high reactance. The radiation resistance decreases with the size causing the antenna reactance to dominate. Although offering the ability to improve the efficiency of an ESA, matching circuits are not an option for two reasons. First, the challenge of designing a matching circuit that is also electrically small. Second, the restricted size of the handheld device that offers little room for additional circuits. Therefore, a self-resonant ESA should be designed to match standard transmission lines while still offering good port-to-port isolation. ***Figure 2*** shows a self-resonant ESA,



▲ *Fig. 1 Electrically small dual-port antenna: (a) antenna design and (b) S-parameters.*



▲ *Fig. 2 Self-resonant dual-port ESA: (a) optimized CSA and (b) S-parameters.*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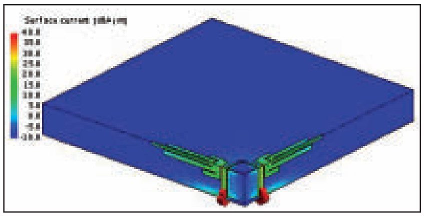
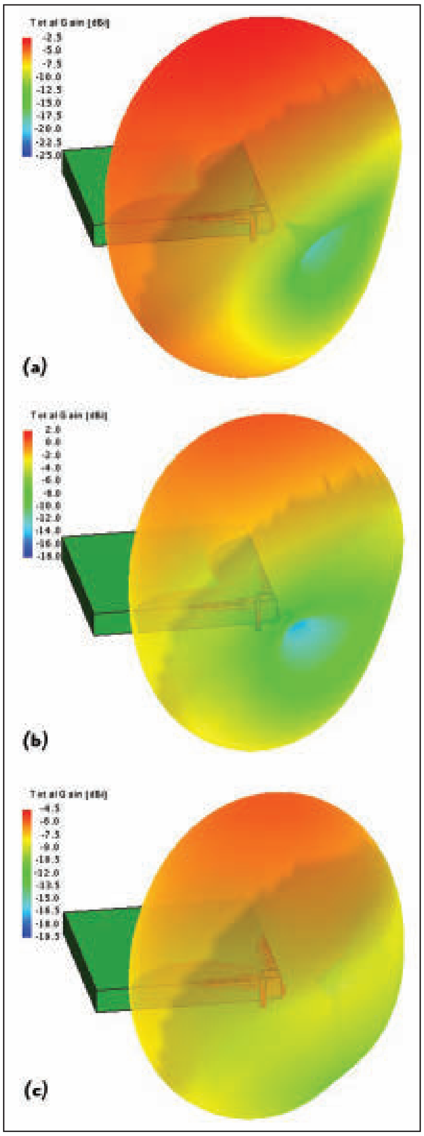


▲ *Fig. 3 Surface current distribution of the dual-port ESA.*



▲ *Fig. 4 Radiation pattern of the dual-port ESA: (a) two ports are excited, (b) one is excited, the other short and (c) one is excited, the other is open.*

which is an optimized version of Figure 1, with better matching and isolation. The ESA condition for the optimized antenna is ka = 0.49 (< 0.5).

The commercial software FEKO[8] has been used throughout the ESA analysis and design stages. The Simplex (Nelder-Mead) and Particle Swarm Optimization (PSO) algorithms were used for the optimization.[9] The Simplex algorithm, a local optimizer, converges much faster compared to the PSO, a global optimizer. However, the success of the Simplex depends on the starting point that carries the disadvantage of converging at a local minimum. The chance of achieving the global minimum, without compromising on speed, has been improved by hybridizing the PSO with the Simplex. The global optimizer will be used to find the starting point for the local optimizer.

Even though both radiating elements of the dual-port antenna are physically connected, the novel feed provides the required isolation. A clear current null can be observed from the surface current distribution of the ESA, as shown in ***Figure 3***.

Similar to the diversity antenna designed by Rao and Wang,[6] the dual-port ESA can be used in three different configurations:

- Both ports act as two independent transmitters (or) receivers (or) one port will be receiving while the other is transmitting.
- One port is excited while the other is shorted or loaded with matching impedance.
- One is excited while the other is left open for a switch diversity application. If the signal level falls below a threshold in this configuration, the receiver switches to another branch in search of a better signal.

Figure 4 shows the radiation pattern of the dual-port ESA in all the above three configurations.

MOBILE HANDSET

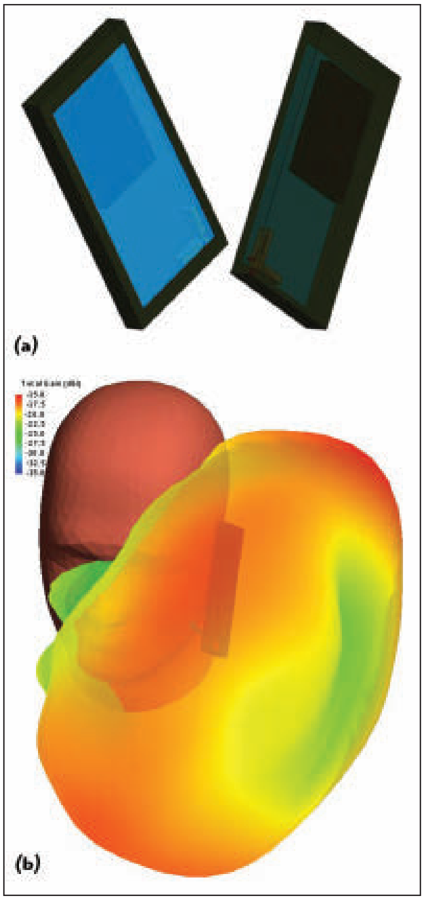
The dual-port ESA can be used for MIMO applications, specifically with cell phones (for its size) to implement LTE in order to reach the 4G standards. ***Figure 5*** shows the antenna in a handset and the radiation pattern from the handset close to a head. The radiation pattern from the handset is near spherical when placed close to the head, which is the desired pattern for cell phone applications. In mobile telecommunications, the channel capacity (bit rate performance) of the MIMO system, which is the driving force of the LTE technology, is as important as the impedance and radiation characteristics of the mobile handset.

CHANNEL CAPACITY

The performance of wireless communication systems fundamentally depends upon the mobile radio channel. As a consequence, predicting the propagation characteristics as well as further performance indicators, such as the channel capacity between the transmitting and receiving antennas of the wireless system, is one of the most important tasks for the radio planning of LTE networks.

The mobile radio channel in urban and indoor areas is characterized by multi-path propagation. Dominant propagation phenomena in these scenarios are the shadowing behind obstacles, the reflection at the walls of buildings, the wave guiding effects (due to multiple reflections) in street canyons or corridors and the diffractions at vertical and horizontal wedges. As deterministic ray tracing models can cope best with such propagation effects, the prediction of the channel capacity is based on a ray tracing wave propagation simulation. The propagation model is fully three dimensional and computes all rays with up to three interactions (including double diffractions and combinations of reflections and diffractions). The prediction of the path loss along the ray is computed with the uniform theory of diffraction (UTD) and with Fresnel coefficients for the reflections. In order to accelerate the time-consuming path determination, the Intelligent Ray Tracing (IRT) Model[10,12] can be utilized.

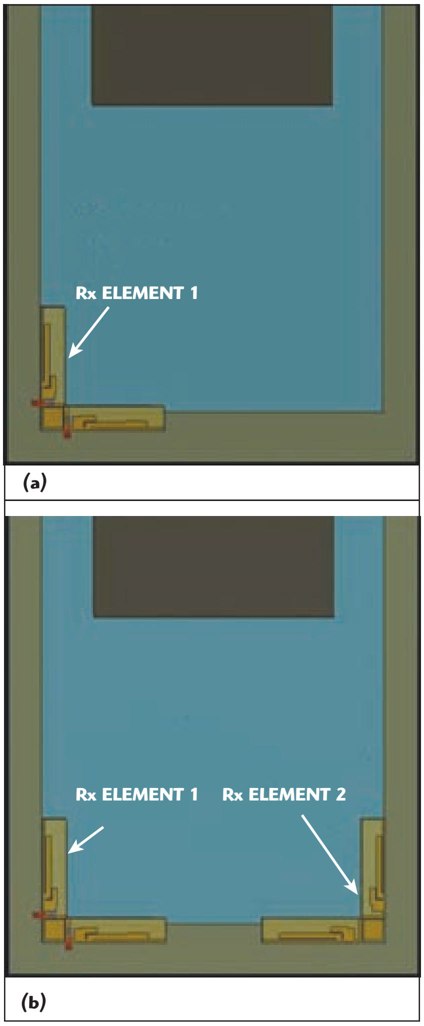
However, the main disadvantage of deterministic wave propagation models is their excessive computation time. The most time-consuming part is the determination of all relevant paths between transmitter and receiver. To avoid large computation times, the IRT Model is used to predict the SISO channel impulse response between the centers of the transmitter and the receiver antenna arrays. As the spacing between the antenna ar-



▲ *Fig. 5 ESA in a handset: (a) front and back view of the handset and (b) radiation pattern of the handset when placed close to a head.*

ray elements is rather small, the same propagation paths are assumed to exist for all antenna array elements and only the signal phases are changing from one element to the other (assuming planar incidence of the waves).[11] Considering such a modular approach avoids re-computing the ray tracing between all the antenna elements of the transmitter and the receiver station during the generation of the MIMO channel matrices, which are required for the computation of the channel capacity according to the well known Shannon formula.[11]

In the following subsections, the channel capacity is evaluated for LTE systems in urban and indoor environments using different MIMO configurations in the 2.6 GHz frequency band. The first configuration considers two antenna elements at the base station and one dual port ESA at the mobile handset. The second system uses the same base station equipment, but two dual port ESAs at the lower



▲ *Fig. 6 Handset with location of receiving elements: (a) 1×2 LTE system with one receiving element and (b) 2×2 LTE system with two receiving elements.*

corners of the handset, as shown in ***Figure 6***. In both examples, the dual-port ESA operates in configuration-II, where one port is excited while the other is shorted or loaded with matching impedance.

In the urban environment, the handset moves along a trajectory of length 2.2 kilometers, as shown in ***Figure 7***. The base station antenna array is located 15 meters above the street level on top of a building, where the signal is radiated from a uniform linear array consisting of two antenna elements with a spacing of ten wave lengths. The average channel capacity along the route is 4.8 and 6.4 bit/s/Hz for the 1×2 and the 2×2 systems, respectively, which clearly shows the benefit of utilizing the MIMO technology within the mobile handset.

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7/16 90° 6 GHZ
SM4531 $172.00
N 90° 18 GHZ
SM3547 $38.77
TNC-BNC 8 GHZ
SM5514 $145.40
ZMA-SMA 18 GHZ
SMW75ACN $297.95
WR75-N 10-15 GHZ
28AC206 $363.60
WR28-2.92 26-40 GHZ
SM4835 $172.53
SSMA-2.92 40 GHZ
ATTENUATORS
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N 5W 18 GHZ
SA18N25WA $232.24
N 25 W 18 GHZ
SA18N507 $343.09
N 50 W 18 GHZ
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SMA 50 W 18 GHZ
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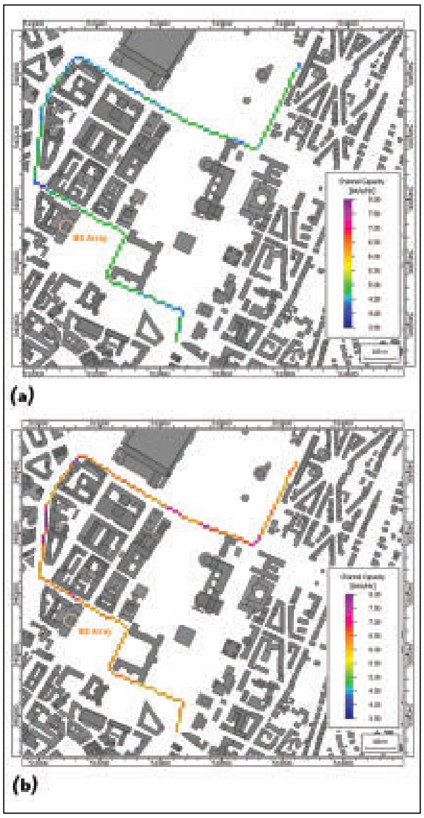
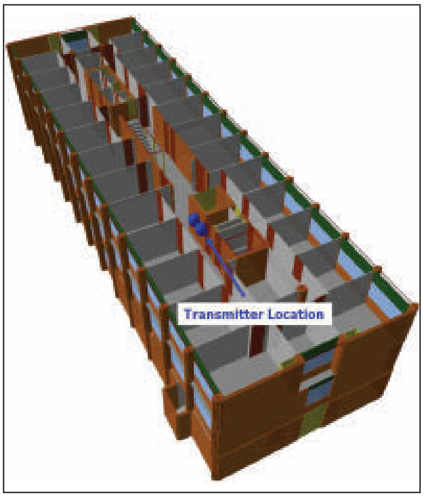
was also selected for the evaluation of the channel capacity. ***Figure 8*** shows the three-dimensional view of the considered indoor environment. The location and orientation of the base station antenna array (blue balls) are depicted as well.

Figure 9 depicts the predicted channel capacity using the same equipment for the base station as well as for the handset as already introduced for the urban environment. An average channel capacity of 4.6 and 5.9 bit/s/Hz is achieved for the 1×2 and the 2×2 systems, respectively, on the upper floor of the building. Some further statistics are listed in ***Table 1***. With an average capacity increase of 1.3 bit/s/Hz, the 2×2 LTE system offers a clear advantage regarding data throughput compared to the 1×2 LTE system.



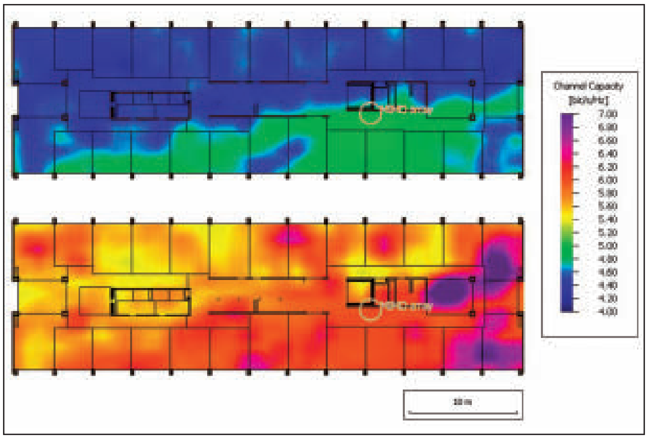
▲ *Fig. 7 Channel capacity along a receiver trajectory in an urban environment: (a) 1×2 LTE system and (b) 2×2 LTE system.*



▲ *Fig. 8 Multi-floor office building with the transmitter location.*

CONCLUSION

This article gives a complete workflow of an antenna design for LTE mobile phone applications, starting from the antenna design to the bit rate channel capacity calculations. The antenna is a dual-port ESA with a novel feeding structure that can be used in three different configurations for the LTE mobile phone applications. The dual-port ESA displays good radiation characteristics when embedded into the mobile handset as well as the handset placed close to the human head. The MIMO analysis is done using the Intelligent Ray Tracing Model to calculate the channel capacity of the mobile handset in both the urban and indoor environments. ■



▲ *Fig. 9 Channel capacity in an indoor environment for a 1×2 LTE system (top) and a 2×2 LTE system (bottom).*

TABLE I
STATISTICS OF PREDICTED CHANNEL CAPACITY IN AN INDOOR ENVIRONMENT FOR 1X2 LTE AND 2X2 LTE SYSTEM

Channel Capacity	1x2 system (bits/s/Hz)	2x2 system (bits/s/Hz)
Minimum value	4.0	5.1
Maximum value	5.0	8.7
Average value	4.6	5.9
Standard deviation	0.2	0.5

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A Miniaturized Multiple Coupled Line Power Divider Employing an R-C-R Isolation Circuit

Using a π-type multiple coupled microstrip line structure (MCMLS) and an R-C-R isolation compensation circuit, an ultra-compact and high isolation power divider was fabricated on a GaAs substrate. The line length of the power divider was reduced to λ/46 by using the π-type MCMLS. The size of the power divider is 0.304 mm², which is 12.1 percent of a conventional Wilkinson power divider on a GaAs substrate. Thanks to the R-C-R isolation compensation circuit, the isolation characteristic of the proposed power divider is highly improved. The proposed power divider shows good RF performances in the C-/X-Band.

In RF devices, such as power amplifiers and mixers, couplers and combiners/dividers are required for their operation.[1] Especially, Wilkinson power dividers and branch-line couplers have been widely used for power splitting/combining.[2-6] However, conventional combiners/dividers employ quarter-wavelength lines,[2-4] which has been an obstacle to the realization of miniaturized on-chip power splitting/combining circuits. In this work, using a π-type multiple coupled microstrip line structure (MCMLS),[7] a miniaturized on-chip power divider was realized on a GaAs substrate. An R-C-R circuit structure, consisting of two resistors and a capacitor, was connected between the two output ports of the power divider to improve its isolation characteristic.

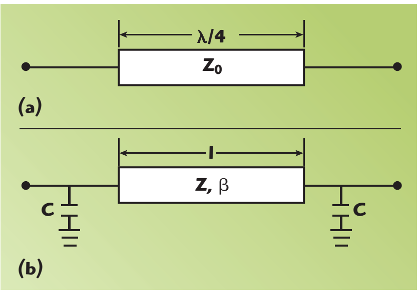
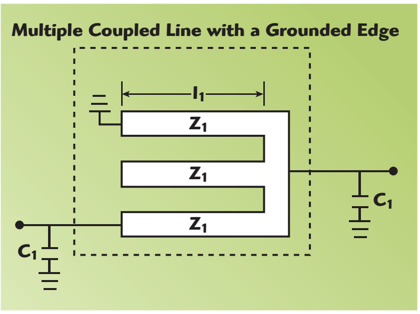


Fig. 1 A quarter-wavelength microstrip line (a) and a conventional π-type single transmission line structure (STLS) (b).

DESIGN OF A MULTIPLE COUPLED LINE POWER DIVIDER EMPLOYING R-C-R ISOLATION COMPENSATION CIRCUIT

Figure 1 shows a quarter-wavelength line and a conventional π-type single transmission line structure (STLS)[5,6] equivalent to the quarter-wavelength line. Using the π-type STLS, miniaturized couplers were fabricated on semiconducting substrates.[5,6] However, as the line length l of the π-type STLS becomes shorter,

Young Yun
Korea Maritime University, Busan, Korea

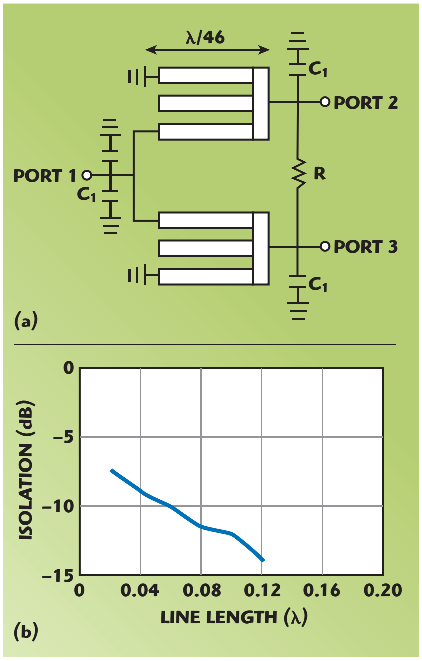


▲ *Fig. 2 π-type multiple coupled microstrip line structure (MCMLS).*

the characteristic impedance Z of the STLS becomes larger, which makes it difficult to fabricate ultra-compact passive components, using the π-type STLS.[5,6] For example, if the line length of the π-type STLS on a GaAs substrate becomes less than λ/12, the characteristic impedance Z becomes higher than 100 Ω. A transmission line whose characteristic impedance is higher than 100 Ω cannot be easily realized on semiconducting substrates, due to a loss originating from its very thin line width.[5,6]

In order to overcome the above problem for the conventional π-type transmission line, a π-type MCMLS was employed. ***Figure 2*** shows the π-type MCMLS.[7] According to a previous study,[7] the characteristic impedance Z_1 of each line comprising the multiple coupled microstrip line was highly reduced by grounding the edge. Therefore, the single line of π-type circuit was replaced by the multiple coupled lines with a grounded edge, which facilitated the realization of miniaturized on-chip passive components on a semiconducting substrate.

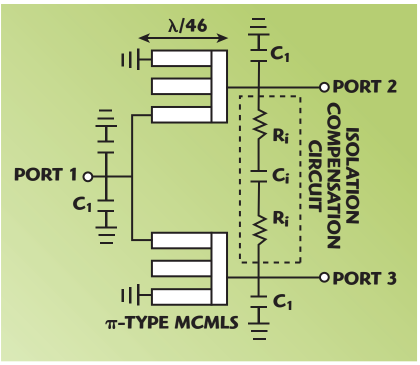
First, a multiple coupled line power divider was fabricated, employing only one resistor on a GaAs substrate. ***Figure 3*** shows the power divider and its isolation characteristic. As shown, like for a conventional Wilkinson power divider, only one resistor was connected between the two output ports. The line length was reduced to λ/46 by using the π-type MCMLS. Unlike the π-type STLS, even though the line length is highly reduced, the characteristic impedance was not rapidly increased. The characteristic impedance of the π-type STLS, with a line length of λ/46, is 200 Ω, which cannot be realized on a semiconductor substrate.



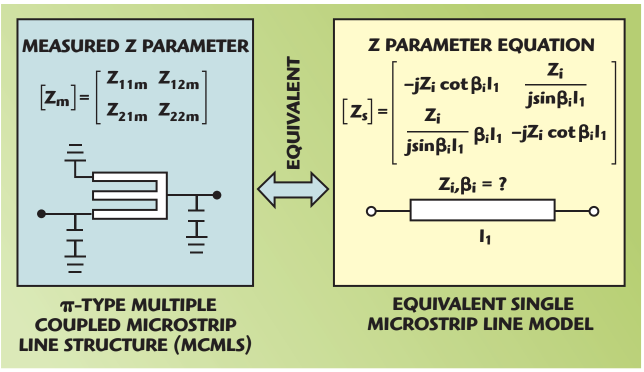
▲ *Fig. 3 Multiple coupled line power divider using one resistor (a) and isolation characteristics as a function of line length (b).*

In the case of the π-type MCMLS, however, if the line length is λ/46, the characteristic impedance Z_1 becomes 60 Ω, which can be easily realized on a semiconductor substrate. The power divider shows an isolation worse than –10 dB in a range of line length shorter than 0.06 λ, which is unsatisfactory for application to a power divider. Especially, a shorter line length results in worse isolation. According to an investigation of the basic characteristics of multiple coupled lines, the isolation characteristic of RF components employing multiple coupled lines is highly deteriorated, due to the parasitic elements between the lines.[7,8] In a previous study,[7] using the π-type MCMLS, a power divider without an R-C-R compensation circuit was fabricated on PCB. Even though it was fabricated on PCB, the degradation of the isolation characteristic was also observed.[7]

In this work, an R-C-R circuit structure was employed to improve the isolation characteristic of the power divider. ***Figure 4*** shows the proposed power divider. As shown in this figure, the R-C-R circuit structure, consisting of two resistors and a capacitor, was connected between the two output ports. The isolation compensation theory and design procedure can be explained as follows. First, as shown in ***Figure 5***, a single microstrip



▲ *Fig. 4 Proposed multiple coupled lines power divider using an R-C-R isolation compensation circuit.*



▲ *Fig. 5 π-type multiple coupled microstrip line structure (MCMLS) and its equivalent microstrip line model with a characteristic impedance Z_i and propagation constant β_i.*

line model equivalent to the π-type MCMLS was extracted. The equivalent characteristic impedance Z_i and propagation constant β_i of the single microstrip line model were extracted so that the measured Z parameter of π-type MCMLS coincides with the two-port Z parameter equation of the single microstrip line model. Using the above method, the Z_i and β_i can be given by

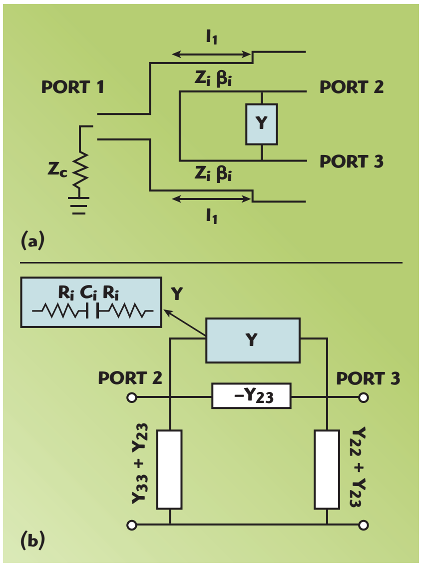
$$Z_i = \sqrt{|Z_{12m}|^2 - |Z_{11m}|^2} \tag{1a}$$

$$\beta_i = \frac{1}{\ell_1} \cot^{-1}\left[\frac{|Z_{11m}|}{\sqrt{|Z_{12m}|^2 - |Z_{11m}|^2}}\right] \tag{1b}$$

where Z_{12m} and Z_{11m} are the measured Z parameters of the π-type MCMLS, and l_1 is the length of the π-type MCMLS. Using the Z_i and β_i, the value of R_i and C_i of the R-C-R circuit were chosen so that the isolation of the proposed power divider was infinite. ***Figure 6*** shows the proposed power divider with port 1 terminated and ports 2 and 3 excited. The π-type MCMLS was expressed as an equivalent microstrip line model with Z_i and β_i. Generally, a Wilkinson power divider with port 1 terminated can be expressed as a simple equivalent circuit shown.[2] Y_{22}, Y_{23} and Y_{33} are Y parameters of the three-port equivalent circuit. According to equivalent circuit analysis of the Wilkinson power divider,[2] Y_{23} can be expressed as follows

$$\frac{1}{Y_{23}} = \frac{(1 - \cos 2\beta_i l_i) Z_i^2 - 2jZ_i \sin 2\beta_i l_i}{2Z_c} \tag{2}$$

In the equivalent circuit, the R-C-R circuit and $-Y_{23}$ are connected with each other in parallel. Therefore, it is clear that ports 2 and 3 will be uncoupled if $Y = Y_{23}$, so that the total admittance between ports 2 and 3 vanished. In the conventional Wilkinson power divider, the line length is λ/4 and βl is π/2. Therefore, from Equation 2, it is clear that Y_{23} becomes a real number, and only a resistor is connected between two isolation ports. In the proposed power divider, however, the line length is λ/46 and Y_{23} becomes a complex number. Therefore, if an R-C-R circuit is used, the admit-



▲ *Fig. 6 Wilkinson power divider with port 1 terminated and ports 2 and 3 excited (a) and its equivalent circuit (b).*

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tance of the R-C-R circuit becomes a complex number and $Y = Y_{23}$ can be satisfied as follows

$$\frac{1}{Y} = 2R_i + \frac{1}{j\omega C_i} = \frac{1}{Y_{23}} \tag{3}$$

From the above equation, the following results can be obtained

$$R_i = \frac{(1-\cos 2\beta_i l_1)Z_i^2}{4Z_c} \tag{4a}$$

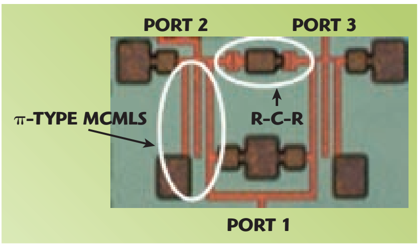
$$C_i = \frac{Z_c}{\omega Z_i \sin 2\beta_i l_1} \tag{4b}$$

In this work, R_i and C_i are 3.04 Ω and 2.7 pF, respectively.

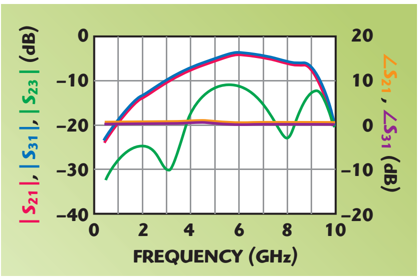
MEASURED RESULTS

Figure 7 shows a photograph of the proposed Wilkinson power divider, which was fabricated on a GaAs substrate. The line length is 260 μm and the shunt capacitor C_1 is 1.83 pF. The size of the proposed Wilkinson power divider is 0.304 mm^2, which is 12.1 percent of a conventional Wilkinson power divider employing quarter-wave lines. The sizes of the proposed Wilkinson power divider and conventional ones on a GaAs substrate are summarized in ***Table 1***.

Figure 8 shows the measured power division, isolation characteristics and phase division characteristics for the proposed power divider. As shown, equal power division characteristics for all frequencies can be observed. S_{21} and S_{31} exhibit a value of –5.4 dB at a center frequency of 8 GHz. In the frequency range of 4.5 to 8.8 GHz, S_{21} and S_{31} show a value of –4.9 ± 1 dB, which is comparable to a conventional on-chip Wilkinson power divider.[5,6] Equal phase division characteristics can also be seen for all frequencies, because a perfect symmetry was maintained in the shape of the proposed power divider. The isolation, (S_{23}) shows a value of –23.5 dB at 8 GHz and values better than –11 dB for all frequencies. To confirm the effectiveness of the R-C-R isolation compensation circuit, the isolation characteristic of the proposed pow-



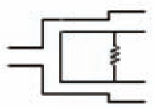
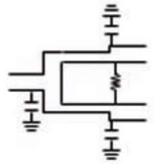
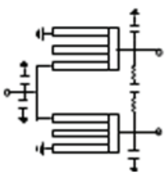
▲ *Fig. 7 Photograph of the multiple coupled line power divider.*



▲ *Fig. 8 Measured RF characteristics of the proposed power divider using an R-C-R isolation compensation circuit.*

TABLE I

SIZES OF THE PROPOSED POWER DIVIDER AND CONVENTIONAL ONES

Items	Size (mm²)	Line Length (mm)	Structure
Conventional Wilkinson power divider employing λ/4 line[2]	2.5	3	
Conventional Wilkinson power divider employing π-type single line[5,6]	1	1.5	
Proposed power divider	0.304	0.26	

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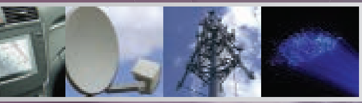

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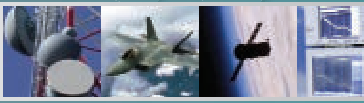

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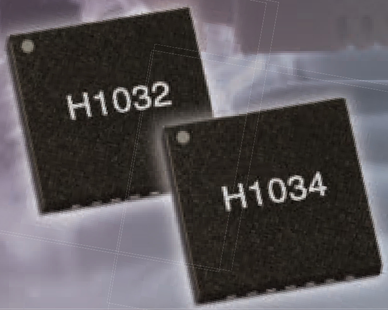

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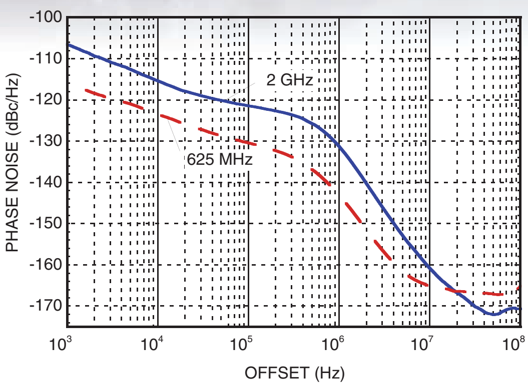
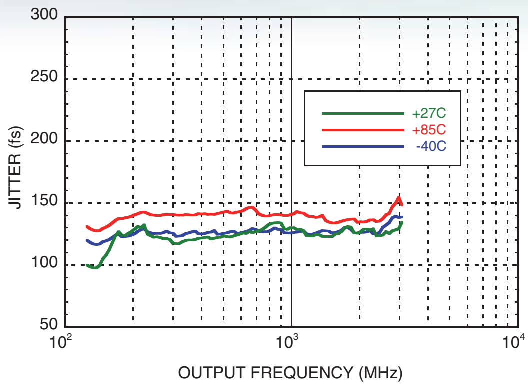


Integrated RMS Jitter



	Frequency (MHz)	Function	Typical Phase Jitter (fs RMS)	Phase Noise Floor (dBc/Hz)	Maximum Reference Freq. (MHz)	Typical Power Consumption (W)	Figure of Merit (Frac/Int) (dBc/Hz)	Part Number
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NEW!	125 - 3000	Clock Generator with Fractional-N PLL+VCO	118 / 78	-165	350	0.86	-227 / -230	**HMC1034LP6GE**

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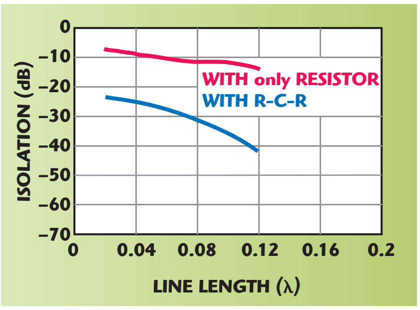

▲ *Fig. 9 Measured isolation of the proposed power divided at 8 GHz with only a resistor and with an R-C-R circuit.*

er divider was compared with that of the power divider employing only a resistor. ***Figure 9*** shows the measured isolation characteristics of the power dividers. The isolation was measured at 8 GHz. As shown, the isolation characteristic of the proposed power divider was highly improved by using the R-C-R isolation compensation circuit. If a transmission line with a length of 0.0217λ (= λ/46) is used, the proposed power divider employing an R-C-R circuit shows an isolation of –23.5 dB, while the power divider employing only resistor shows an isolation of –7.5 dB.

CONCLUSION

In this work, using an MCMLS and an R-C-R isolation compensation circuit, an ultra-compact and high isolation power divider was fabricated on a GaAs substrate. The line length of the power divider was reduced to λ/46 by using the π-type MCMLS. The size of the proposed power divider was 0.304 mm^2, which was 12.1 percent of a conventional Wilkinson power divider on a GaAs substrate. An R-C-R isolation compensation circuit was employed to highly improve the isolation characteristic of the power divider. If a transmission line with a length of 0.0217λ (= λ/46) is used, the proposed power divider, employing an R-C-R circuit, showed an isolation of –23.5 dB, while the power divider employing only resistor showed an isolation of –7.5 dB. The proposed power divider showed good RF performances in the C-/X-Band. The isolation was better than –11 dB in the C-/X-Band. Owing to the perfect symmetry in its shape, the proposed power divider showed equal power and equal phase division characteristics for all frequencies. The power division characteristic in the C-/X-Band, S_{21} and S_{31}, showed a value of –4.9 ± 1 dB, which was comparable to a conventional on-chip Wilkinson power divider. The above results indicate that the proposed power divider is a promising candidate for application to power coupling and dividing of RF devices on MMIC. ■

ACKNOWLEDGMENTS

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Compact Lowpass Filter with Wide Stopband Using a Tapered Microstrip Resonator Cell

A tapered compact microstrip resonator cell (T-CMRC) is proposed, in order to design a lowpass filter with ultra wide stopband and low insertion loss. By optimization of this structure and insertion of open stubs and delta stubs, undesirable response and harmonics were suppressed. A lowpass filter, consisting of two T-CMRCs in series, was designed to show the advantages of high and ultra wide rejection in the stopband and compact size. The proposed filter has a stopband from 1.97 to 22.3 GHz with insertion loss better than 0.1 dB and return loss better than 20 dB. Measurement results show good agreement with the simulation.

A microstrip lowpass filter (LPF) is one of the vital components in a microwave communication system. Compact circuit size, low insertion loss in the passband and a wide stopband are necessary to meet modern microwave communication system requirements. Due to compact size, low cost, easy fabrication and convenient integration with other microwave circuits, planar resonators have increasingly been taken into consideration to be employed in microwave filter design. One of the techniques that can be applied in microstrip LPF synthesis is using a one-dimensional (1D) photonic band gap (PBG) structure with a microstrip transmission line. The PBG structure exhibits bandstop and slow-wave characteristics, which can be used to extend the stopband with compact circuit size. The 1D photonic band gap as a compact microstrip resonator cell (CMRC) was first introduced in 2000.[1] Other types of CMRCs, such as a spiral compact microstrip resonator cell (SCMRC),[2] a lowpass filter using symmetric rectangular coupled capacitors,[3] a lowpass filter using tapered compact microstrip resonator cell (T-CMRC) with a non-uniform cell dimension[4] and a slit-loaded tapered compact microstrip resonator cell (SLTCMRC)[5] were proposed later. All of these use the photonic band gap to get a decrement number of the harmonics in the stopband with a compact size. However, in these proposed filters, the insertion loss in the passband and spurious response suppression in the stopband remain as the main challenges. To ob-

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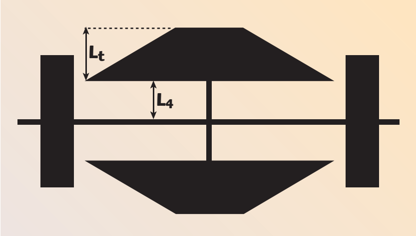
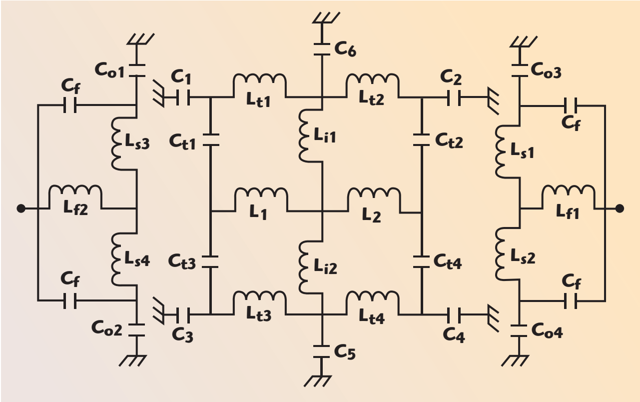
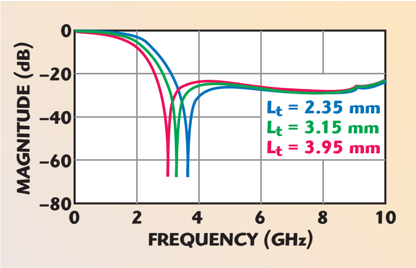


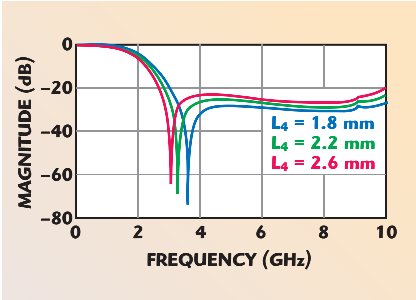
▲ *Fig. 1 Structure of the proposed T-CMRC.*



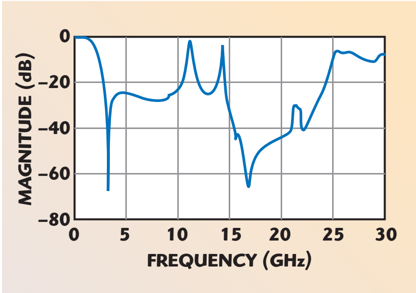
▲ *Fig. 2 L-C equivalent circuit of the proposed resonator.*



▲ *Fig. 3 Simulated S-parameters of the proposed resonator as a function of L_t.*



▲ *Fig. 4 Simulated S-parameters of the proposed resonator as a function of L_4.*



▲ *Fig. 5 S-parameter of the proposed resonator.*

tain wideband harmonic suppression, a defected ground structure (DGS), using slotted-ground-plane resonators, was introduced[6] and a coupled-line hairpin unit was described,[7] which can be a candidate for designing the LPF, instead of cascading several resonator cells. Due to the fact that the ground plane is etched, this structure does not provide mechanical robustness. Some other techniques have been proposed to synthesize microstrip lowpass filters such as an in-line beeline CMRC,[8] stepped-impedance hairpin resonators,[9] symmetrically loaded radial-shape patches[10] and a miniaturized LPF with triangular and high-low symmetrically loaded impedance resonators.[11] However, the insertion loss in the passband and a wide stopband and spurious suppression in the stopband remain as drawbacks of the proposed filters.

In this article, a lowpass filter with an ultra wide stopband and a compact size, using a tapered compact microstrip resonator cell, is proposed. By tuning the lengths of the tapered and of the open stubs and the spacing between them, the stopband performance can be extended. The simulation of the designed structure has been accomplished using an EM-Simulator (ADS).

FILTER DESIGN

The structure of the proposed T-CMRC is shown in ***Figure 1***. It shows that the compact microstrip resonator cell consists of two tapered cells and four vertical open stubs. The narrow connecting lines lead to the increment of series inductance. In contrast, the gap between the central narrow line and tapered cells increases the shunt capacitance, so it can give an attenuation pole in the stopband. As a result it will have an ultra wide stopband. The L-C equivalent circuit of the proposed resonator is obtained using the transmission line model shown in ***Figure 2***, which is described as follows: L_1 and L_2 are the inductances of the central line; L_{t1} to L_{t4} are the inductances of the tapered cells; L_{s1} to L_{s4} are the inductances of the open stubs; L_{f1} and L_{f2} are the inductances of the feed line; L_{i1} and L_{i2} are inductances of the vertical line; C_1 to C_6 are the capacitances between tapered cells and ground; C_{t1} to C_{t4} are the capacitances between tapered cells and central line; C_{01} to C_{04} are the capacitances of the open stubs; and C_f is the capacitance between the feed line and the open stubs.

The proposed resonator is implemented on a (RT/Duroid 5880) substrate, with a relative permittivity, height and loss tangent equal to 2.2, 20 mil and 0.0009, respectively. The simulated S-parameters of the proposed resonator as a function of L_t and L_4 are shown in ***Figures 3*** and ***4***. As shown, by decreasing L_t from 3.95 to 2.35 mm, the transmission zero will move up from the lower frequency to 2.99 GHz. When L_4 increases from 1.8 to 2.6 mm, the transmission zero at 3.53 GHz will approach the lower frequency. The transmission zero can be controlled by increment and decrement of the parallel capacitance and series inductance. The reason that the transmission zero approaches the lower frequency is that the increase in series inductance leads to a decrease in the resonant frequency of the equivalent LC circuit. The tapered cells are used to control the transmission zeros and the cutoff frequency. By optimizing the tapered cells' dimensions, the cutoff frequency can be reduced. The open stubs are used to provide the additional capacitance and inductance to control the harmonics and spurious suppression.

In order to achieve ultra wide stopband, the open stubs need to be optimized. The S-parameter simulation of the proposed resonator is illustrated in ***Figure 5***. It can be seen that its insertion loss from DC to 1.33 GHz is less than 1 dB. The $|S_{21}|$ is –20 dB at 2.82 GHz. The proposed structure has a transmission zero at 3.26 GHz, with –67.87 dB in the stopband near the passband.

SIMULATION AND MEASUREMENT

To obtain a filter with an ultra wide stopband, two resonators with the same dimensions are used. For more

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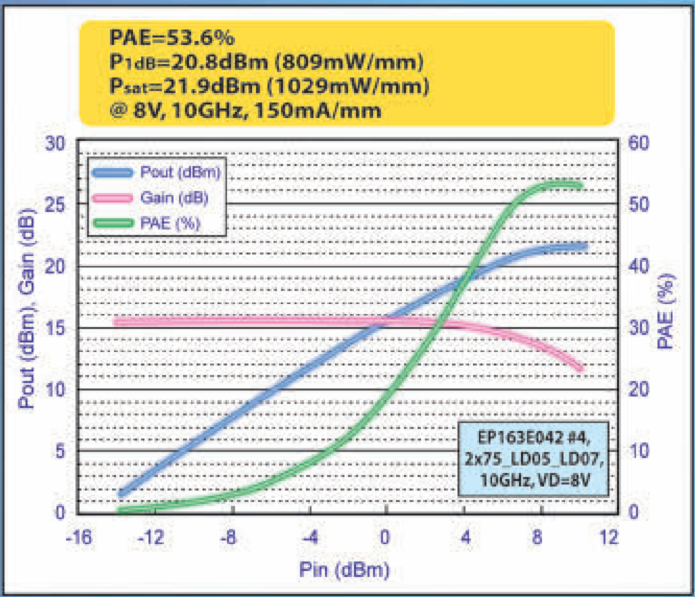

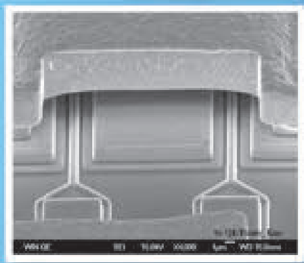

Comparison Table for 0.1μm, 0.15μm, 0.25μm and 0.5μm pHEMT

	PP10	PP15	PP25-21	PP50-11
Vto (V)	-0.9	-1.2	-1.2	-1.4
Idss (mA/mm)	450	500	345	350
Idmax (mA/mm)	720	650	460	480
GM (mS/mm)	750	495	380	310
VDG (V)	9	10	19.2	20
ft (GHz)	130	85	65~72	32
Fmax (GHz)	175	180	160	85
PldB (mW/mm)	533.25 (3.5V)	670 (5V)	809 (8V)	587 (8V)
Psat (mW/mm)	764.3 (3.5V)	820 (5V)	1029 (8V)	851 (8V)
Gain (dB)	14.35	18.1	15.6	15.5
PAE (%)	53.57	55	53.6	53.5
Frequency	29 GHz	10 GHz	10 GHz	10 GHz

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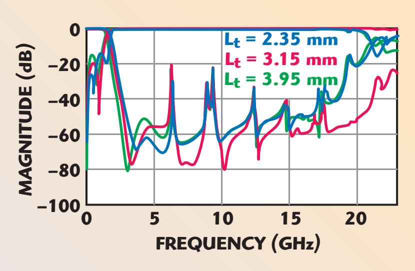
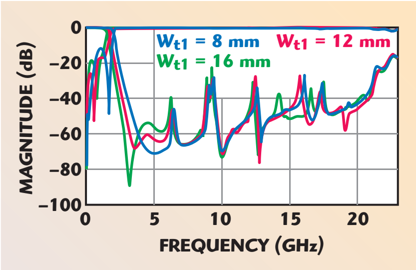


▲ *Fig. 6 Simulated S-parameter of the proposed filter as a function of L_t.*



▲ *Fig. 7 Simulated S-parameters of the proposed filter as a function of W_{t1}.*

attenuation of the harmonics in the stopband, the open stubs and delta stubs are vertically connected to the central microstrip line. If the stopband is divided into two parts, namely the lower frequencies part and higher frequencies part, the open stubs will be used to control harmonics and spurious suppression at lower frequencies and harmonics at higher frequencies are suppressed using the delta stubs.

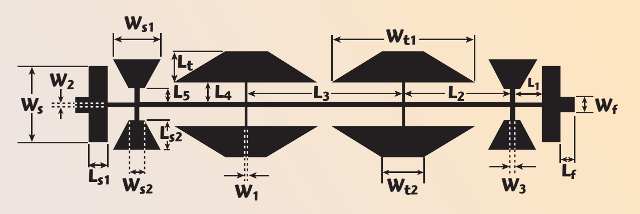
An EM-Simulator (ADS) was used to optimize the resonator dimensions in order to obtain the LPF with the desired characteristics. As shown in ***Figure 6***, by increasing L_t from 2.35 to 3.95 mm, the transmission zero at 3.7 GHz has been moved to a lower frequency. A similar case has happened in ***Figure 7***, in which W_{t1} was increased from 8 to 16 mm. Therefore, the transmission zero in the stopband can be easily controlled with the dimensions of the proposed resonator. The dimensions of the obtained LPF shown in ***Figure 8*** are as follows: W_{t1} = 15.07 mm, W_{t2} = 4.08 mm, L_t = 3.15 mm, W_{s1} = 5.07 mm, W_{s2} = 1.6 mm, L_{s2} = 3 mm, L_1 = 2.94 mm, L_2 = 10.95 mm, L_3 = 15.9 mm, L_4 = 2.2 mm, L_5 =1.5 mm, W_1 = 0.2 mm, W_2 = 0.3 mm, W_3 = 0.45 mm, L_f = 1.5 mm, W_f =1.5 mm, L_{s1} = 2 mm and W_s = 7.9 mm.

The proposed LPF, using the obtained T-CMRC structure with the above dimensions, has been fabricated with a microelectronic technology in accordance with the pattern shown previously. A photograph of the fabricated filter is shown in ***Figure 9***. The measurements of the proposed LPF are carried out using an Agilent network analyzer N5230A. ***Figure 10*** shows the simulated and measured S-parameters of the lowpass filter using the proposed structure, where $|S_{11}|$ and $|S_{21}|$ are in dB. As can be seen, the transition band is from 1.58 to 1.97 GHz with −3.25 to −20.25 dB, respectively. Significantly, two transmissions zero at 3.3 and 5.6 GHz with −76.33 and −59.86 dB will contribute to create a sharper transition from the passband to the stopband. The insertion loss in the passband is less than 0.1 dB from DC to 1.15 GHz, which is 73.25 percent of the passband. The return loss is better than 20 dB, which means a good impedance match to the I/O. The return loss in the stopband region is close to 0 dB.

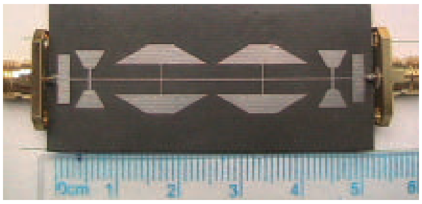
By optimizing the open stubs, delta stubs and tapered dimensions, the harmonics in the stopband are more attenuated and the stopband is observed from 1.97 to 22.3 GHz with better than 20 dB, which is approximately 167.6 percent bandwidth; therefore, the designed filter has an ultra wide stopband. The relative stopband bandwidth (RSB) is defined as:

$$\text{RSB} = \frac{\text{Stopband Bandwidth}}{\text{Stopband Center Frequency}}$$

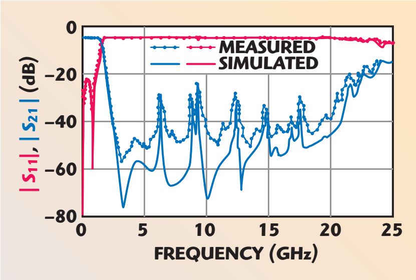
It is also interesting to notice that the T-CMRC lowpass filter has a 167.6 percent stopband, with larger and better performance than the filters cited in the references, as shown in ***Table 1***. In the table, the suppression factor (SF) is based on the stopband suppression. For example, if the stopband suppression is less than −15 dB, then SF is considered as 1.5. Based on the results, it can be claimed that the T-CMRC filter has at least two advantages over the conventional tapered structure: (i) wider stopband and (ii) flat response in the passband. The proposed structure, compared with the conventional tapered compact microstrip resonator cell,[4] has a 25.38 percent reduction in size and 17.72 percent increase in



▲ *Fig. 8 Structure of the proposed filter.*



▲ *Fig. 9 Photograph of the fabricated filter.*



▲ *Fig. 10 Simulated and measured S-parameters of the lowpass filter.*

TABLE I

COMPARED CHARACTERISTICS OF SOME LOWPASS FILTERS

Ref.	Relative Stopband Bandwidth (RSB)	Insertion Loss (IL)	Return Loss (RL)	Supression Factor (SF)
[2]	0.826	0.4	16.4	2
[3]	1.079	0.5	20	2
[4]	1.525	1	19.5	2
[7]	1.36	1.2	10	1
[8]	1.18	1	15	2
[10]	1.323	0.2	33	1.5
[11]	1.574	0.4	10	1.5
This	1.676	0.1	20	2

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Model Number	Frequency (GHz)	Gain (±dB, Max.)	Gain Flatness (±dB, Max.)	Noise Figure (dB, Max.)	VSWR In/Out (Max.)	Output Power (dBm, Min.)	DC Power @15V (mA, Nom.)
AMF-2B-00030300-150-32P	0.03-3	20	2.5	15	2:1/2.5:1	32	650*
AMF-4D-00100100-30-30P	0.1-1	44	1	3	2.2:1	30	850
AMF-3B-00500100-13-33P	0.5-1	43	1.5	1.3	2:1	33	1700
AMF-4D-00500200-25-33P	0.5-2	40	2	2.5	2:1/2.3:1	33	1400
AMF-4B-00800250-50-34P	0.8-2.5	40	3	5	2:1/2.3:1	34	2700
AMF-3B-01000200-35-30P	1-2	30	1	3.5	1.8:1	30	900
AMF-3B-01000200-20-33P	1-2	35	1	2	1.5:1	33	1200
AMF-5D-01000200-15-33P	1-2	50	1.5	1.5	2:1/2.3:1	33	1500
AMF-3B-01000200-50-40P	1-2	35	3	5	2.2:1/3:1	40	4100
AMF-3D-01000400-45-30P	1-4	28	1.5	4.5	2:1/2.3:1	30	800
AMF-4D-01000400-35-30P	1-4	39	1.5	3.5	2:1/2.3:1	30	900
AMF-4D-01000800-85-30P	1-8	28	2	8.5	2.2:1	30	1100
AMF-4D-00400600-50-30P	0.4-6	34	2	5	2:1/2.3:1	30	650
AMF-3B-02000400-20-30P	2-4	35	1	2	2:1	30	950
AMF-4B-02000400-15-33P	2-4	50	1.5	1.5	2:1	33	1600
AMF-5B-02000600-70-33P	2-6	34	2	7	2:1	33	2200
AMF-4B-02000600-70-37P	2-6	35	2	7	2:1/2.8:1	37	4800
AMF-4B-02000800-80-36P	2-8	40	2.5	8	2:1/2.8:1	36	4800
AMF-3B-02001800-30-30P	2-18	35	2	3	2.2:1	30	2000
AMF-3B-02001800-60-32P	2-18	35	2.5	6	2:1/2.3:1	32	4500
AMF-3B-02002000-60-30P	2-20	40	2.5	6	2:1/2.5:1	30	4500
AMF-5B-04000800-60-30P	4-8	33	1.5	6	2:1	30	1400
AMF-4B-04000800-50-33P	4-8	36	1	5	2:1	33	1500
AMF-6B-06001800-80-33P	6-18	35	2.5	8	2.1:1/2.2:1	33	3500
AMF-2B-06001800-65-35P	6-18	45	3	6.5	2.1:1/2.2:1	35	6500
AMF-6B-06001800-120-40P	6-18	43	5	12	2:1/2.3:1	40	12,500

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bandwidth. The skirt performance is improved, so the transition band has 13.3 percent decrements. The stopband is from 1.97 to 22.3 GHz, and has 44.66 percent increase. The size of this filter is 51.98 × 11 mm.

CONCLUSION

In this article, a lowpass filter, based on an enhanced microstrip resonator using a tapered compact microstrip resonator cell, is presented. The lowpass filter has the characteristics of a low insertion loss, an ultra wide stopband and a high return loss. A compact ultra wide stopband lowpass filter is designed by connecting two of the proposed T-CMRC in series. Tapered cells, open stubs and delta stubs, which are coupled to the main line, allow the designer to control the stopband location and reduce the number of harmonics. The designed filter has a 25.38 percent reduction in size, a 17.72 percent increase in bandwidth and the stopband is from 1.97 to 22.3 GHz with a 44.66 percent increase in the stopband compared to the conventional tapered compact microstrip resonator cell. With all these features, the proposed filter is applicable for modern communication systems. ■

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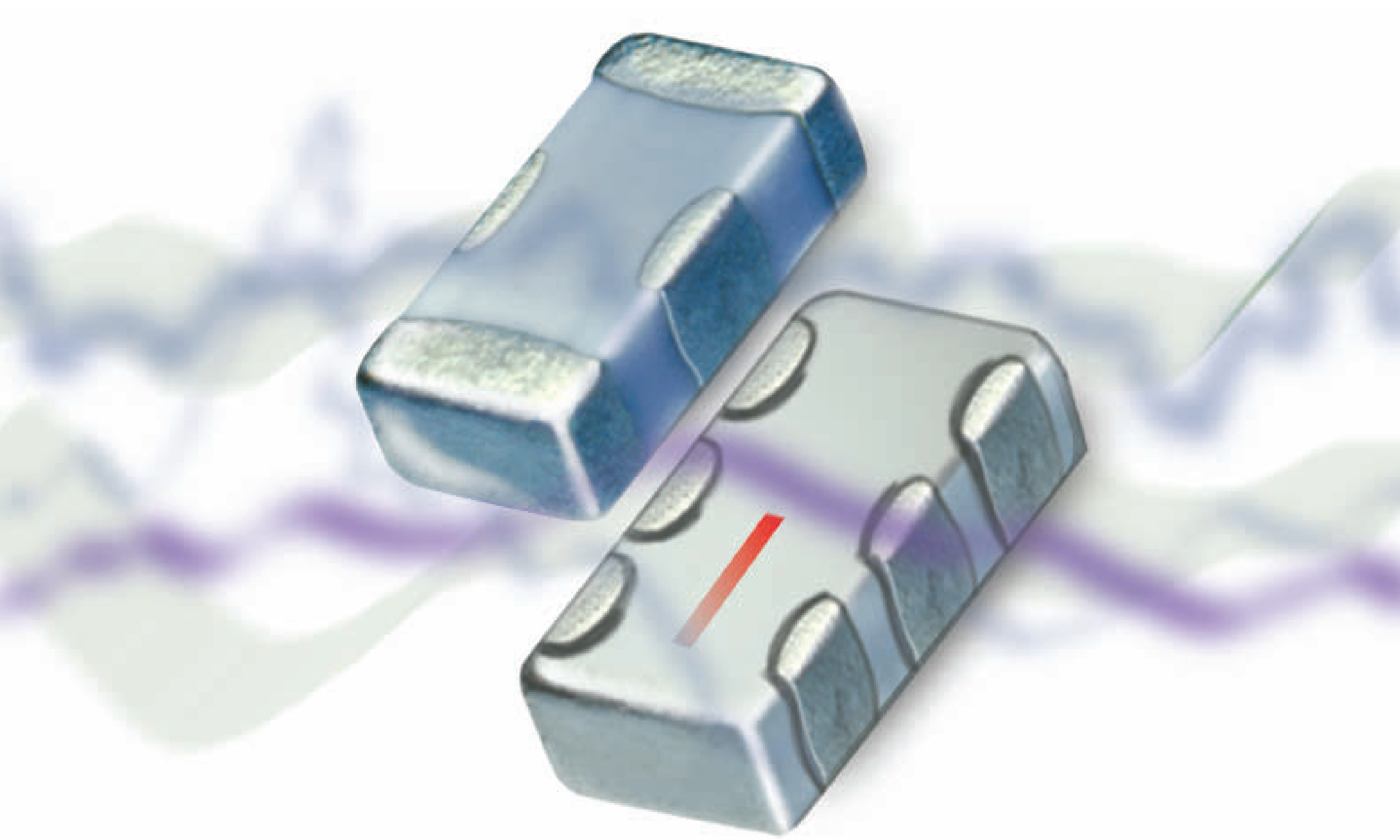

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Optimization of a Waveguide-Backed Slot Antenna Array

A 3D planar EM simulator is used to optimize a waveguide-backed slot antenna array for use in wireless technology applications. The array is formed from a series of slots backed by sections of open waveguides. Because of the field distribution in the slots, the antennas can be made longer than a ½ wavelength, leading to greater efficiency and directivity. The antennas are easy to manufacture in standard PCB technology. The arrays are optimized for bandwidth and return loss using the optimizers in Microwave Office and the electromagnetic (EM) simulator AXIEM. The optimization process was expedited through new design automation features, whereby the feed network made use of the schematic layout to EM extraction design flow and the waveguide dimensions were optimized using a variable controlled EM layout.

INTRODUCTION

The antenna was developed by two of the authors of this paper.[1,2] In their original work, the antenna was manufactured using a machined assembly approach. They also measured simple arrays in various configurations. One of the major advantages of the design is that it is amenable to standard PCB production. This type of antenna should be of interest to the wireless community where issues of the antenna's cost, bandwidth and gain are all important drivers. The current state of the investigation is to find an optimal array design using the antenna.

The second part of this article shows how the design tools were used to come up with good candidates for the array design. Investigations include optimizing the array's directivity, return loss and bandwidth. For optimal performance, the array needs both optimized layouts of the corporate feed and the antenna itself. AXIEM, AWR's 3D planar EM simulator, was used to optimize the performance of the antenna and antenna feed design. Variables were used to control the layout of the antenna, allowing the layout of the antenna to be optimized directly in EM simulation. An alternative approach would be to develop a user defined EM model, in which the data points are automatically obtained from EM simulation. The circuit simulator would then use interpolation when calling the database to get any required set of parameter values.[3]

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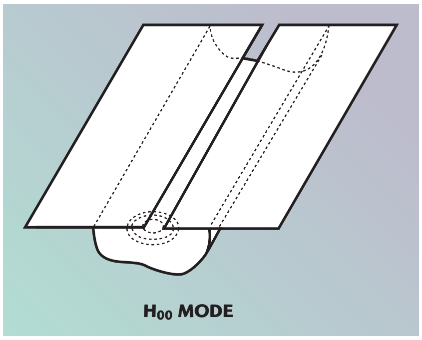


Fig. 1 Ground plate with a slot backed by a cylinder.

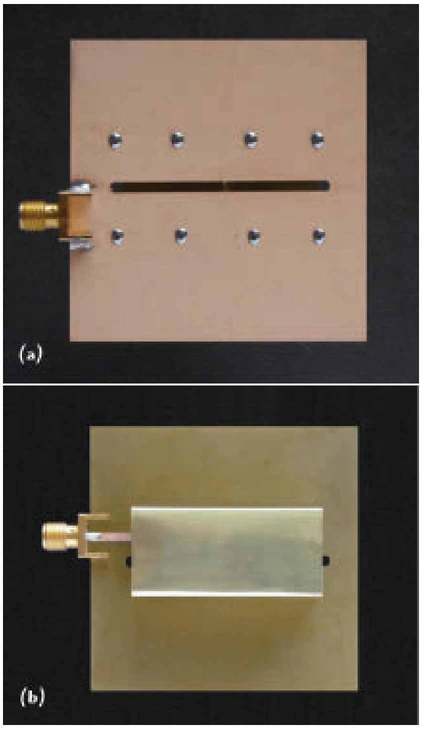


Fig. 2 Front (a) and rear (b) views of the original antenna.

BASIC ANTENNA OPERATION

The basic operating principle of the antenna is shown in ***Figure 1***. Slot antennas are widely used in planar environments. The limitation in their performance is the length of the slot, which is typically required to be less than half a free space wavelength, thereby limiting their radiation efficiency. Cavities are used to back the slot for two reasons: first, it prevents radiation from the bottom of the slot, and second, it increases the gain at the waveguide resonance. Unfortunately, a cavity also decreases the bandwidth of the antenna. The antenna used here uses a waveguide instead of a cavity. In particular, the two ends of the waveguide are left open. There is therefore no cavity resonance to restrict the bandwidth. At the same time, the dominant waveguide mode, the H_{00} mode,[4,5] allows for a longer slot, up to almost a wavelength. This helps the gain and efficiency of the antenna.

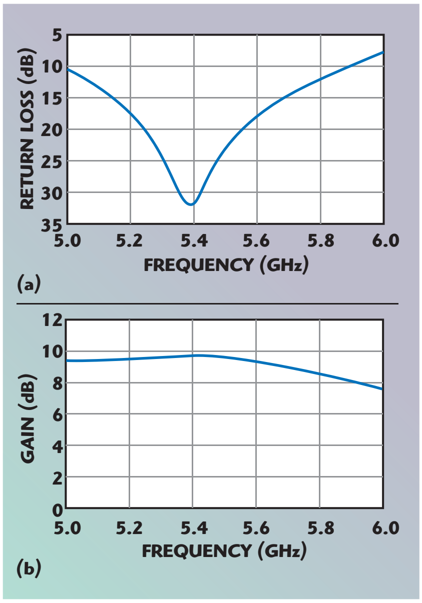


Fig. 3 Return loss (a) and gain (b) for the single element antenna.

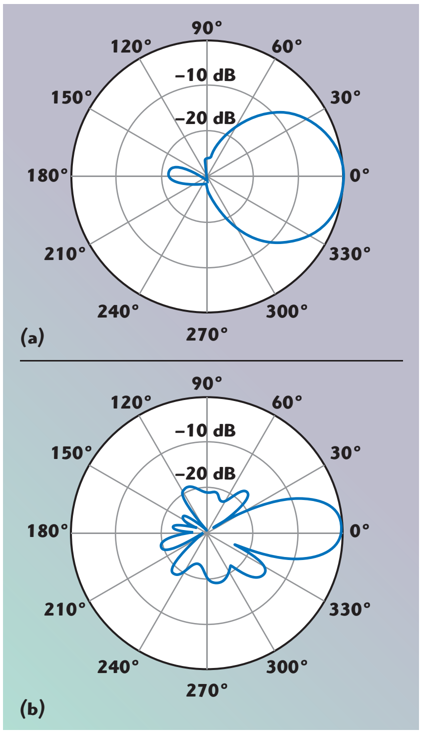


Fig. 4 Field patterns for the four-element array: horizontal plane-perpendicular to the slots (a) and vertical plane-parallel to the slots (b).

The performance of the antenna has been experimentally verified for both single slots, as well as arrays of two and four slots. In the original investigation, the antennas were constructed by mechanically attaching the waveguides, as shown in ***Figure 2***.

The antenna was manufactured using 30 mil RO4350B laminate with a ground plane size of 60 × 60 mm. The slot has dimensions of 2 × 44 mm. The slot length is 0.8 wavelengths long at the frequency of operation, 5.4 GHz. The waveguide has horizontal dimensions of 18 × 40 mm, and a depth of 11 mm. The experimental results were encouraging. For example, ***Figure 3*** shows the return loss and gain of the antenna. Assuming a design goal of 13 dB return loss, the bandwidth of the antenna is about 10 percent, with gain of about 9.8 dB in the center of the band.

Various array configurations were then tried. For example, ***Figure 4*** shows the E and H antenna patterns for a four-element array. The array was designed to operate at 2.4 GHz. The four slots were parallel to each other with a half wavelength distance between them. A corporate feed was etched on the opposite side of the substrate, which for this experiment was 40 mil RO4350B laminate. The antenna efficiency compared to the theoretical maximum, which can be achieved for the given aperture with uniform field distribution, is over 94 percent.

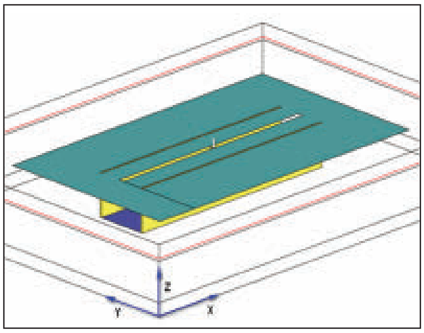
One of the advantages of this type of antenna is that the slots are isolated from each other to a much greater degree than a normal slot antenna array. Measurements show isolation better than -30 dB between elements.

OPTIMIZING THE DESIGN

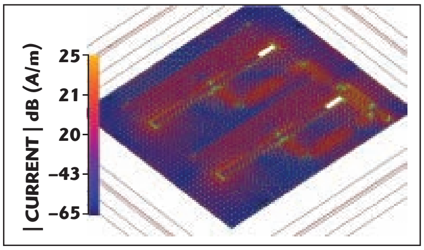
The performance of the antenna array depends on a number of critical parameters:

- The layout of the feed network.
- Slot size and waveguide dimensions.
- Substrate thickness and dielectric constant.

The EM simulation tool was used to perform the parametric studies and performance optimization, in this case: return loss, bandwidth and gain. The 3D planar EM analysis performed by AXIEM is well suited to this type of antenna study. First, it is not enclosed in a box, making it a natural fit for planar antenna problems. Second, the planar nature of the antennas geometry lends itself well to a 3D pla-



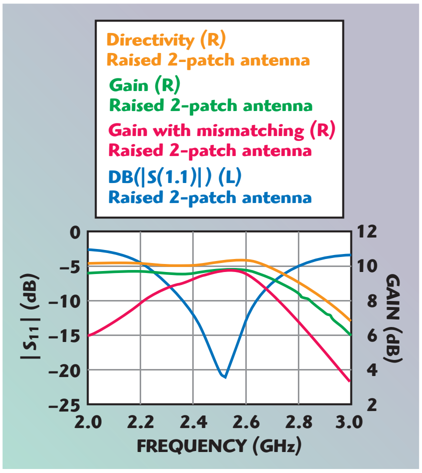
▲ *Fig. 5 A single slot and waveguide drawn in AXIEM.*



▲ *Fig. 6 Currents for a two-slot corporate-fed array.*

nar simulator. The antenna consists of horizontal metal and the vertical walls of the cavity. In PCB technology, the vertical walls will probably be a tightly packed row of vias that can be included in the EM simulations (although this was not tried in this study). The decision was made to use a planar simulator rather than a full 3D EM simulator to avoid the use of radiation boundary conditions at the edge of the meshing domain that can increase the simulation time. In our experience, planar simulators will be faster for this type of geometry, and because we are optimizing, speed of simulation is an important factor.

The first group of simulations looked at the physical geometry of the antennas themselves. A simple preliminary layout is shown in ***Figure 5***. A single slot was studied. Note that the feed of the antenna has been simplified. Port 1 is a simple internal port across the middle of the slot. Later studies looked at a more realistic feed network. Parameters varied and included the slot width, length and waveguide dimensions. There are a variety of ways to control the optimization in the design environment, including Microwave Office (MWO). AXIEM has the capability of using parameters to control the drawing of the EM layout directly. Therefore, the various widths and lengths of the slot



▲ *Fig. 7 Return loss and gain of the dual-slot antenna.*

and waveguide can all be controlled by a few parameters, which in turn are optimized. Either the parameters themselves are run through an optimizer, which is very time consuming as an EM simulation is required at each step of the optimization, or an EM-based model is created in which the parameters are swept over a reasonable number of steps and the optimizer is then run on the model. For this example, the model approach was used.

The goals in the next phases of the study were to array the slots, and to design the corporate feed network. The corporate feed network was created in the MWO schematic editor using models and optimized in the conventional manner. The layout was then automatically exported to AXIEM using the EM extraction technology. In this manner, the layout from the schematic (the corporate feed) and EM drawings (the slots and waveguides) can be combined easily without the need for a manual redraw. The current distribution for a two-slot corporate fed array is shown in ***Figure 6***.

The currents show the optimized corporate feed on an inner layer of the substrate. Note that the current distribution on the lengths of slot is relatively uniform, which is one of the important design goals of the antenna. The slots were 2.7 × 108 mm long on a 30 mil thick substrate with a dielectric constant 3.45. This makes the slots 0.8 wavelengths long at the frequency of operation 2.45 GHz.

Figure 7 is a sample of the results obtained for this example, the return

HIGH POWER PRODUCTS

POWER DIVIDERS

Model #	Frequency (MHz)	Insertion Loss (dB) [Typ./Max.] ◊	Amplitude Unbalance (dB) [Typ./Max.]	Phase Unbalance (Deg.) [Typ./Max.]	Isolation (dB) [Typ./Min.]	VSWR (Typ)	Input Power (Watts) [Max.] ¤	Package
2-WAY								
DSK-729S	800 - 2200	0.5 / 0.8	0.05 / 0.4	1 / 2	25 / 20	1.3:1	10	215
DSK-H3N	800 - 2400	0.5 / 0.8	0.25 / 0.5	1 / 4	23 / 18	1.5:1	30	220
P2D100800	1000 - 8000	0.6 / 1.1	0.05 / 0.2	1 / 2	28 / 22	1.2:1	5	329
DSK100800	1000 - 8000	0.6 / 1.1	0.05 / 0.2	1 / 2	28 / 22	1.2:1	20	330
DHK-H1N	1700 - 2200	0.3 / 0.4	0.1 / 0.3	1 / 3	20 / 18	1.3:1	100	220
P2D180900L	1800 - 9000	0.4 / 0.8	0.05 / 0.2	1 / 2	27 / 23	1.2:1	5	331
DSK180900	1800 - 9000	0.4 / 0.8	0.05 / 0.2	1 / 2	27 / 23	1.2:1	20	330
3-WAY								
S3D1723	1700 - 2300	0.2 / 0.35	0.3 / 0.6	2 / 3	22 / 16	1.3:1	5	316

◊ In excess of theoretical split loss of 3.0 dB
¤ With matched operating conditions

HYBRIDS

Model #	Frequency (MHz)	Insertion Loss (dB) [Typ./Max.] ◊	Amplitude Unbalance (dB) [Typ./Max.]	Phase Unbalance (Deg.) [Typ./Max.]	Isolation (dB) [Typ./Min.]	VSWR (Typ)	Input Power (Watts) [Max.]	Package
90°								
DQS-30-90	30 - 90	0.3 / 0.6	0.8 / 1.2	1 / 3	23 / 18	1.35:1	25	102SLF
DQS-3-11-10	30 - 110	0.5 / 0.8	0.6 / 0.9	1 / 3	30 / 20	1.30:1	10	102SLF
DQS-30-450	30 - 450	1.2 / 1.7	1 / 1.5	4 / 6	23 / 18	1.40:1	5	102SLF
DQS-118-174	118 - 174	0.3 / 0.6	0.4 / 1	1 / 3	23 / 18	1.35:1	25	102SLF
DQK80300	800 - 3000	0.2 / 0.4	0.5 / 0.8	2 / 5	20 / 18	1.30:1	40	113LF
MSQ80300	800 - 3000	0.2 / 0.4	0.5 / 0.8	2 / 5	20 / 18	1.30:1	40	325
DQK100800	1000 - 8000	0.8 / 1.6	1 / 1.6	1 / 4	22 / 20	1.20:1	40	326
MSQ100800	1000 - 8000	0.8 / 1.6	1 / 1.6	1 / 4	22 / 20	1.20:1	40	346
MSQ-8012	800 - 1200	0.2 / 0.3	0.2 / 0.4	2 / 3	22 / 18	1.20:1	50	226
180° (4-PORTS)								
DJS-345	30 - 450	0.75 / 1.2	0.3 / 0.8	2.5 / 4	23 / 18	1.25:1	5	301LF-1

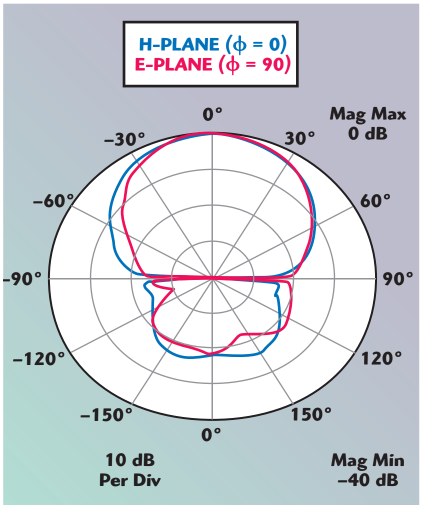
◊ In excess of theoretical coupling loss of 3.0 dB

COUPLERS

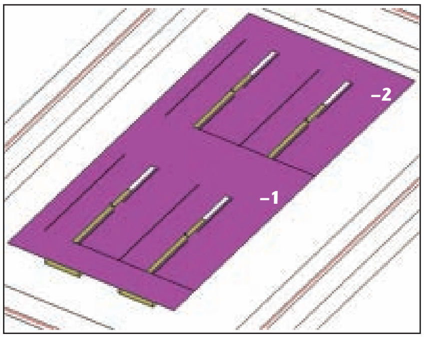
Model #	Frequency (MHz)	Coupling (dB) [Nom]	Coupling Flatness (dB)	Mainline Loss (dB) [Typ./Max.]	Directivity (dB) [Typ./Min.]	Input Power (Watts) [Max.] ¤	Package
KDS-30-30	30 - 512	27.5 ±0.8	±0.75	0.2 / 0.28	23 / 15	50	255 *
KBS-10-225	225 - 400	10.5 ±1.0	±0.5	0.6 / 0.7	25 / 18	50	255 *
KDS-20-225	225 - 400	20 ±1.0	±0.5	0.2 / 0.4	25 / 18	50	255 *
KBK-10-225N	225 - 400	10.5 ±1.0	±0.5	0.6 / 0.7	25 / 18	50	110N *
KDK-20-225N	225 - 400	20 ±1.0	±0.5	0.2 / 0.4	25 / 18	50	110N *
KEK-704H	850 - 960	30 ±0.75	±0.25	0.08 / 0.2	38 / 30	500	207
SCS100800-10	1000 - 8000	10.5 ±1.5	±2.0	1.2 / 1.8	8 / 5	25	361
KBK100800-10	1000 - 8000	10.5 ±1.5	±2.0	1.2 / 1.8	8 / 5	25	322
SCS100800-16	1000 - 7800	16.8 ±1.5	±2.8	0.7 / 1	14 / 5	25	321
KDK100800-16	1000 - 7800	16.8 ±1.5	±2.8	0.7 / 1	14 / 5	25	322
SCS100800-20	1000 - 7800	20.5 ±2.0	±2.0	0.45 / 0.75	12 / 5	25	321
KDK100800-20	1000 - 7800	20.5 ±2.0	±2.0	0.45 / 0.75	14 / 5	25	322

* Add suffix - LF to the part number for RoHS compliant version.
¤ With matched operating conditions

Unless noted, products are RoHS compliant.



▲ *Fig. 8 Radiation patterns for the two-element array.*



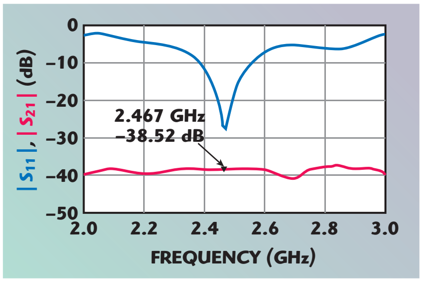
▲ *Fig. 9 Two-coupled dual-slot antenna.*

loss and gain of the antenna. Note that the $|S_{11}| < -12$ dB and the gain and directivity are relatively flat over the range of operation, from 2.4 to 2.6 GHz. ***Figure 8*** shows the radiation patterns for the array.

The final example shows the isolation between the various slots. ***Figure 9*** shows four slots, grouped into two of the dual-slot antennas studied in the previous example. Each of the dual-slot antennas is again fed by a corporate feed. The designers were concerned about coupling between the two groups of elements. A high level of coupling would degrade the performance of the array.

Figure 10 shows the coupling between the two groups of antennas. It is about -38 dB at the frequency of operation. This is significantly lower than the coupling that would occur without the waveguides. Figure 10 also shows the return loss of one of the dual-slot antennas not be degraded by the presence of the other antenna.

The antenna can be used as a principal radiating element in low, medium and high gain directional panel antennas as well as a basic element in base station or smart antenna designs. The antenna is suitable for MIMO applications because of good isolation, below -35 dB, and frequency range of the antenna impedance match is up to 22 percent ($|S_{11}| < -10$ dB). The antenna is easy to manufacture using conventional PCB technology. Active components such as phase shifters, amplifiers, or switches can be easily integrated in the antenna feeding network.



▲ *Fig. 10 Mutual coupling between the dual-slot antennas.*

CONCLUSION

A waveguide-backed slot antenna array was simulated and optimized using the 3D planar EM simulator, AXIEM and MWO design environment. New software capabilities allow the designer to use parameters in the layout to directly optimize shapes or to create EM-based models, which can in turn be optimized. The design environment allows schematic layout to be sent directly to the EM simulator. In this example, the corporate feed was optimized using models in the schematic, whereas the antenna was optimized directly in the EM simulator. Therefore, maximum simulation efficiency was obtained. Models were used where available, and direct EM optimization was used where they were not. ■

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Micro-Material Processing in the Electronic Lab

The UV laser is widely regarded as a universal tool for material processing. So, it is significant that the new LPKF ProtoLaser U3, that is suitable for the laboratory, can now also structure laminated printed circuit board substrates, expanding the already broad line-up of materials to include this important application.

LAMINATED SUBSTRATES

Laser systems have been playing an important role in this area for several years. In a patented process, the ProtoLaser S structures laminated substrates using a laser with a wavelength of 1064 nm. The laser beam first separates the strip conductors, then hatches the rub-out surfaces and subsequently removes the hatched metal strips.

The UV laser system previously available for prototyping is positioned very differently. It processes a broad range of materials, separates flexible and thin rigid printed circuit boards, structures invisible TCO coatings, cuts ceramic and exposes metal resists for production of ultra-fine conductors. However, up until now, laminated materials could not be handled by this system.

That has changed with the introduction of the ProtoLaser U3, which combines the capabilities of both ProtoLaser systems into one universal tool. This system is a good example of the wide range of laser technology when the mechanical components, the control systems and the machine software work well together. The laser source used is a proprietary development in the 355 nm range. It operates with a typical output of 5 to 6 W and works in a frequency range of 10 to 200 kHz. With a focus diameter (spot size) of 15 μm and a scanner resolution of 2 μm on the material, the system is also designed for the processing of ultra-fine structures.

Just like the previous UV system, the ProtoLaser U3 processes the entire range of materials and in addition, handles the structuring of laminated substrates. This system can thus carry out a whole series of tasks in printed circuit board prototyping:

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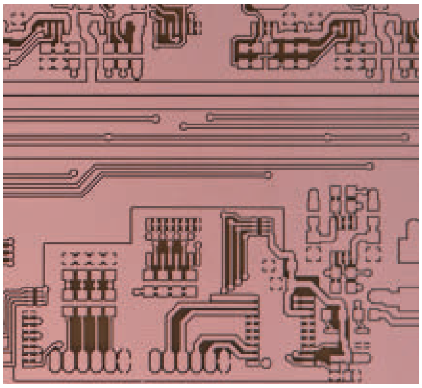
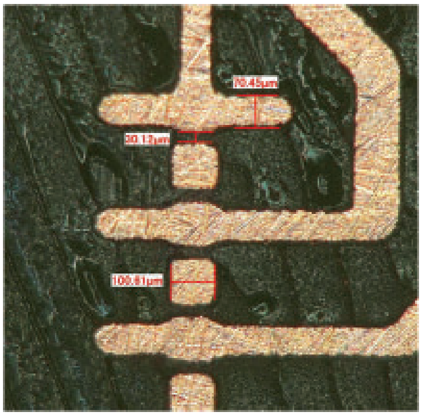
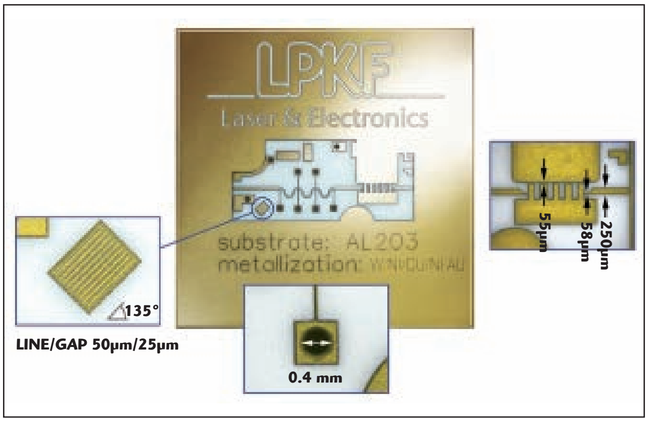


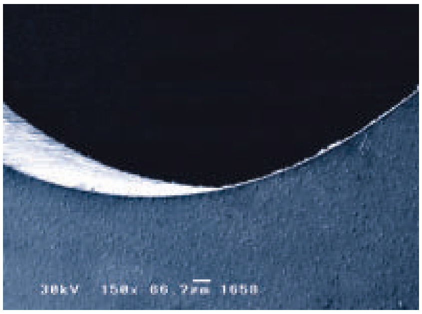
▲ *Fig. 1 Structuring of laminated substrates, e.g., FR4, takes place in an isolation process: the laser beam separates the desired conductor tracks from the surrounding copper.*



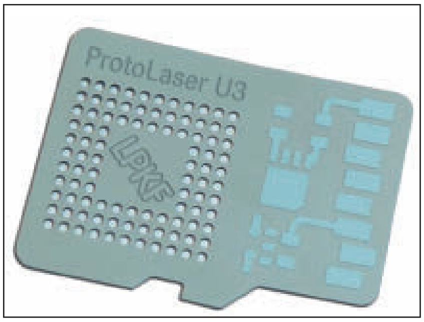
▲ *Fig. 2 With a pitch of only 100 µm, this prototyping process is more precise than many serial processes.*



▲ *Fig. 3 Highly precise structures on a small coated ceramic plate with dimensions of 25 × 25 mm.*



▲ *Fig. 4 Precise cuts: The UV laser beam separates sensitive ceramic materials. Shown here is Al_2O_3.*



▲ *Fig. 5 Suitable for harsh environments: The ProtoLaser U3 structures, engraves and cuts LTCC components in one pass.*

ductor network from substrate plates that are coated all over (see ***Figures 1*** and **2**).

Drilling: by cutting holes with exactly defined diameters, holes or blind holes can be created. The penetration depth of the laser beam can be controlled very precisely by the number of repetitions.

Embedding of components in the printed circuit board: the UV laser cuts the recesses or, in the case of multilayer printed circuit boards, the holes in which components are positioned are flush with the surface.

Decap: rigid-flex printed circuit boards are produced in manufacturing as 'sandwiches' of various substrate materials. The UV laser beam cuts out the rigid elements in areas that are to be flexible in the end product.

Depaneling: the UV laser detaches individual printed circuit boards from the larger base material. In the process, neither mechanical nor thermal damage occurs, and even irregularly shaped contours are no problem for the scanner-controlled laser beam.

Cutting prepreg and cover layers: both materials are flexible and sensitive to distortions. In laser processing, a vacuum table takes over the fixing while the laser beam is responsible for contactless processing without mechanical strain.

On laminated materials such as FR4, distances and lines of 30/70 µm can still be created without damaging the sensitive substrate. For this type of structuring, LPKF includes a special hood for the laser processing head.

PROCESSING CERAMIC MATERIALS

The suitability of the UV laser system for processing ceramics is an important consideration. A core capacity of laser processing is structuring high-quality RF circuitry, e.g., gold on ceramic. The material compounds are sensitive to mechanical actions and geometric deviations, are expensive and cannot be processed adequately with conventional tools. The solution is a laser system that vaporizes tiny amounts of gold coating pulse by pulse and leaves the metalized network structure of the circuitry unaffected, as illustrated in ***Figure 3***.

The UV laser is also impressive in separating ceramic with a clean cut edge, as shown in ***Figure 4***. The versatility of the system is demonstrated again with the example shown in ***Figure 5*** – in a single step, the UV laser structures the LTCC pattern, cuts circles inside, engraves the marking and separates the entire component with an irregular contour from the truss.

The compact system has a footprint of only 875 by 750 mm, meaning it can be transported and sited in laboratories easily; wheels make it readily moved to wherever it is needed. It requires only one power connector, a dust extractor and a compressed air connection, with the compressed air playing a decisive role in the removal of metal strips.

Quick prototyping reduces the time it takes to launch a product to the market. Being able to produce series-like prototypes and small batches independently ensures that confidential data does not leave the development lab. This is often an important criterion for companies. The LPKF ProtoLaser U3 addresses these issues and when it comes to quality, the UV laser in combination with capable CAM software offers significant advantages.

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Drive Test Software Offers Complete LTE MIMO Measurements

Network operators want to take full advantage of new and existing resources when they upgrade to LTE, and MIMO technology can increase the capacity of LTE networks. Rohde & Schwarz has added MIMO-specific measurements to its R&S ROMES4.65 drive test software, enabling network operators and infrastructure manufacturers to collect important MIMO data during a drive test. Such data can be essential in determining where an investment in MIMO would pay off in their coverage area and where MIMO can be implemented smoothly and efficiently.

▲ *Fig. 1 The R&S TSMW network scanner.*

When used with the R&S TSMW network scanner (shown in ***Figure 1***) with its two integrated receivers, the R&S ROMES software can measure the MIMO channel matrix for 2×2 systems. The output is basically the channel matrix with complex values, namely amplitude and phase. This measurement needs to be done by each terminal using MIMO. Out of the channel matrix a Singular-Value-Decomposition is calculated, which are known as Singular Values, and these are used to obtain the Condition Number (CN).

The condition number qualifies the channel to determine whether it is 'ill-conditioned' (MIMO not applicable) or 'well-conditioned' (MIMO usable). Examples of 'well-conditioned' and 'ill-conditioned' field data are

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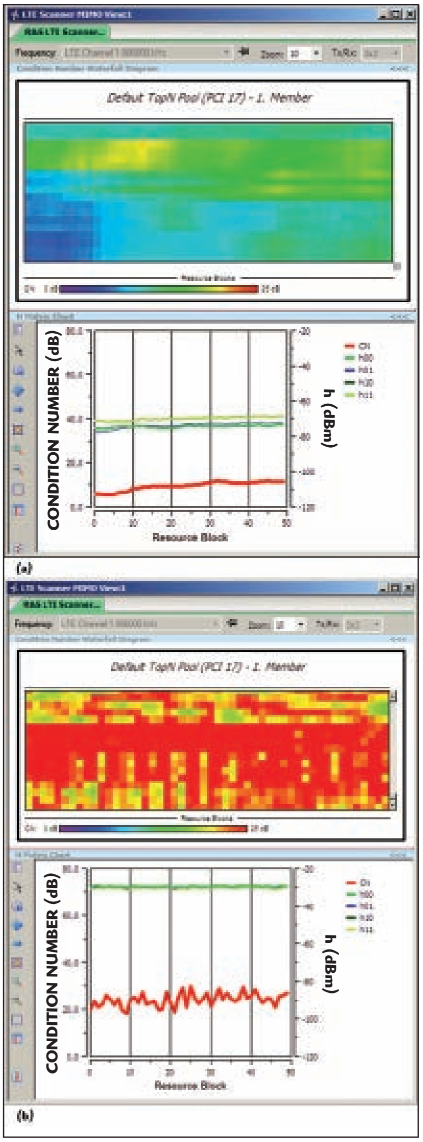
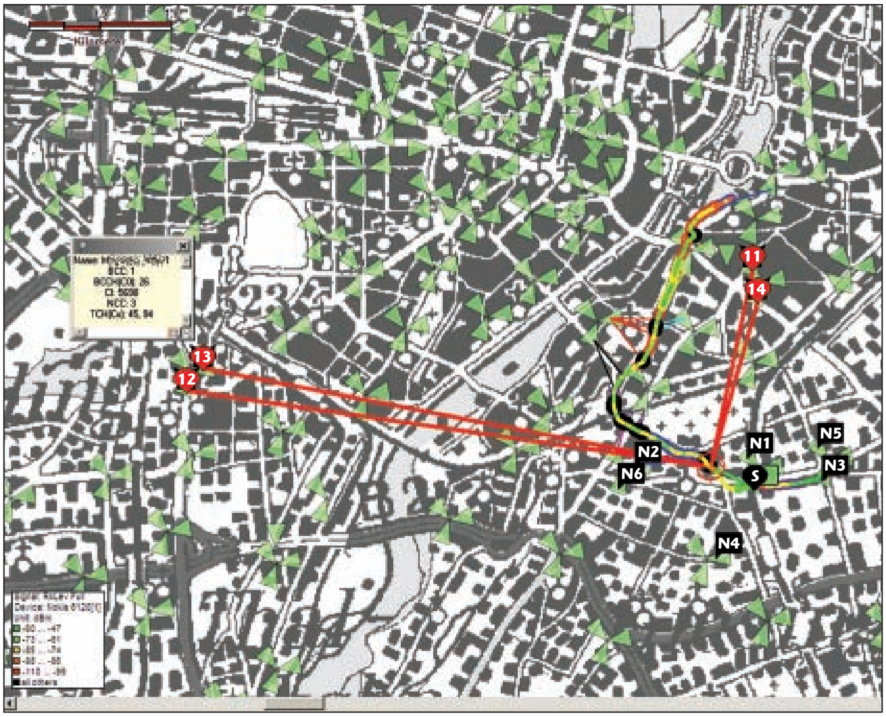
Munich, Germany



▲ *Fig. 2 Examples of 'well-conditioned' (a) and 'ill-conditioned' (b) field data.*



▲ *Fig. 3 Map showing the position of the interference (dotted line), the cell currently providing coverage (S) and the four interfering cells (11, 12, 13 and 14). N1 and N2 are the current neighboring cells and the color of the route indicates the received signal strength of the GSM mobile phone.*

shown in ***Figure 2***. In a case with CN < 10 dB, this 'well-conditioned' channel matrix would be useful when recovering the data streams. If the CN is > 15 dB it can be expected that data recovery would be very sensitive to noise.

MIMO PERFORMANCE

As well as the condition number, the full MIMO performance also depends on the signal to interference plus-noise ratio (SINR) of the signal. Determining the CN and the SINR per Resource Block (per sub-band) brings a better understanding of the whole LTE-MIMO channel. Interference, fading, multipath, antenna correlation and noise can be the reasons to degrade MIMO performance.

To evaluate the MIMO performance, R&S ROMES4.65 software calculates the data that indicates the capacity gain that can be achieved with MIMO. A GPS receiver assigns this data to the exact position and clearly displays it on a map, as shown in ***Figure 3***. The software performs MIMO measurements on all bandwidths up to 20 MHz and interference can be detected over the entire bandwidth used by the LTE signal.

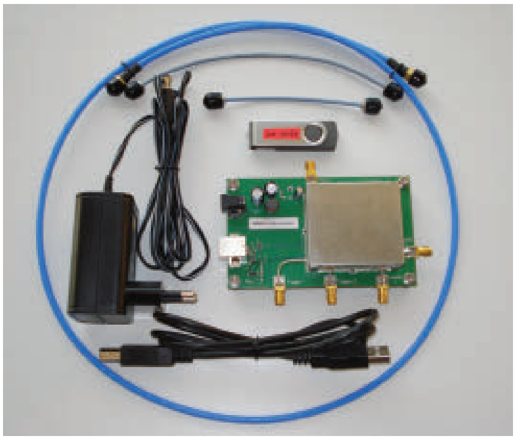
INTERFERENCE ANALYSIS

LTE is a single frequency network (SFN) that is identified by a reuse factor of 1, which means that neighboring cells use the same frequency ranges. Interference is therefore especially frequent and must be analyzed to avoid capacity losses. The R&S TSMW network scanner was developed specially for this task and features a C/I value of -20 dB. Therefore, even interference signals that are 20 dB weaker than the strongest signal can be measured, which makes it possible to identify the interferers and to reduce them.

The network scanner can also distinguish between signals that have the same physical cell ID but come from different eNodeBs. There is no difference whether the measurement is performed in the FDD mode or in the TDD mode. Furthermore, the R&S TSMW combined with the R&S ROMES drive test software not only covers LTE but also UMTS, GSM and CDMA standards, meaning that network operators can test all their mobile radio networks with a single instrument. The R&S TSMW supports all frequencies from 30 MHz to 6 GHz, offering a test solution that covers existing and future frequency bands, making it a cost-effective investment for today and tomorrow.

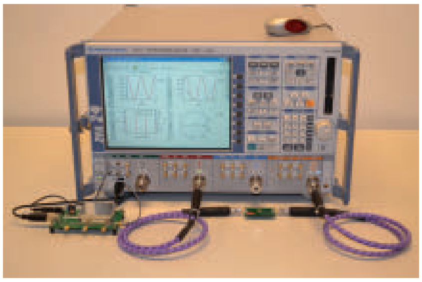
Rohde & Schwarz has added MIMO-specific measurements to its R&S ROMES4.65 drive test software. Using this feature, the R&S TSMW network scanner can quickly identify interferers that reduce MIMO performance in LTE networks. This measurement data can be exported for later field-to-lab applications. Using fading emulators, a complete mobile radio network can be reproduced in the lab, simulating real field conditions.

Rohde & Schwarz,
Munich, Germany
+49 89 4129 12345,
www.rohde-schwarz.com.

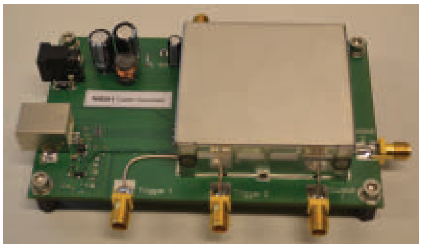


Nonlinear Starter Kit Supports Selection of 4-port VNAs

The NM310S is a cost-efficient nonlinear starter kit, allowing engineers to make their first steps in the nonlinear world with their vector network analyzer (VNA). VNAs are extensively used to characterize the small-signal behavior of diodes, transistors, amplifiers, etc., by measuring S-parameters. Now with the nonlinear starter kit, the VNA is easily extended, in an affordable way, to characterize the large-signal behavior of these devices.



▲ *Fig. 1 NM310S starter kit connected to a Rohde & Schwarz ZVA24.*



▲ *Fig. 2 The NM201 20 MHz to 3 GHz double-output comb generator.*

Extending a VNA with this kit offers such options as the ability to assess how a diode is clipping the RF signals and offers the ability to see the RF drain voltage and currents of a transistor to improve the amplifier design. It can also allay any doubt about large-signal transistor models. The starter kit is also suitable for characterizing and improving multipliers, dividers and high-speed digital components.

The NM310S is a software/hardware combination, enabling the VNA to characterize in time and frequency domain the harmonic behavior of active components from 20 MHz to 3 GHz. This limited frequency range is suitable for measuring fundamental and two additional harmonics for telecommunications applications with a carrier around 1 GHz.

The starter kit supports a selection of 4-port Agilent and Rohde & Schwarz VNAs. ***Figure 1*** shows the starter kit connected to a Rohde & Schwarz ZVA24. On top of the standard measurement capabilities of the vector network analyzer, the NM310S kit provides calibrated measurement capability of the time waveforms of the incident and reflected waves or voltages and currents at the ports of a component under test.

The kit consists of three main components. The first is a NM201 20 MHz to 3 GHz double-output comb generator (shown in ***Figure 2***), where one output is used as synchronizer,

NMDG NV
Bornem, Belgium

European Microwave Week 2012
Amsterdam RAI, The Netherlands
October 28th - November 2nd 2012

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- European Microwave Conference (EuMC)
- European Radar Conference (EuRAD)

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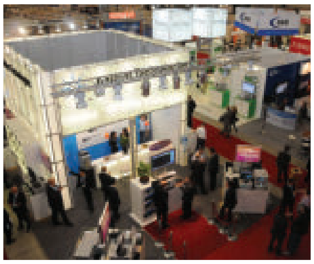

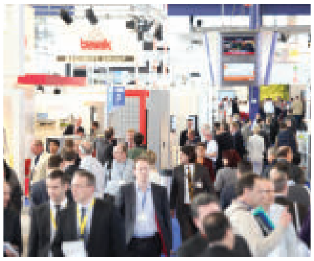

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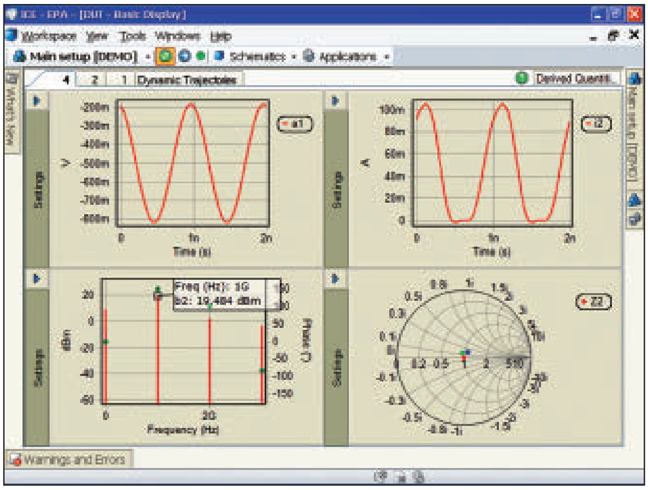

▲ *Fig. 3 Screenshot of a transistor measurement in ICE – top-left: input incident wave, a1, vs. time, top-right: clipped output current, i2, vs. time, bottom-left: output transmitted wave, b2, vs. frequency, bottom-right: load reflection gamma.*

enabling the reconstruction of time waveforms while the second output is used as Harmonic Phase Reference (HPR) supporting the required phase calibration. The second component is a SMA connection kit, while the third is a USB stick containing NMDG's Integrated Component Characterization Environment (ICE) software installer, an ICE license, a quick start guide and several tutorials.

ICE is easy-to-use software for nonlinear HF component characterization, supporting system configuration, absolute calibration and measurement. It aims to characterize the complete nonlinear behavior of components under realistic conditions with almost real-time feedback. ***Figure 3*** is a screenshot of a transistor measurement in ICE. It allows different instruments and equipment to be combined, enabling realistic stimuli-response measurements. With an easy-to-use graphical user interface, the user configures and calibrates the system to perform accurate nonlinear measurements.

The NM310S can be extended in frequency range to suit more application needs. It is possible to perform, amongst others, nonlinear measurements under non-50 Ω environment by adding passive and/or active tuners and under pulsed conditions by adding pulsed DC and/or RF generators.

To make these accurate nonlinear measurements available for design engineers to improve their design work, NM310S can also be extended with S-functions. S-functions are the S-parameters for nonlinear components and can be coupled in ADS™ from Agilent Technologies and MWO/VSS™ from AWR.

NMDG NV,
Bornem, Belgium
32 3890 4612,
info@nmdg.be,
www.nmdg.be.

Ultra-Rel® Wideband Hermetic Ceramic Mixer

The MAC-80MH+ from Mini-Circuits is an LTCC double balanced mixer operating from 2800 to 8000 MHz, in a hermetic ceramic surface-mount package. LO power is +13 dBm with a low conversion loss of 5.8 dB typical, high L-R isolation of 29 dB typical and IP3 of 16 dB typical. The IF frequency range is DC to 1250 MHz. Maximum ratings for operating and storage temperatures are –55° to 100°C, maximum RF power is 200 mW and maximum IF current is 40 mA.

The mixer is hermetically sealed, aqueous washable, low profile (0.060") and RoHS compliant in accordance with EU Directive (2011/65/EU). Typical applications include satellite up and down converters, line of sight links, and defense communications.

The MAC ceramic hermetic mixer lineup now covers a frequency range from 0.3 to 12 GHz, and LO levels from 4 to 17 dBm. This Mini-Circuits product family delivers broadband performance suitable for instrumentation, with an ultra-reliable, ultra-low-profile case that meets or exceeds aerospace and military ground requirements for hermeticity, thermal shock, vibration, acceleration and more. They are well suited for military use and anywhere long-term reliability is needed such as high moisture areas, busy production lines, high-speed distribution centers, heavy industry, outdoor settings and unmanned facilities.

VENDORVIEW

Mini-Circuits,
Brooklyn, NY (718) 934-4500,
www.minicircuits.com.

Equalized Cable Runs

The Cobham Cable Products group has integrated an adjustable equalizer with a variable attenuator module into an ETNC jack/ ETNC jack bulkhead adapter for incorporation into cable runs. The result is that cable runs of different cable sizes and length have matched, constant insertion loss over broad frequency ranges. The design has been qualified for military airborne applications aboard jet aircraft.

Now, with the equalizer/attenuator adapter connected in series, cable runs can have the same amplitude response for short runs to the aircraft nose, moderate length runs to the aircraft wings or long runs to the aircraft tail.

The equalizer/attenuator module can be integrated into adapters of other configurations or interfaces, (Type N or SMA, for example). It can also be integrated directly into connectors on the assembly. No external power source is required. Cobham optimizes the designs to fit the application.

SPECIFICATIONS FOR EQUALIZER ADAPTER ONLY

- Frequency Range: from < 0.5 to > 18 GHz
- VSWR: 2.0:1 maximum
- Insertion Loss: Can correct differences greater than 25 dB over the specified frequency band
- Power: Receive levels
- Temperature Range: -40° to +70°C
- Altitude: up 70,000 ft
- Vibration: > 20 G RMS

SPECIFICATIONS FOR TYPICAL LONG EQUALIZED CABLE RUN (> 100 FEET IN 4 OR 5 SEGMENTS)

- Frequency Range: from < 0.5 to > 18 GHz
- VSWR: 2:1
- Insertion Loss: Equalized to IL at highest frequency
- IL Flatness: ± 4 dB maximum (less for shorter runs)

Cobham Antenna Systems, Exeter, NH (603) 775-5200, www.cobham.com.

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Bargain Corner

VENDORVIEW

AR RF/Microwave Instrumentation's bargain corner features discounted RF test instruments, including amplifiers, antennas, field probes and much more. Many models still include warranties.

AR RF/Microwave Instrumentation,
160 School House Road,
Souderton, PA 18964

www.ar-worldwide.com

Amplifiers and Subassemblies

CTT Inc. has completed a new and expanded website, which includes more than 175 all-new amplifier products and provides ease of use for visitors in search of high-power and low-noise amplifiers and subassemblies, within the frequency spectrum of 10 MHz to 100 GHz. The updated website includes product listings for high and medium power amplifiers, including broadband, narrowband, rack-mount and a new line of GaN-based power amplifiers. Mechanical outline drawings are also available in PDF format for download.

CTT Inc.,
241 East Java Drive,
Sunnyvale, CA 94089

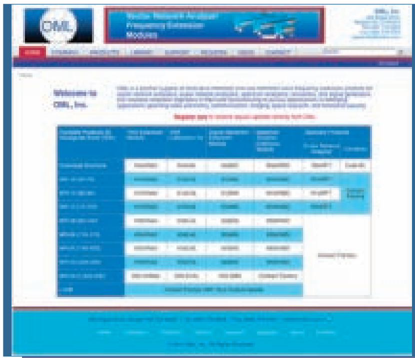
www.cttinc.com

New Website with Social Media

Kaelus is pleased to announce the launch of www.kaelus.com. The newly designed website presents Kaelus's full product portfolio in one easy to navigate location. A few of the new website features include a high-level and targeted product search, the ability to easily identify Kaelus locations and partners, online registration for training and links to all of the company's social media pages.

Kaelus,
12503 E. Euclid Drive, Suite 7,
Centennial, CO 80111

www.kaelus.com



Measurement Products

OML Inc. has launched a new website design at www.omlinc.com. This new website adds modern navigation features so visitors can usually access information in less than three clicks. Simply click on a cell in the new home page table to immediately download brochures and datasheets organized by product categories and waveguide bands. Product categories include: VNA modules; VNA calibration kits; source modules; harmonic mixers; and specialty products. Waveguide bands span 50 GHz to 0.5 THz.

OML Inc.,
300 Digital Drive,
Morgan Hill, CA 95037

www.omlinc.com

"What's New" Webpage

VENDORVIEW

Interactive graphics on the "What's New" page link visitors to featured new product details, microsites and supplier-sponsored promotions. Part detail pages for new products include parametric data for key attributes, pricing and availability, and links to datasheets and other documentation. The "What's New" page includes links to "New Products News," the company's e-newsletter, and the New Product Selector Guide, an interactive PDF updated monthly with links to the newest parts.

Richardson RFPD Inc.,
40W267 Keslinger Road, LaFox, IL 60147

www.richardsonrfpd.com

VCO and PLL Modules

Z-Communications announces a new company website with enhanced functionality and updated navigation. The new site features Z-COMM's entire line of VCO and PLL modules accessible through an easy-to-use product selector. Users can quickly search for parts by center frequency or model number. Datasheets, mechanical drawings and application notes are provided for download. The company's short form product selection guide is also available for download in PDF format.

Z-Communications Inc.,
14118 Stowe Drive, Suite B,
Poway, CA 92064

www.zcomm.com

Test and Measurement

Handheld Oscilloscopes

VENDORVIEW

Agilent Technologies has added two new oscilloscopes to its portfolio of handheld instruments: the 100 MHz U1610A and 200 MHz U1620A, the first handheld units to include a color VGA display. With up to three viewing modes (indoor, outdoor and night vision), these instruments enable engineers to view signal waveforms by zooming in to capture glitches under all lighting conditions. Key measurement capabilities include a sampling rate of 1 or 2 GSa/sec and two safety-isolated input channels. Analysis capabilities include deep memory, 1,000-times zooming, and dual zoom windows for overview and detailed displays.

Agilent Technologies Inc.,
Santa Clara, CA (800) 829-4444,
www.agilent.com.

High Power Combiner

Delta's Model S6117 high power combiner operates with less than 0.8 dB of insertion loss and VSWR less than 1.35:1 over the entire 2 to 8 GHz frequency range. Amplitude tracking is less than ±0.2 dB. Phase tracking is less than ±4 degrees. The unit can handle 200 W.

Delta Microwave,
Oxnard, CA (805) 751-1100,
www.deltamicrowave.com.

5 to 500 MHz Power Divider/Combiners

VENDORVIEW

MECA's two-, three- and four-way power divider/combiners are optimized for excellent performance across all bands from 5 to 500 MHz. Their rugged construction makes them ideal for all low-frequency systems. Product is always available from stock to two weeks ARO in N and SMA connector configurations. Made in the U.S. with a 36-month warranty.

MECA Electronics Inc.,
Denville, NJ (973) 625-0661,
www.e-meca.com.

Directional Couplers

RLC Electronics' high-power directional couplers offer accurate coupling, low insertion loss and high directivity in a compact package. The standard units are optimized for two octave bandwidths and are available with a choice of

coupling values. These units are ideal for sampling forward and reflected power with a negligible effect on the transmission line and low intermodulation products. Impedance: 50 ohms; coupling (nominal): 30, 40 or 50 dB; power: 500 W avg., 10 kW peak, 250 W; and accuracy (including frequency variation): ±1.0 dB.

RLC Electronics,
Mt. Kisco, NY (914) 241-1334,
www.rlcelectronics.com.

Temperature Controllers

TotalTemp has developed the SD14, a new standard model thermal platform. The surface area is 3.75" × 3.75" (14 sq in/90 sq cm). The plate itself rests in a well insulated rugged stainless steel chassis measuring only 3-3/8" H × 14.5" W × 17-3/4" D. The SD14 can be configured with either one of the TotalTemp temperature controllers, the Synergy Nano or the Watlow EZ Zone. All the standard options are available as well including the durable polycarbonate probing cover for nitrogen gas purging to eliminate condensation, failsafe systems for user settable high/low temperature limits, adapter plates and more.

TotalTemp Technologies Inc.,
San Diego, CA (888) 712-2228,
www.totaltemptech.com.

Amplifiers

Solid-State Amplifiers

VENDORVIEW

AR RF/Microwave Instrumentation has introduced a family of new solid-state amplifiers that are more compact, more efficient and more powerful than previous models. The new "S" Series covers 0.8 to 4.2 GHz and powers up to 1200 W. These models employ a new design that delivers more than twice the power of older models. With these improvements, AR has maintained the superior rugged design for mismatch tolerance and excellent linearity.

AR RF/Microwave Instrumentation,
Souderton, PA (215) 723-8181,
www.ar-worldwide.com.

Virtual Vector Reflectometer

CMT introduces a new class of vector network analyzer, the virtual vector reflectometer Planar R54, operating in frequencies from 85 MHz to 4.2 GHz. Portable and lightweight, R54 is powered and operated via a single USB interface by external PC. Comparable to industry leaders, but at a fraction of the cost, R54 easily partners with a virtual power meter, and is ideal for use on DUTs in the field accurately and without use of testing cables.

Copper Mountain Technologies,
Indianapolis, IN (317) 222-5400,
www.coppermountaintech.com.

Dual Output Amplifier

Microsemi introduces the AML618P5012, a high efficiency dual (combined) input, dual output power amplifier operating over 6 to 18 GHz bandwidth. The amplifier delivers +31 dBm power at each output and is designed to operate up to a 95°C base plate temperature. AML618P5012 is available with an input power protection option up to 2 W CW. This design is available in a high-density package with 3.5" L × 1" W × 0.3" H. RF connectors are SMP. The DC supply is +10 V at 2.2 amps.

Microsemi,
Santa Clara, CA (408) 727-6666,
www.amlj.com.

25 W Amplifiers

Two new 25 W amplifiers covering the 20 to 500 MHz and 20 to 1000 MHz ranges have been added to Microwave Amplifiers' wideband GaN family of products covering 20 MHz to 6 GHz, with various output levels to 100 W. Incorporating reverse power, reverse polarity and over temperature protection with 40 percent efficiency, these amplifiers offer a reliable solution in OEM applications. Both models are also available in a test and measurement bench top form, suitable for a rapid proof of concept or for general laboratory use.

Microwave Amplifiers Ltd.,
Nailsea, Bristol, UK +44 01275 853196,
www.microwaveamps.co.uk.

Surface-Mount Amplifier

VENDORVIEW

Mini-Circuits PSA4-5043+ is a E-PHEMT based ultra-low noise MMIC amplifier operating from 50 MHz to 4 GHz with a unique combination of low noise and high IP3 making this amplifier ideal for sensitive high dynamic range receiver applications. This design operates on +3 to +5 V supply at only 33 mA at 3 V and 56 mA at +5 V, is internally matched to 50 ohms and is supplied in a super small SC-70 (SOT-343) MSL 1 package.

Mini-Circuits,
Brooklyn, NY
(718) 934-4500,
www.minicircuits.com.

New Products

High Power Discrete Amplifier

RFMD's new RF3928B is a 65 V, 380 W high power discrete amplifier designed for S-Band pulsed radar, air traffic control and surveillance, and general-purpose broadband amplifier applications. The RF3928B's features include: wideband operation from 2.8 to 3.4 GHz; advanced GaN HEMT and heat-sink technologies; optimized evaluation board layout for 50 Ω operation; integrated matching components for high terminal impedances; 65 V operation typical performance: pulsed output power 380 W; small-signal gain 13 dB; drain efficiency 50 percent; and -40° to 85°C operating temperature.

RFMD,
Greensboro, NC
(336) 664-1233,
www.rfmd.com.

Components

Multilayer Organic RF Inductor

AVX has developed a multilayer organic RF inductor in a 0402 case size that offers tight tolerance in a small footprint. Providing high-Q and high self-resonance, the RoHS-compliant MLO™ 0402 Series inductor features an inductance range of 1 to 32 nH. The low profile MLO 0402 Series inductor also offers high self-resonant frequency, and can support frequencies well above 1 GHz. These advanced devices are expansion matched to printed circuit boards, allowing for improved reliability.

AVX Corp.,
Fountain Inn, SC
(864) 967-9304,
www.avx.com.

SMT Termination

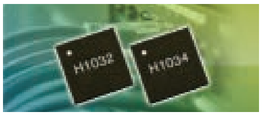
VENDORVIEW

EMC Technology has added another SMT termination to its broad line of surface-mount products. The SMT252503ALN2F offers outstanding performance in a tight tolerance two percent unit. Using EMC's patented asymmetrical wrap geometry, the thermal dissipation of the surface-mount termination is improved by increasing the solderable grounding area. This eliminates the need for bolt down heat sinks and tabs, thereby reducing assembly costs. All products are available in RoHS versions and are supplied on tape and reel for high volume pick and place applications.

EMC Technology,
Stuart, FL
(772) 600-1360,
www.emc-rflabs.com.

SMT Clock Generators

VENDORVIEW



Hittite Microwave has launched two new SMT packaged clock generators, the HMC1032LP6GE and the HMC1034LP6GE. The HMC1032LP6GE and the HMC1034LP6GE offer programmable frequency synthesis from 125 MHz to 3 GHz in both integer- and fractional-N relationships to their reference clocks. The HMC1032LP6GE is ideal for clocking DSP, FPGA and high-performance processors, and operates from 125 to 350 MHz, while the HMC1034LP6GE is designed to meet the stringent requirements of high-speed data converters and physical layer devices (PHY), and operates from 125 MHz to 3 GHz.

Hittite Microwave Corp.,
Chelmsford, MA (978) 250-3343,
www.hittite.com.

Ultra-Wideband Doubler

VENDORVIEW

MITEQ's Model SYS2H1324N01X is an ultra-wideband doubler that features an input frequency range of 6950 to 12,450 MHz and an output frequency range of 13,900 to 24,900 MHz. Electrical specifications include: Gain/loss of 0 dB; input power min. of 13 dBm; input power max. of 18 dBm; and an output power of 13 dBm. The operating maximum temperature range is -20° to 65°C.

MITEQ Inc.,
Hauppauge, NY (631) 439-9469,
www.miteq.com.

Highpass Filter

VENDORVIEW

PMI Model HP-26D5G-40G-CD-292FF is a suspended substrate, highpass filter that has a passband of 26.5 to 40 GHz. This model offers less than 2 dB insertion loss while offering over 54 dB of rejection at 20 GHz and below. This model is supplied in an ultra-small housing that measures only 0.65" × 0.65" × 0.50" in size and is supplied with 2.92 mm female connectors.

Planar Monolithic Industries Inc.,
Frederick, MD (301) 662-5019,
www.pmi-rf.com.

30 GHz Drop-In Isolator

VENDORVIEW

Renaissance Electronics has designed a new drop-in isolator for SatCom applications covering the 30 to 33 GHz frequency range. The unit has less than 1 dB insertion loss and more than 16 dB isolation and return loss over the temperature range of -20° to +60°C It is capable of handling 40 W of forward and 10 W of reflected power.

Renaissance Electronics Corp.,
Harvard, MA
(978) 772-7774,
www.hxi.com.

Analog Front End

Texas Instruments Inc. (TI) introduced an analog front end (AFE) for femtocell base stations and portable software-defined radio (SDR) applications. The low-power, 12-bit AFE7225 integrates a dual 125-MSPS analog-to-digital converter (ADC) and dual 250-MSPS digital-to-analog converter (DAC). It operates 25 percent faster than the competition, while increasing the signal-to-noise ratio (SNR) by 2 dB and providing up to five times the DAC output current. In addition to the AFE7225, the 12-bit AFE7222 is available for lower bandwidth, power-sensitive applications. It integrates a dual 65-MSPS ADC and dual 130-MSPS DAC and uses only 398 mW in full-duplex or 212 mW in half-duplex receive mode at full speed.

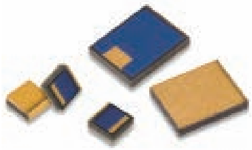
Texas Instruments Inc.,
Dallas, TX,
www.ti.com.

Broadband Power Divider

TRM Microwave's Model DL 162030 is a broadband, 16-way power divider that is well suited for radar and SatCom applications from 20 to 3000 MHz. The maximum amplitude balance is ±0.8 dB while the phase imbalance between output ports is ±10 deg. Isolation between output ports is at least 18 dB. The maximum input and output VSWR is 1.60:1. Model DL162030 is rated for CW input power levels to 20 W, and delivers output signals with maximum insertion loss of 4.5 dB. It is supplied in a rugged aluminum housing measuring 9.4" × 3.0" × 0.40" with SMA connectors. The power divider is designed for operating temperatures from -15° to +55°C.

TRM Microwave,
Bedford, NH
(603) 627-6000,
www.trmmicrowave.com.

Diamond Substrate Surface-Mount Terminations



The excellent heat dissipative properties of CVD diamond substrates allow high power terminations and resistors in very small packages. RFMW's CT0402D is a 10 W termination packaged on a standard 0402 size diamond substrate. Operating frequencies are from DC to 8 GHz. CVD diamond thermal conductivities are about three to four times that of copper at 1000 to 1800 W/m-K and far beyond Beryllia and Aluminum Nitride, making them ideal for high reliability and space applications or where printed circuit space is at a premium. RFMW supports the EMC Technology diamond substrate products as well as BeO and AlN devices.

RFMW Ltd.,
San Jose, CA (408) 414-1450,
www.rfmw.com.

Low-Noise Block Downconverter

RADITEK announced a new low-noise block downcoverter, a phase-locked LO, Ka-Band (20.2 to 21.2 GHz) with a noise figure of 1.7 dB and 60 dB gain. It operates from 18 to 24 V at 400 mA maximum. It has a WR42 interface, type

N IF out, 10 MHz reference in, on DC bias line/IF port. It has 45 dB image rejection and 15 dBm P1dB IF frequency 1 to 2 GHz. It operates to 10,000 feet ASL. These units are proven in the field and are fully RoHS compliant.
RADITEK Inc., San Jose, CA (408) 266-7404, www.raditek.com.

Terminal Chip Resistors

Available with voltage ratings up to 3 KV and resistance values from 100 k up to 100 G Ω, the new Ohmite HVC Series of wrap around terminal chip resistors have a standard TCR of 100 ppm and standard tolerances of five percent, although tolerances as low as 0.50 percent can be achieved. Voltage coefficients range from as low as 10 and up to 100, depending on resistance value. Supplied in 0805, 1206 and 2512 package sizes, the range comprises 23 stock part numbers. The thick film resistors have an operating temperature range of -55° to +155°C and the matte tin contact with a nickel barrier is designed for extended shelf life so the product is suitable for inventory support.
Ohmite Manufacturing Co., Arlington Heights, IL (847) 238-0300, www.ohmite.com.

3 dB, 90° Hybrid Coupler

VENDORVIEW

Werlatone's Model QH8911 is a 90° hybrid coupler that covers the full 80 to 1000 MHz band. Rated at 250 W CW, this three-port design, wherein the difference port is internally terminated with a high power termination, eliminates the need for a customer-supplied external load. Measuring 4.25" × 2.88" × 1", this unit is specifically designed for military and commercial environments.

Werlatone Inc., Patterson, NY (845) 278-2220, www.werlatone.com.

Connectors

DC to 18 GHz SMA Connectors

Ducommun's 2S Series features SMA connectors and a frequency range of DC to 18 GHz. The 2SE Series also features options for SMA connectors and a frequency range of DC to 26.5 GHz. Both series are available with failsafe, latching self cut-off, or pulse latching options. Weight (max.): 2.1 oz. RF impedance: 50 ohms nominal, operating temperature (failsafe): -55° to +85°C ambient, operating temperature (latching): -25° to +85°C ambient, and operating life: 1,000,000 cycles min.
Ducommun LaBarge Technologies, Carson, CA (310) 513-7200, www.ducommun.com.

Enhanced Performance SMA Connectors

VENDORVIEW

Richardson RFPD Inc. announced immediate availability and full design support capabilities for a series of Enhanced Performance SMA connectors from Carlisle Interconnect Technologies. The EPSMA (Enhanced Performance) series provides mode free performance to 27 GHz. In addition, the connectors are tuned to provide ultra low VSWR to 27 GHz (typically 1.15:1). This new product offering consists of field replaceable styles with industry standard flange configurations and pin sizes. The connectors offer low RF leakage (less than 90 dB), and all interfaces conform to MIL-STD 348. Applications for the Carlisle IT EPSMA series include defense electronics and test & measurement, plus modular amplifiers, power amplifiers, M/W switches, attenuators and VCOs.

Richardson RFPD Inc., LaFox, IL (630) 208-2700, www.rell.com.

Sources

HCMOS Clock Oscillator

Crystek's CCHD-957 is a new ultra-low phase noise HCMOS clock oscillator with standby mode, featuring an extremely low close-in phase noise of -100 dBc/Hz at 10 Hz offset and a typical noise floor of -170 dBc/Hz at 100 kHz offset. The Crystek CCHD-957 HCMOS clock oscillator also features a "Standby Function" – when placed in disable mode, the internal oscillator is completely shut down and its output buffer is placed in tri-state. This family is housed in a 9 × 14 mm SMT package and operates with a +3.3 V power supply consuming 15 mA of current. Stability is rated at 20 to 50 ppm (0° to +70°C) and ±25 to 50 ppm (-40° to +85°C). The CCHD-957 generates frequencies between 10 and 50 MHz. Its output driver is capable of driving ±24 mA, translating to a rise/fall time of ~3 nsec max. at 20 to 80 percent Vcc with a 15 pF load.

Crystek Corp., Ft. Myers, FL (800) 237-3061, www.crystek.com.

Frequency Synthesizer

The KB-39500 frequency synthesizer operates fixed at 39.5 GHz, features low phase noise (<-80 dBc/Hz max. at 10 KHz) and +18 dBm output power. The unit locks to an external 10 MHz reference. The unit is available in fixed or programmable frequencies to 40 GHz with internal or external references, improved phase noise and reduced package sizes. Programmable designs are available with step sizes as low as 100 Hz. The KB units are designed for applications such as millimeter-wave, radar, fixed/mobile (VSAT), SatCom and digital radio. Custom units are available in fixed and programmable frequencies from 12 to 40 GHz in a standard package of 5.00" × 2.50" × 1.25".

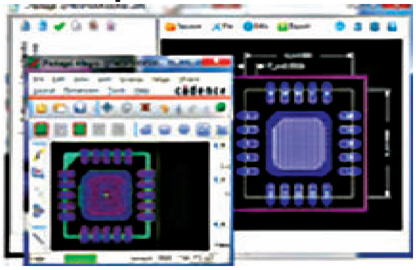
EM Research Inc., Reno, NV (775) 345-2411, www.emresearch.com.

Voltage-Controlled Oscillator

Z-Communications announced a new RoHS compliant voltage-controlled oscillator (VCO) Model USSP2350-LF for mobile communication system applications where low power consumption and small package size are critical. The USSP2350-LF covers the frequency range of 2300 to 2400 MHz in 0.5 to 3.0 V of tuning voltage. This high performance VCO comes available in a compact surface-mount package measuring a mere 0.2" × 0.2" × 0.04" while operating off 2.7 V and drawing only 6 mA, typically.
Z-Communications Inc., Poway, CA (858) 621-2700, www.zcomm.com.

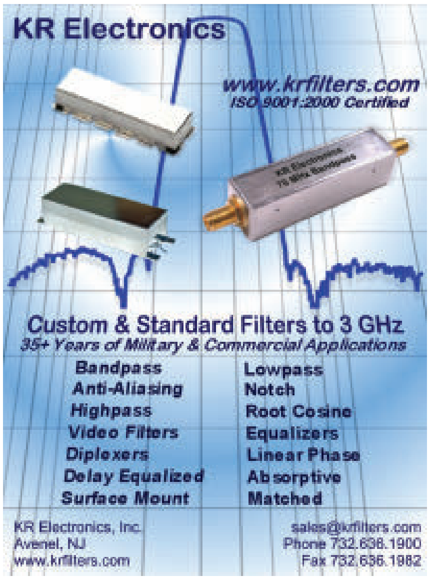
Software

PCB Footprint Model Software



EMA Design Automation has released FootprintGen, an app that accurately automates the generation of complex PCB footprint (land pattern) models in a fraction of the time compared to typical manual methods. Both user-defined and the IPC-7351 standard settings are fully supported across a broad range of component families. FootprintGen supports multiple user settings with user configurable line and text widths for solder mask, assembly, pad and other layers.
EMA Design Automation, Rochester, NY (800) 813-7494, www.ema-eda.com.

MICRO-ADS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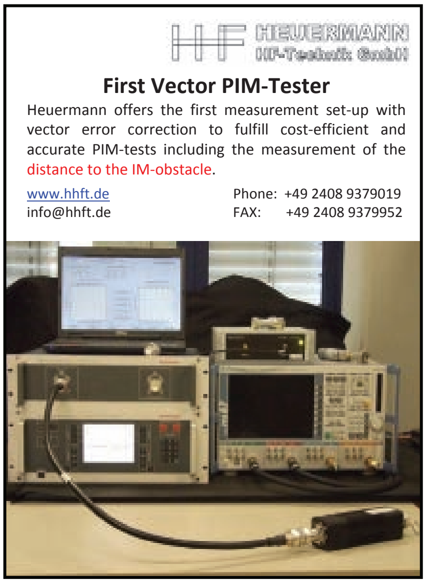
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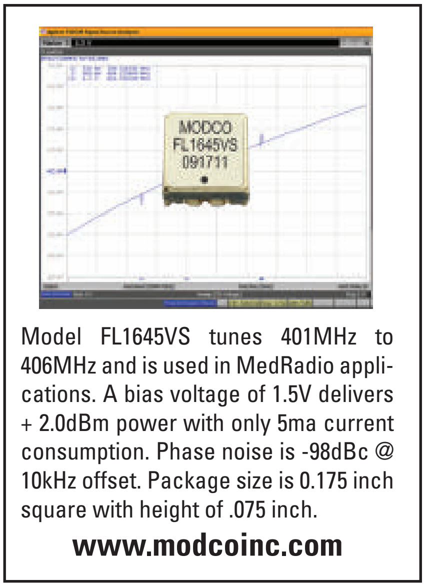
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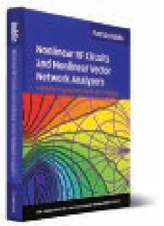

Nonlinear RF Circuits and Nonlinear Vector Network Analyzers

Patrick Roblin

With increasingly low-cost and power-efficient RF electronics demanded by today's wireless communication systems, it is essential to keep up to speed with new developments. The trend is to design RF radios with wider bandwidth and lower power dissipation for supporting new services. Therefore, RF radios have to be more efficient and cost effective along with covering more bands with each new generation. This book presents key advances in the field needed by engineers regarding emerging patterns in large-signal measurement techniques, modeling and nonlinear circuit design theory supported by practical examples.

Topics covered include: novel large-signal measurement techniques that have become available with the introduction of nonlinear vector network analyzers (NVNA), such as the LSNA, PNA-X and SWAP; direct extraction of device models from large-signal RF dynamic loadlines; characterization of memory effects (self-heating, traps) with pulsed RF measurements; interactive design of power-efficient amplifiers and oscillators using ultra-fast multi-harmonic active load-pull, Volterra and poly-harmonic distortion (X-parameters) behavioral modeling, oscillator phase noise theory, balancing, modeling and poly-harmonic linearization of broadband RFIC modulators and development of a frequency selective predistorter to linearize power amplifiers.

Dr. Jan Verspecht, IEEE Fellow and expert in the field, said this book is great for both gurus and apprentices in the field of characterization and network analysis of nonlinear RF circuits. It allows engineers to review the latest in this field in one comprehensive book. This endorsement makes this a recommended book to read on the topic of nonlinear RF circuits and NVNAs for engineers or academics in the field.

To order this book, contact:

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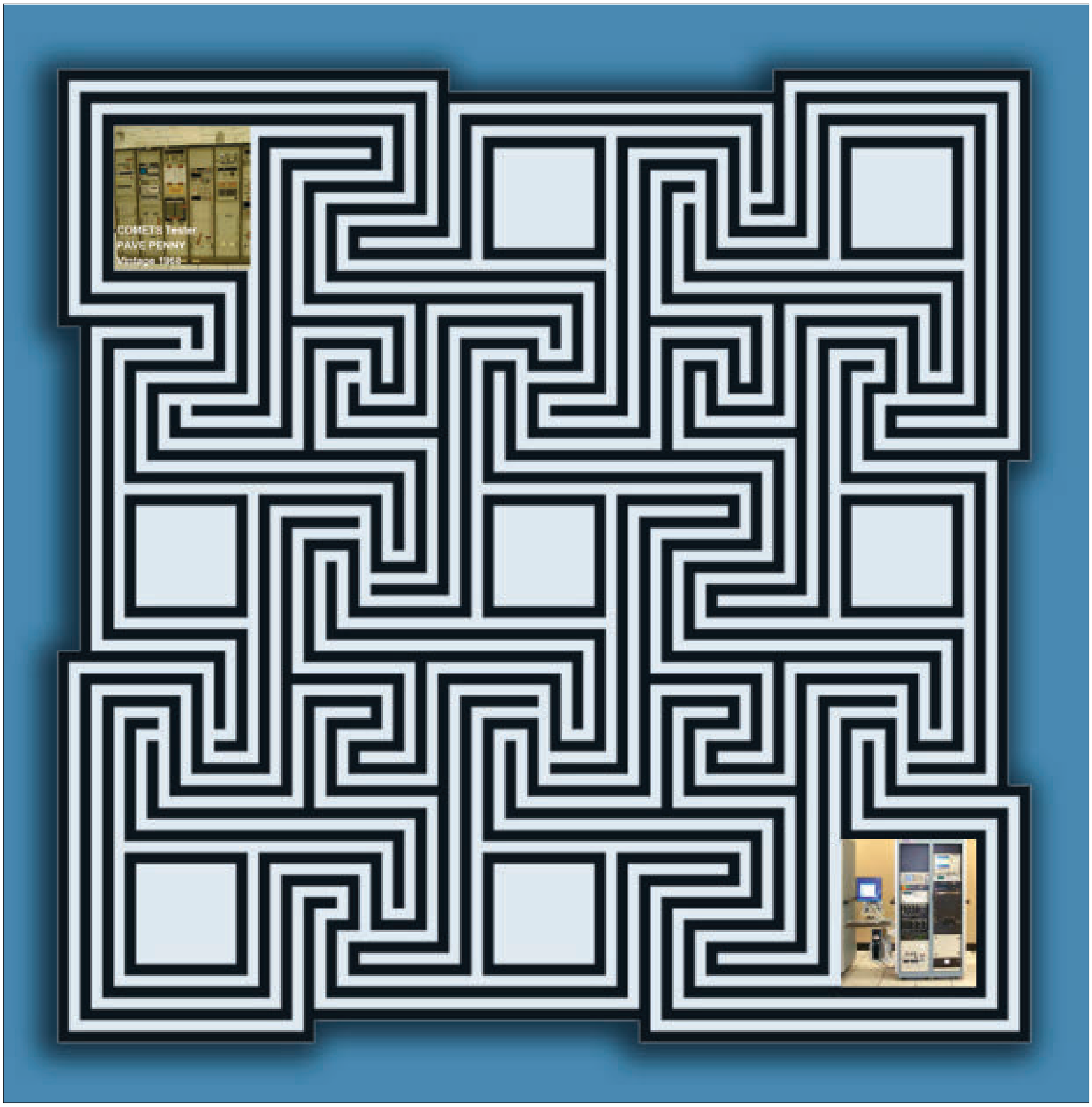

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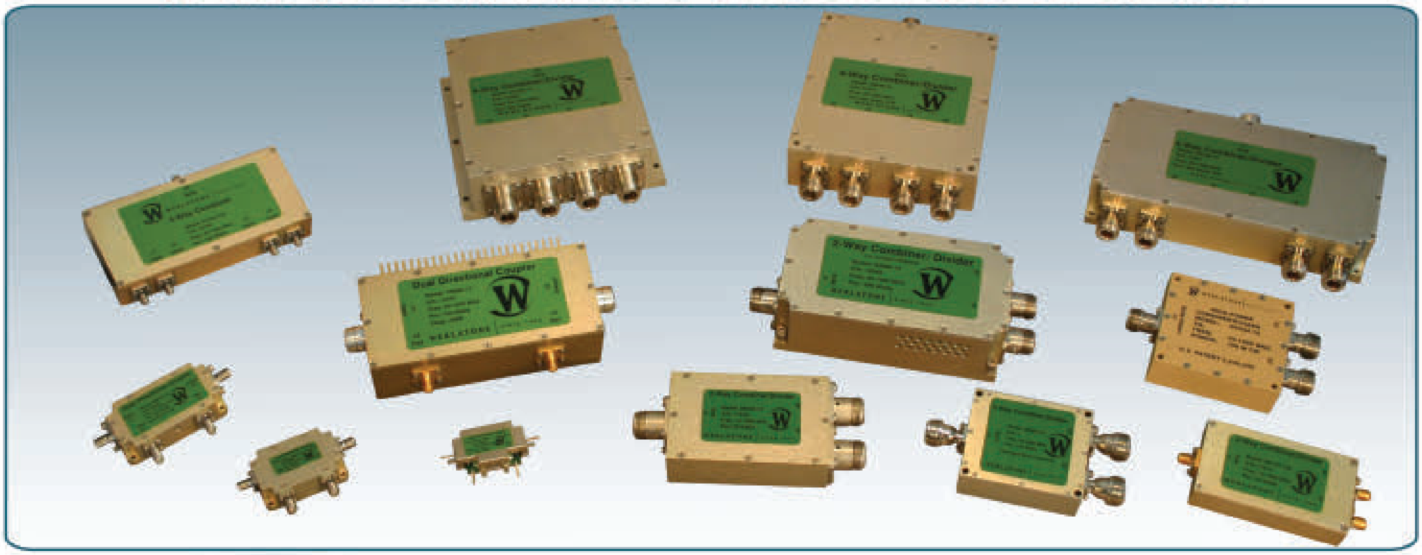

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D8632	2-Way	20-1000	50	2.2 x 2.02 x 1.5	0.7	1.40:1	20
D8300	2-Way	20-1000	100	2.45 x 2 x 0.91	0.5	1.35:1	20
D8544W*	2-Way	20-1000	100	2.85 x 2.5 x 1	0.5	1.35:1	18
D8682	2-Way	20-1000	500	5.2 x 2.65 x 1.8	0.6	1.35:1	15
D8851W*	2-Way	20-1000	500	5.6 x 3.05 x 1.8	0.6	1.35:1	15
D7365	4-Way	20-1000	100	5 x 2 x 1	0.75	1.35:1	20
D7439	4-Way	20-1000	250	5 x 5 x 1.5	0.75	1.35:1	18
D8746	4-Way	20-1000	500	7.2 x 3.5 x 1.4	0.7	1.35:1	15
D9048	4-Way	20-1000	500	5 x 4.7 x 1.4	0.6	1.35:1	17

* "W" references a Watertight Design

Dual Directional Couplers

Model	Coupling (dB)	Frequency (MHz)	Power (WCW)	Size (Inches)	Insertion Loss (dB)	VSWR	Directivity (dB)
C8858	40	10-1000	250	2.09 x 1.16 x 0.57	0.4	1.30:1	20
C8631*	40	20-1000	150	1.5 x 0.95 x 0.5	0.35	1.25:1	20
C8696	40	20-1000	150	1.76 x 1.16 x 0.57	0.35	1.25:1	20
C8686	40	20-1000	500	5.2 x 2.7 x 1.7	0.35	1.25:1	20

* Non-Connectorized / Tabs

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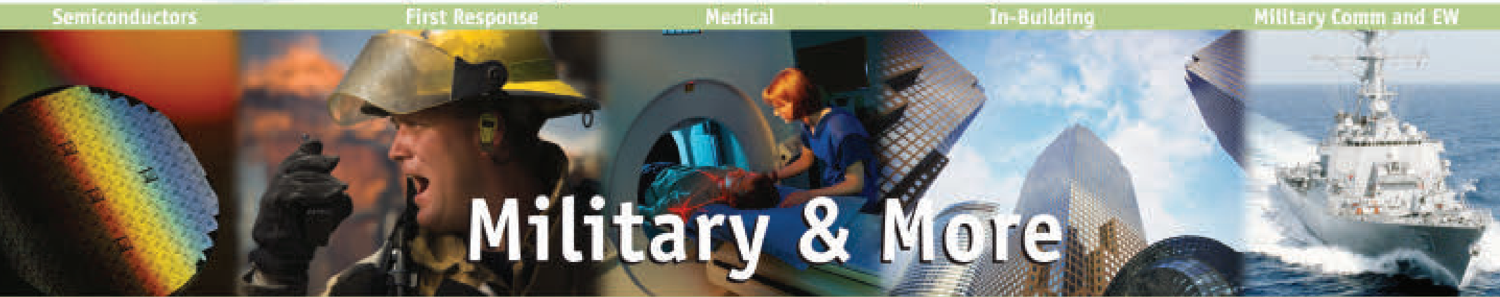

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2012 RF Connector and Cable Assembly Outlook

From its very beginning, the RF/microwave industry has understood that a good electrical connection between coaxial components, modules, subsystems and large platforms should not be taken for granted. Like high tech plumbers, our professional predecessors developed the coaxial cable and connector systems that allowed microwave signals to flow with minimal disruption and insertion loss through the modular electronic building blocks of today's communication, avionics, EW, radar, measurement, medical and industrial high frequency systems. In addition to addressing electrical performance, these manufacturers have also developed products that provide reliable and repeatable mechanical connections for all types of hostile operating environments and applications.

As modules and system technologies continue to evolve, so too does the state of interconnect technology. Similar to Moore's Law, these systems follow a universal trend toward miniaturization and added functionality, placing new demands on the interconnect design. Meanwhile, pressure to reduce costs combined with the availability of cheaper offshore labor is changing the manufacturing landscape and global supply chain. Cost, miniaturization and complexity are leading factors in a changing RF cable and connector market. In this special report, Microwave Journal examines these market and technology trends as well as some noteworthy developments among manufacturers.

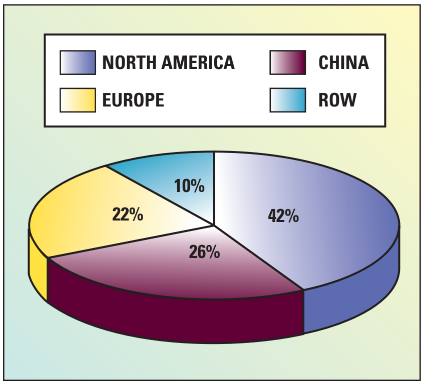
RF CONNECTOR MARKET TRENDS

According to connector/cable industry analyst Bishop and Associates Inc., the global RF connector market is expected to reach nearly $3 billion in annual sales this year. This reflects a decade's worth of growth ranging from 8 to 11 percent per year. Seventy percent of RF connector sales are attributed to four major market sectors, namely communications, military, computers and industrial. These markets represent high volume consumer products as well as the high performance, low-volume/high-mix products required by aerospace and defense. Markets that are not traditionally associated with RF, such as transportation and medical applications are expected to show significant growth as wireless monitoring and machine-to-machine (M2M) becomes the norm.

Fleck Research estimates the North American connector market to be valued at $1.3 billion, compared to a $765 million connector market in China and a $650 million European connector market. The rest of the world makes up the remaining 10 percent (see ***Figure 1***). Emerging markets such as China and India are the fastest growing with CAGRs well into the teens.

Each market has its own driving factors pushing RF connectors toward miniaturization

David Vye
Microwave Journal *Editor*



▲ *Fig. 1 Percentage of global RF connector sales in 2010, according to Fleck Research.*

and increased bandwidths. Smaller connectors are critical to reducing the size of handhelds, tablets and the next generation of laptop computers such as Intel's recently announced Ultrabook. Miniaturization also helps lower the overall weight of RF systems in airborne applications, which is needed to reduce fuel consumption. Conserving fuel is especially critical for launching spacecraft and lengthening the mission time and range of next-generation UAVs, such as the smaller platforms slated to replace today's Predator force.

MIL/AERO

The military/aerospace market for cable assemblies represents approximately 11 percent of the worldwide market for all cable assemblies (including non-RF) at a value of $12.7 billion in 2010. In that year, China had the most growth, at 21 percent, and Japan had the least amount of growth at eight percent. The military and aerospace industry is a major source of technology development and jobs. Unlike other industries, the defense business depends critically on governments to be regulators, customers and investors. On average, over the last five years, governments worldwide have consistently spent 2.7 percent of their global gross domestic product on military expenditures.

In 2010, North America led connector sales to the military/aerospace sector with 47 percent of all worldwide defense end-market sales, according to research by Bishop and Associates. North America has consistently demonstrated strong connector sales to the aerospace/defense sector and enjoyed the second-largest year-to-year growth in 2010. According to the same report, China ranked behind Europe and Japan in overall connector sales to the military sector but exhibited the greatest growth over the previous year.

Much of China's military spending for connectors and cable assemblies remains invisible to the outside world, as products are produced in government-run factories and many of the components are not purchased on the open market. The information that is available points to a rapidly growing market that may open up to commercial competition in the near future. RF connectors manufactured in China for internal consumption and export include a variety of types (discussed later in this article) such as SMA, SSMA, SMB, SSMB, MMCX, SMP, SMZ, SMC, SA, BMA, BNC, TNC, N, K, F and SPC3.5. These commonly have nickel- or gold-plated contacts. Compact variants MMCX, SSMA and SSMB, and 1.9, 1.85 and 1 mm units are also popular targets by manufacturers in China because of the miniaturization trend in targeted applications.

Meanwhile, the U.S. military will keep its defense systems updated with the latest and greatest technology, i.e. smaller, lighter, faster and more mobile systems, by frequently replacing the electronic modules in its older airplanes that may have a service life of thirty years or more. Therefore, modules must be connectorized to support regular replacement. This approach drives the demand for both standard and customized connector solutions.

Unfortunately, a recent report from Fleck Research confirms the overall weakening of demand for military connectors in upcoming years. Former Defense Secretary Robert Gates initiated the rethinking of future DoD spending citing a shift in the U.S. military's global focus/priorities and in anticipation of funding cuts in an era of government austerity. As a result some new programs will be delayed or cancelled.

For the Marines, the F-35B Joint Strike fighter was threatened with a two-year delay. Recently, Defense Secretary Leon Panetta removed the F-35B model from its two-year "probation" a year ahead of schedule; this was only after its development was put back on track with two other F-35 models being developed for the U.S. Air Force and Navy. Still, the Marine Expeditionary Fighting (ship-to-shore) vehicle has been cancelled and the Army's SLAMRAAM surface-to-air missile and over-the-horizon launch platform have also been nixed.

Aerospace and defense analyst Rob Spingarn projects that spending cuts on defense could total approximately one-third of the total $2.4 trillion spending cuts over the next 10 years as outlined in the debt deal from this summer's debt ceiling fight between congress and the Obama administration. Spingarn believes that the majority of the DoD cuts are likely to be in procurement, starting in fiscal 2012 and 2013, with specific program cuts identified in early October 2011.

GOOD NEWS FOR DRONES

On the upside, Fleck Research considers the most significant factors governing future military connectivity include the federal government's mounting interest in the use of UAVs and the escalating challenges to competing with China as a formidable military power. This past summer, Sen. Kent Conrad (D - ND) told reporters for Avionics Intelligence that the number one request he has heard from combatant commanders in battlefield situations is for more unmanned aircraft. Moreover, the demand for drone-enabled surveillance has spread into other vertical segments such as law enforcement and border control.

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UNITED KINGDOM	29.803	7%
CHINA	15.272	3%
GERMANY	22.807	5%
ITALY	15.134	3%
OTHER EUROPEAN	47.024	11%
OTHERS	23.654	5%

Notes: Percentages are rounded; each country shown as follows.
Developing Countries
Industrialized Countries

▲ *Fig. 2 Overall global arms exports in 2010.*

Although the U.S. Defense budget may be flat or down slightly year-over-year, the U.S. market for arms export is still strong. Responsible for nearly 40 percent of the total yearly global arms sales in 2010, the U.S. is by far the largest exporter of arms. According to a report on Conventional Arms Transfers to Developing Nations (Sept. 2011) by Richard Grimmett of Congressional Research Services, U.S. arms exports totaled $170.7 billion, followed by Russia ($81 billion), France ($37.4 billion), UK ($29.8 billion), Germany ($22.8 billion) and China ($15.3 billion) (see ***Figure 2***). Sale of advanced military hardware to areas such as the Middle East and Taiwan will help maintain the cable assembly market for mil/aero products through 2012.

Defense cuts have not affected the development and production of UAVs, with platforms that supposedly range from the size of a large insect, right up to that of a conventional fighter jet. For the period to 2015, it is projected that the market will have a 10 percent CAGR with the global market exceeding $94 billion by 2021 according to a Teal Group Corp. report from last March. Growth for RF connectors in UAV applications will likely track this 10 percent CAGR. In addition to offering ruggedness, performance and lower size/weight, RF connectors targeting use in UAV platforms will need to withstand altitudes up to 70,000 feet, temperatures from -60° to 75°C and frequencies up to 40 GHz.

SHIFTING SANDS IN THE MARKET

Who will benefit most from this demand? Each market has its own set of priorities dictated by a variety of factors. Pricing certainly drives a portion of many buying decisions and is forcing suppliers to lower their manufacturing costs as best they can. And yet, the true cost of using a particular vendor's connector or cable assembly includes additional considerations such as performance, quality, reliability, catalog (available products), on-time delivery, manufacturing capacity and the ability to successfully execute custom engineering in a timely manner.

Literally thousands of companies manufacture RF connector and cable assemblies globally. Leading vendors do well in various connector/cable assembly markets according to how strongly they compete in any of these areas and how important that attribute is to a given market. Reputation and existing customer relationships, along with continued investment in R&D to improve performance, size and manufacturing should allow these companies to survive and expand. Strong brand awareness and a reputation for quality and reliability have considerable value in the interconnect component market today. As foreign competition heats up and lower priced products hit the market, brand loyalty may help leaders to retain customers and maintain margins.

Regular, in-depth conversations with end-customers are often required to ensure that product specs meet or exceed their needs. Developing clear two-way communication for product and service related support builds trust and ultimately improves the end product. As a result, many leaders are successful in getting their products "spec'd in" to OEM require-

ments, which drives customer loyalty (by increasing switching costs) and allows for premium pricing relative to commodity products.

This dedicated in-house expertise has helped industry leaders expand their share within growing niches in the market. For example, companies focusing on the military and aerospace market have been able to develop long-term customer relationships with premium pricing arrangements. Industry specialization makes companies more attractive for take-over because specialization allows the new parent company to increase their exposure to specific end-customer markets. These acquisitions are often easier to integrate into the existing customer-based structure of the overall organization. As a result, premium valuations are frequently attached to any company targeted for a merger or acquisition if they have developed a clear specialization in the medical, military, aerospace and/or industrial markets.

Fig. 3 Cable assembly line in China (courtesy of Wellshow Technology Co.).

Still, the manufacturing supply side has been undergoing some interesting shifts over the past few years. Firstly, components are increasingly being manufactured in places where the labor costs less than in the U.S. A number of leading manufacturers have developed offshore manufacturing capabilities in order to achieve significant cost savings, especially for high-volume production runs. Although many companies outsource these activities, many leaders own and operate manufacturing facilities in order to retain greater control over quality and production schedules (see ***Figure 3***).

As a result, electronic product manufacturing continued to migrate to China in 2011 despite recent increases in wages. One recent report indicated that average wages for Chinese workers will double by 2015. Therefore, the incentive for many U.S.-based companies to move into China is now focused more on being close to growth markets rather than low-cost manufacturing.

A second factor that may push development offshore is the DoD's effort to restrict the flow of bleeding-edge technologies. ITAR is hindering the ability of U.S. companies to compete globally. By restricting the counties to which U.S. manufacturers can sell their best technology, ITAR limits the ability of these suppliers to generate revenue through exports while encouraging foreign markets to develop these technologies independently. The proposed ITAR reforms may help alleviate some of these issues, but they appear to be far from getting approved in the near future.

In the last two decades, regional shifts in manufacturing has left voids in some basic areas, including master tool and die making, precision metal working and assembly as well

as high-volume production, particularly in small, high-volume systems. This trend is unlikely to change as long as Western labor must compete with the work conditions, hours and wages that are only acceptable to a worker in an emerging market. In the short term, markets relying on high levels of performance and manufacturing achieved through sophisticated engineering and automation will favor domestic production. Long term domestic production is at risk unless this advantage is maintained or the global landscape changes (i.e. scarcity of materials, trade barriers, security restrictions, etc.). Arguably, China's competitive advantages are largely due to government subsidies, sparse regulation on the environmental impact of dirty manufacturing and most importantly – currency manipulation. The current political dialog of re-investing in American manufacturing and skilled training comes at a critical time but will also require a tougher stance on global trade and manufacturing processes to be effective.

CABLE ASSEMBLY MANUFACTURING

The majority of system integrators have found it cost effective to shift their cable assembly design to specialized suppliers with established solution-oriented design, quality and manufacturing techniques. The given application will dictate whether the interconnect will be exposed to harsh outdoor conditions, require specific performance characteristics such as low passive intermodulation (PIM) and which cable type, i.e. hand-formable, semi-rigid or flexible is needed. Cable assembly houses also invest in the dedicated equipment necessary to produce high tolerance, reliable components, such as those shown in ***Figure 4***.

A typical coax cable assembly house will have a number of critical component dimensions measured and controlled through their own proprietary statistical process control program. Hipot and continuity testing along with visual inspection and gauge measurements are used to ensure that the process is in control. Typical in-house testing includes parameters such as VSWR, insertion loss, phase and delay measurements, as well as most standard mechanical and environmental tests (temperature range, humidity, vibration, shock and abrasion) as required by the standards called for by the given application.

Cable types and connectors have become rather specialized to meet the exact demands of how and where they intend to be used. For instance, test cables are designed for precision, flexibility and reliability over numerous mating/unmating cycles. One of the ways manufacturers address the wear and tear of high connection cycles is through improved surface plating of the connector. Although gold, silver and nickel are still widely used, proprietary platings have been developed by many manufacturers that combine these materials, as well as add additional materials to provide improved plating options.

One leading supplier offers a proprietary tri-metal plating solution containing copper, tin and zinc as an enhanced alternative to nickel/gold plating. The non-allergenic, nickel-free connector offers low-contact resistance, over 1000 mating cycles, and reasonable corrosion resistance. It is also non-magnetic, so its PIM characteristics are comparable to silver. For even more abrasion and corrosion resistance, a non-magnetic nickel-phosphorus base material with a thin plating of gold is also available. This product provides for twice as many mating cycles as components based on standard gold plating, as well as low and stable contact resistance and added protection against oxidation and corrosion.

RF assemblies are increasingly found in remote wireless monitoring systems from oil fields and factory floors to hospital medical equipment. There are RF assemblies in the medical field, both in general and disposable applications. The proliferation and ubiquity of wireless systems and their RF interconnects has led to concern over environmental impact. Legislation regarding end-of-life product recycling and additional safety requirements is having an impact on cable manufacturers. Industry standard RG-type PTFE/FEP cables are extremely resistant to decomposition. Regulations mandating that manufacturers recycle products at the end of their service life will eventually off-set the cost-saving benefits associated with the continued use of PTFE

▲ *Fig. 4 CMC semi-automatic stripper assures quality with precision and stable tolerance control.*

cable. PTFE cables also contain halogen, which gives off highly toxic and corrosive gases when ignited, creating major safety issues. In response, certain manufacturers are beginning to offer cable products that are halogen-free and composed of recyclable plastics that are not as resistant to decomposition as PTFE.

CONNECTOR TYPES

RF connector types are segmented into primary families and sub-families, organized by size, frequency, coupling method and style. The frequency range of any connector is limited by the excitation of the first circular waveguide propagation mode in the coaxial structure. A decrease in the diameter of the outer conductor will result in an increase in the highest usable frequency. Filling the airspace with dielectric material in order to support the inner conductor will lower the highest usable frequency while also increasing the insertion loss.

Various connector types employ a range of mating technologies. The mating process typically changes the geometry of the mating surfaces and resistance loss at those interfaces as well as geometric changes, which result in variation of impedance and loss. This is an area where designers of high-precision connectors and cable assemblies focus their attention. Most connectors are designated as male or female depending on their internal structure. Many female connector types are designed with slotted fingers to accommodate tolerance variations of the mating male inner conductor. This design feature can reduce repeatability, introduce a small inductance and may eventually wear out after numerous re-connects.

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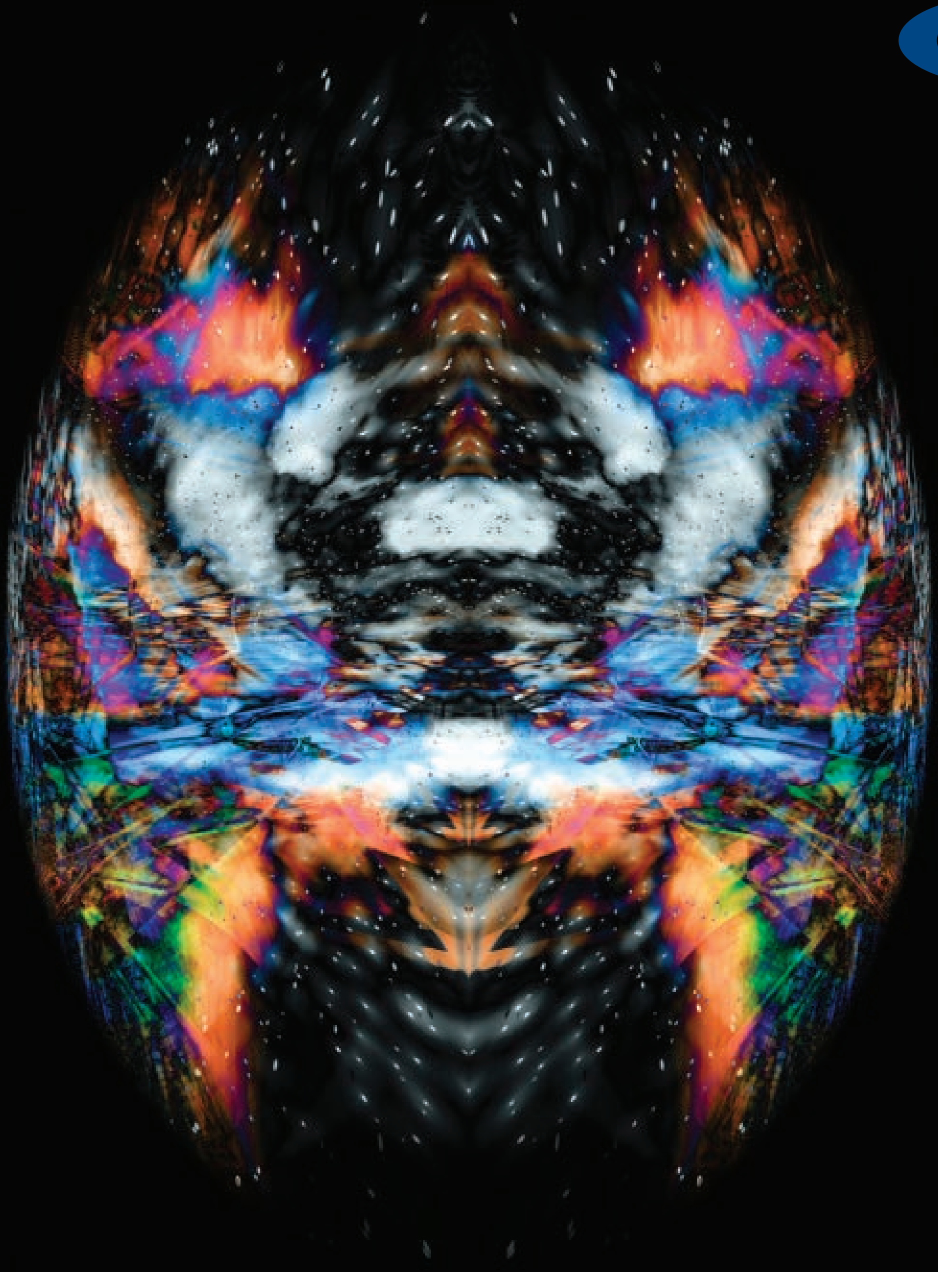

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Board-to-board connectors are commonly found among all the major markets and represent the fastest growing members of the connector family. One example is the notebook PC with built-in wireless card and multiple antennas. PC manufacturers are required to make their products field serviceable by designing them with replaceable screen and system boards. Board-to-board connectors allow these components to detach from each other. With thinner system packages and wide format screens, real estate is becoming a real challenge to connector suppliers. In addition, 802.11x devices operating at higher frequencies are driving the need for very small, high-performance interconnects as well as a rise in the number of multi-port coax solutions being offered on the market.

Many manufacturers are setting their sights on board-to-board connectors because of the variant's low production costs and wide use in wireless equipment, including base stations, remote radio heads (RRH) and GPS devices. Several foreign enterprises have launched MCX, MMBX, IMP and SMP series. The last is composed of two connectors placed on two PCBs or modules and an adapter. In the next three to five years, these three parts are forecast to merge, which will help lower outlay and raise precision levels. Local makers therefore expect RF connectors to replace coaxial cable assemblies in board-to-board applications gradually. The latter, however, will continue to be the primary choice in the external connections of communication, military and industrial equipment.

STANDARD CLASS

The Type N connector was originally designed in the 1940s for military systems operating below 5 GHz. Most sources attribute the "N" designation to an RF engineer from Bell Labs named Paul Neil. Subsequent improvements to its design have pushed the mode-free performance up to 18 GHz. The "Bayonet Neil-Concelman" commonly known as the BNC was originally designed for military use but has gained wide acceptance in video and RF applications to 2 GHz. A threaded version known as the TNC helped resolve the connector's leakage and geometric stability problems, allowing the TNC to be used up to 12 GHz. The 7/16 DIN is a high-power 50 Ω connector originally developed by Spinner. This relatively new connector is growing in popularity especially in wireless applications including cellular towers. This connector, which is plated in silver or gold, performs up to 7.5 GHz.

SUB-MINIATURE CLASS

The SMA (Subminiature A) connector was designed by Bendix Scintilla Corp. and Omni-Spectra Corp. as the OSM connector, and is one of the most commonly used RF/microwave connectors. This connector is often used with semi-rigid cables, which are connected infrequently. In contrast, the subminiature B (SMB) snap-mount connectors are rated to 4 GHz but usable up to 10 GHz for applications requiring easy and fast connect/disconnect operations. Its mechanical design leads to poor electrical performance especially for low noise applications. The SMC is a threaded type connector that is ideal for size constraints and in the case where a threaded solution is viable.

MICRO-MINIATURE CLASS

Smaller versions of the SMA include the Sub-SMA or SSMA and OSSM types. At 70 percent the size of an SMA, these connectors are typically rated up to 26 GHz, but special high-performance versions are available with mode-free performance up to 40 GHz. Other snap-on types include the MCX family (MCX and MMCX), which are rated to 6 GHz. These connectors are 70 percent and 50 percent the size of an SMB connector, respectively, offering about

Family classification varies, but some commonly recognized groupings and connector types include:

Standard Coax
- N Type, HN (high voltage N type) – screw-on, up to 11 GHz
- SHV, BNC HT, MQ HT, THT-20 – high voltage
- C/SC Type, bayonet coupling, high power, up to 11 GHz
- 7/16 DIN – screw on, high power, low PIM, up to 8 GHz

Miniature Coax
- BNC, mini-BNC, TNC, bayonet coupling, mil, RF and video apps, up to 4 GHz
- UHF, Miniature UHF, M-Type – screw-on, up to 1 GHz
- Dezifix (Rohde & Schwarz)
- GR874 (General Radio)
- LC

Sub-Miniature Coax
- SMB – snap-on, up to 4 GHz
- SMC – #10-32 screw-on, up to 10 GHz
- FME – screw-on, easy connect, up to 3 GHz
- SMA including variants:
  – 3.5 and 2.92 mm connectors, which cross-mate with SMA
  – 2.4, 1.85 and 1.0 mm connectors, which do not cross-mate with SMA
- FAKRA – snap-lock, automotive RF, up to 4 GHz
- SMZ connector - System 43 (BT43 and High Density HD43) for use in DDF
- MHV/SHV

Micro-miniature types
- OSMT/SSMT – surface-mount, 3 mm height profile, up to 6 GHz
- MCX, OCX – snap-on, up to 6 GHz
- MMCX – micro-mini snap-on, board-to-board or cable, up to 6 GHz
- QSL – low profile, ruggedized for wireless, multiple ports, up to 6 GHz
- OSMM – smaller than SSMA, higher order moding is over 450 GHz
- SMP/SMPM – push-on, performance up to 40 GHz
- SSMA – smaller version of SMA, up top 40 GHz

Ultra-miniature Coax
- IMP – press-on, low cost, board-to-board
- MMT – snap-on, low profile SMT, up to 8 GHz
- MMS – snap-on, low profile SMT, WLAN and GPD handhelds, up to 6 GHz
- UMP – press-on, secure, board-to-peripheral, up to 6 GHz
- U.FL/IPX/IPEX/IPAX/MHF/AMC – WiFi antenna to Mini-PCI board, up to 6 GHz

Precision types
- APC-7 – 7 mm sexless, low reflection for test/meas. applications, up to 18 GHz
- Higher frequency versions with dimensions 1.0 mm (110 GHz), 2.4 mm (50 GHz), 2.9 mm (40 GHz), 3.5 mm (26.5 GHz)

Quick-lock connectors
- QMA, Mini-QMA – designed to replace SMA (18 GHz)
- QN (QL-N), SnapN, HPQN – designed to replace low power N type (11 GHz)
- WQMA – Waterproof version of QMA

Blindmate
- GPO, GPPO (Gilbert)
- OS-50P, OSMT, BMA, OSP, OSMP, OSSP (M/A-COM)
- SMP, SSM

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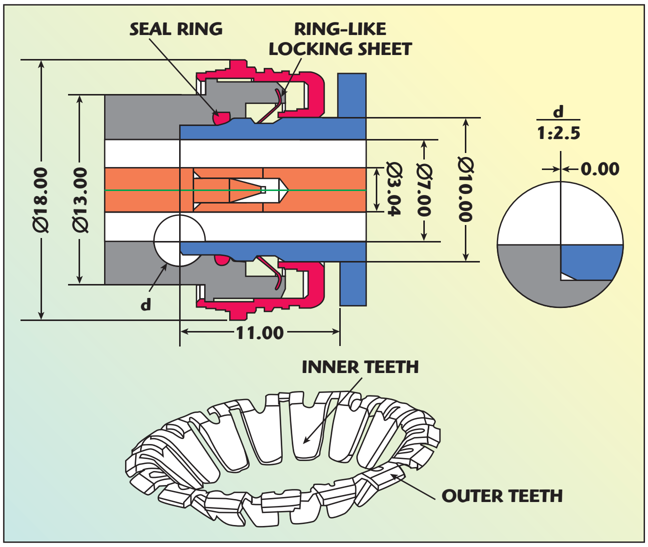
IF/RF MICROWAVE COMPONENTS

the same number of reliable reconnects (~ 500).

PRECISION CLASS

This class of connectors is used most often in a test environment where accurate and repeatable measurements are required. One well known type is the sexless APC-7 originally designed by Amphenol. Amphenol's APC was the first instrument-grade coaxial connector series to achieve repeatable TE_{11} mode resonance-free signal transmission from DC to 50 GHz with a minimum return loss of 26 dB. These 50 W connectors were designed primarily for use in test and measurement equipment where reliable performance is critical for repeated connect/disconnect cycles. The "Precision SMA" connector was designed by Wiltron (now Anritsu), another test and measurement manufacturer. The two basic geometries are the 3.5 mm/Wiltron WSMA and the 2.92 mm/Wiltron K.



▲ *Fig. 5 Cross section of HPQN type quick lock RF connector mechanical design and locking ring.*

QUICK LOCK

This connector family was created by the Quick Lock Formula Alliance (QFL), which consists of leading connector manufacturers. Available since 2003, these quick-connect RF connectors were designed to replace the widely used SMA connectors and Type N connectors in cases where the connection/disconnect operation need to be faster and easier by eliminating the need for a torque wrench. In the case of QMA, its basic structural parameters and electronic performance are very close to that of the original SMA connector making it backward compatible with this design.

Variations on a QL N-type connector include the NQ, SnapN and HPQN. The QN designed originally between 2002 and 2004 eliminated the threaded coupling with a snap-in retention and an integrated sealing ring. Unfortunately, clearance between the contact surfaces of the outer conductors leads to instability and potential discontinuity of characteristic impedances. Because of this deficiency, the SnapN design placed a spring at the rear of the outer conductor of the plug rather than between the contact surfaces of the connector's two outer conductors. While improving the performance, the elasticity of the spring made the connector performance susceptible to external forces such as heavy cable swing. The HPQN designed in 2007 improves on this design through the use of a ring-like locking washer, which is fixed in the plug and locks the mating slope of the jack (see ***Figure 5***).

SUMMARY

The HPQN connector represents one example of the ongoing efforts to develop new designs and manufacturing processes to deliver higher performance, lower cost, ease-of-use and a variety of other specific attributes targeting the increasingly specialized requirements for high frequency interconnect technology. The overall market is going at a steady clip of about 8 to 10 percent per year for the past decade, tracking the growth of its leading markets, namely computers, telecommunications, aerospace/defense and industrial. As market competition continues to drive design improvements, connector, cable and cable assembly manufacturers will strive to innovate with new and evolving products. These companies help keep the wireless world connected. ■

The Importance of Knowing Your Cable Constraints

The cost of failure in many of today's electrical applications dictates the need for highly reliable RF/microwave cable assemblies — whether failure translates to lost revenue, production downtime, or customer safety. Using ruggedized assemblies has become one of the most common solutions for preserving reliable performance. However, having a ruggedized RF/microwave cable assembly does not necessarily mean the assembly needs to be over-engineered; it simply needs to be properly designed to ensure it is appropriate for the intended use. Understanding the constraints of your application and the environment in which it will be used can ensure that the RF/microwave cable assembly will be properly engineered to provide precise and repeatable measurements with stable electrical performance for your application. Challenges during installation, usage considerations and constraints of the physical environment all affect a cable's performance.

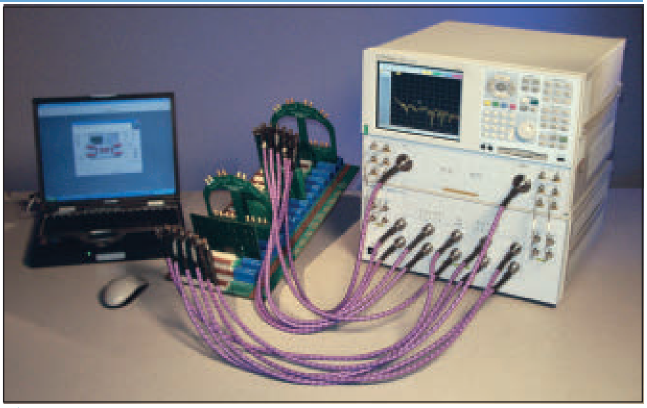
INSTALLATION CONSTRAINTS

Where and how the RF/microwave cable assembly will be installed has a direct impact on the long-term reliability of the cable. Understanding the installation process can help determine which materials are best for the assembly's construction. For example, if the assembly must be routed through a tight space, size and durability should be evaluated. If the assembly will be pulled through a conduit, the cable's outer jacket also needs to be abrasion-resistant. And, if the assembly needs to be twisted so it can be routed around other equipment, it needs to be very flexible with a small bend radius. All of these situations mean that the cable's construction needs to withstand the installation and protect the conductors during use (see ***Figure 1***).

PAUL PINO
W. L. Gore & Associates, Landenberg, PA

If the distance between the two connection points for the cable assembly is very short, signal reflection and voltage standing wave ratio (VSWR) can have an adverse effect on the measurement accuracy. Adding a service loop in the cable can allow more flexibility and help eliminate length tolerance issues.

▲ *Fig. 1 The tight spaces and routing challenges of installation in an aircraft can easily compromise the performance of RF/microwave cable assemblies.*



▲ *Fig. 2 In a laboratory environment, RF/microwave cable assemblies are frequently bent, twisted and pulled, which can affect the precision and repeatability of measurements (courtesy of Agilent Technologies).*

USAGE CONSIDERATIONS

How the RF/microwave cable assembly will be used is another important aspect to consider when selecting the right cable. Like the installation process, the application for which the assembly is intended often defines the type of materials used in the assembly's construction as well as its performance requirements.

Cable Handling: The first, and probably foremost, consideration is whether the cable will be left in place once it is installed or whether it will be handled frequently. When the cable is connected to equipment handled manually, it is much more likely to experience flexure, and frequent flexing can potentially affect the precision and repeatability of measurements. An operator can kink, pinch, or crush a cable by stepping on it, rolling over it, or wrapping it around a piece of portable equipment during transport. Therefore, tensile strength is essential in overcoming mechanical stress on the cable. Externally ruggedized cables cannot always withstand this type of torque. However, internally ruggedized cables can improve phase and amplitude stability with flexure because they are crush-resistant and maintain excellent tensile strength even at a small bend radius (see ***Figure 2***).

Another consideration for cables that are frequently handled is whether they will be used in a high-throughput application. These applications require frequent attaching and detaching of the cable from the device under test (DUT). Assemblies engineered for this type of application should reduce the need for frequent recalibration and time-consuming troubleshooting due to testing errors. Selecting a reliable RF/microwave cable assembly with a quick-turn connector can also increase throughput by eliminating the need for a torque wrench.

Size Constraints Versus Insertion Loss: For applications that require RF/microwave cable assemblies, insertion loss is usually a critical performance specification. For some applications, the size of the cable assembly is also important, and there can be a trade-off between insertion loss and cable length or diameter. With RF/microwave cable assemblies, loss is directly related to cable diameter. An application may have a specific loss target as well as an overall cable diameter target; however, in some instances, the maximum diameter target could prevent the loss requirement from being met. The combination of longer distance and loss target may mean that the cable needs a larger diameter. In aerospace systems, for example, engineers often specify a maximum cable diameter because smaller cables mean less weight. Reducing the weight of a cable assembly may compromise its durability and electrical performance with use. Choosing a high-quality cable with a lower dielectric constant will translate to a lower loss for a given diameter. However, it is important to focus on the dielectric constant of the finished cable assembly rather than that of the raw materials.

Phase or Time-Delay Matching: RF/microwave cable assemblies may require phase or time-delay matching to ensure that every cable within a set has its time delay or phase length within a specified tolerance range. This type of matching can be either absolute (i.e., one or more assemblies having a specific time delay or phase length target value plus/minus the tolerance) or relative (i.e., a set of assemblies with time delay or phase length within a specified match window). Phase-matched assemblies are usually used in applications with phase-array radar, differential signaling and power combining. For applications that require phase or time-delay matching, it is critical to select a cable assembly that is also phase-stable over flexure so that performance is maintained.

Power Handling at Frequency of Interest: Assemblies are usually specified with an adequate margin of safety to ensure that they can handle the maximum amount of power at the desired frequency range. However, environmental conditions, such as high temperatures, vacuum, humidity, etc., can affect the power requirements. A cable assembly dissipates heat energy using three mechanisms: conduction, convection and radiation. Temperature or pressure changes directly affect the cable's ability to reduce heat by convection, with a vacuum completely eliminating it. This leaves only conduction through the outer braid and center conductor of the cable assembly and radiation as alternative mechanisms. One of the consequences of these environmental conditions is thermal breakdown caused by heating within the cable and connector due to power dissipation. To understand power handling challenges, it is necessary to understand temperature and pressure requirements as well as the continuous average power value at a specific frequency being put to the cable.

For power handling at certain frequencies, the type of connector used with the RF/microwave cable assembly is

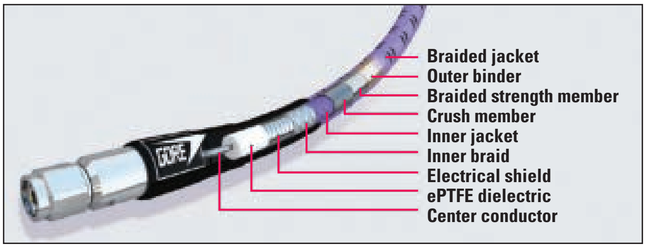


Fig. 3 RF/microwave cables with robust shielding at the outer conductor can minimize crosstalk and electromagnetic interference.

also important. Like cable assemblies, connectors are rated based on how they handle power as a function of frequency. Charts are available that detail the power handling capability of various connectors. In addition, since high amounts of power under certain conditions may generate a significant amount of heat, the type of solder used for terminating the connectors should also be considered.

THE PHYSICAL ENVIRONMENT

The physical environments in which RF/microwave assemblies are being used today are becoming more challenging. Assemblies are being exposed to such conditions as extreme temperatures, vibration and constant electromagnetic interference (EMI). These environmental challenges vary significantly, depending on the application. For example, a cable assembly used in a controlled-environment laboratory encounters very different environmental conditions from one analyzing flight data in an aircraft. Like all constraints, the impact of these environmental challenges can be minimized by selecting a RF/microwave cable assembly engineered to withstand them.

Temperature and Pressure: Temperature and pressure variations can affect a RF/microwave assembly's VSWR and insertion loss performance. High temperatures increase insertion loss, while low temperatures reduce insertion loss. This is due to thermal effects and their impact on electron activity. VSWR can be altered by physical changes in the assembly as a result of expansion and contraction due to temperature change.

Temperature changes can also affect phase length. As the temperature approaches an extreme, the electrical length will change; if it does not change at the same rate as the temperature when returning to normal (a state known as hysteresis), it is very difficult to apply error-correction techniques to the signal.

Temperature and pressure can also affect the cable's durability. Low temperatures can make cable materials brittle, and high temperatures cause them to become very soft. Vacuum leaches oils and additives out of certain materials, which could have an adverse effect on a cleanroom manufacturing process.

Vibration: Whether used on a manufacturing floor or in an aircraft, RF/microwave cable assemblies can be exposed to significant shaking and vibration. Phase and amplitude stability during flexure and shake need to be evaluated for any assemblies that will be used in these types of environments. Utilizing a high-quality cable that is phase- and amplitude-stable will provide more precise and repeatable results by preserving the integrity of the signal.

Electromagnetic Interference (EMI): Today's electronic equipment is increasingly complex, with many electrical subsystems generating their own signals, all of which can interfere with the performance of a RF/microwave cable assembly. In addition, assemblies are also being used in environments where high-voltage signals are continually being transmitted. For example, portable test analyzers with RF/microwave assemblies are used in the telecommunication industry to test the performance of cell tower antennas with constant interference that could compromise the integrity of the test measurements. Choosing a cable with robust shielding at the outer conductor will minimize any possibilities of cross-talk or EMI (see ***Figure 3***).

Abrasion and Cut-Through: In addition to being a consideration during the installation process, abrasion and cut-through are constraints that can be found in many environments — aircraft applications, handheld analyzers used in the field, portable equipment around which the assembly is wrapped during transport, etc. Some jacketing materials, such as polyurethane and engineered fluoropolymers, are more abrasion-resistant and durable than others, so potential exposure to abrasive surfaces should be considered when designing a cable assembly for a specific application.

VERIFYING PERFORMANCE

Because precise and repeatable measurements are so important with RF/microwave cable assemblies, it is important to discuss with the manufacturer what types of performance testing have been done on the assembly. Mechanical tests — such as a flex test with repeated bending of 180 degrees or more, or the pull test to simulate use as a tether — can verify the assembly's electrical performance while it is operating under conditions such as crushing, abrasion, potential cut-through and continuous flexing. During these tests, insertion loss and VSWR should be evaluated.

The cable's electrical performance should also be measured while simulating the physical environment in which it will operate — conditions such as temperature, altitude, pressure and vibration. For example, it is important to monitor impedance during altitude change, mechanical shock and vibration tests. By adding a clamp force during a temperature cycling test, the cable assembly's dielectric withstanding voltage can be monitored to see how the jacket and conductor change. After the cable is put through substantive mechanical and environmental tests, the manufacturer should again verify that the electrical performance, dielectric and jacket materials remain stable within the requirements of the application.

CONCLUSION

RF/microwave cable assemblies need to be engineered to withstand demanding applications in which precise and repeatable measurements are essential. Understanding the constraints of an application and the environment in which the RF/microwave cable assembly will be used can ensure that it will be properly engineered to provide consistent, repeatable measurements with stable electrical performance for that application. And performance testing can ensure that the cable will maintain reliable performance. The proper cable assembly can save time and money over the life of the equipment because it can reduce equipment downtime, eliminate cable failure and increase service life. ■

Case Study: Using Electromagnetic Simulation to Ensure EMC Compliance

KEC designs and manufactures EMC backshells for standard circular, rectangular and "D" type connectors, as well as a range of bulkhead glands and fittings, conduit systems and cable harnesses. KEC has built its place in the market by providing quality electrical shielding between a harness system's connectors and the cable through the use of shielded backshells and continuity between connectors and panels. But over time they began to realize that customers were buying their components and giving them to others to build complete harness systems. They responded by expanding their offerings to include the entire EMC interconnect cable harness design and build process.

As they have grown the business, differentiating themselves from the competition has become an important goal. To accomplish this, KEC is developing further expertise in the area of electromagnetic simulation of the harness systems. By modeling and simulating customers' designs, KEC can identify problems early in the process and recommend corrections before the EMC certification stage. This enables customers to avoid costly mistakes and pass certification testing on the first try.

THE CHALLENGE

When researching potential unmet needs in their target markets, KEC's team focused on the challenges their customers faced during EMC testing and certification. In addition to the demanding requirements of the defense and aerospace markets, international legislation has created rigorous specifications that challenge many other industries such as telecommunications, railroad and computing.

USING EM SIMULATION TO ENSURE EMC COMPLIANCE

Because it is very expensive if a device fails EMC compliance and has to be redesigned and retested, manufacturers need confidence that

REMCOM INC.
State College, PA

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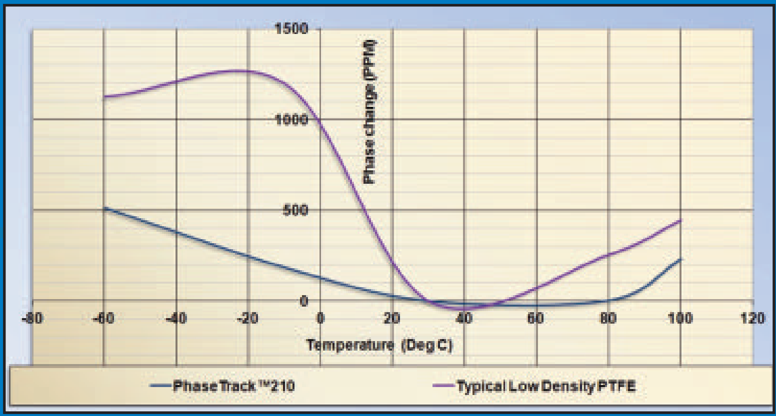

PhaseTrack™210 cable assemblies are only one of the Times Microwave Systems product families developed to solve demanding Phase Critical Applications:

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www.timesmicrowave.com

the harness system is in compliance before integrating it into their designs and installing it into their equipment. KEC recognized that providing simulated results early in the design stage could greatly assist their customers. It also happened to be a unique technology that was not being offered by anyone else.

David Dyson, chairman at KEC, said, "We realized that we could provide a more complete solution for customers by testing the harness system first using EM simulation. The simulations demonstrate how the shielding protects the wiring and signals from RF fields, allowing us to pinpoint weaknesses if they exist. We can then help the customer to redesign until the simulation results are satisfactory. The goal is to pass the certification the first time."

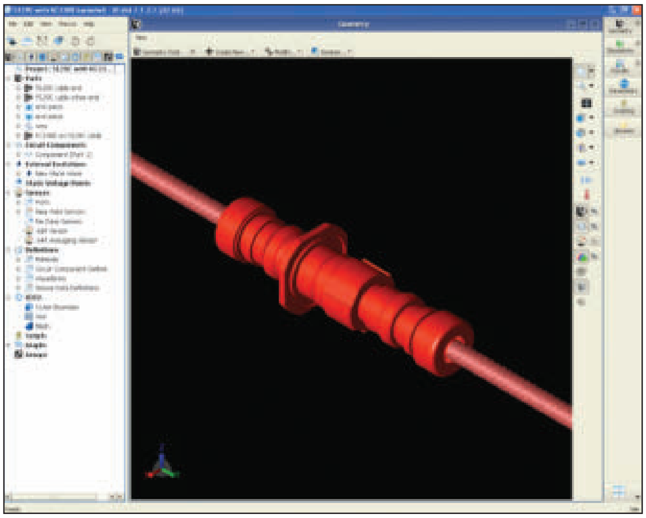

Fig. 1 Geometry for cable harness test.

In order to implement their strategy, KEC's next step was to shop for an EM simulation tool that they could use on their own to model and simulate the harness systems. KEC approached various providers of EM simulation software and decided on Remcom's full-wave 3D EM solver.

Simon Ireland, design and development engineer at KEC, said, "We chose XFdtd because the product is so easy to use. The XF7 interface is intuitive, making it simple to set up complex problems."

Several different applications were tested, based on some key customers' specific projects. One project included both commercial and academic problems. From the academic side, a series of dipole antennas and other textbook type simulations were examined in order to compare the simulation outputs with theoretical solutions. From the practical/commercial side, a series of test harnesses were manufactured and put through EMC testing. Simulations of these test harnesses were then performed to compare the simulation outputs with real world problems (see ***Figure 1***).

Another scenario examined the design of a folded metal backshell as an alternative to castings for low production runs. KEC had to design the metal folds in such a way that would allow the backshell to fit together, and there were several ways in which this could be achieved. By simulating the different options in XF7, a measureable difference was seen, enabling the team to choose the best design option (see ***Figure 2***).

"Remcom impressed us with their software, specifically the ease of use, but also with the support received during the product trial," Ireland said. "Remcom engineers provided very detailed responses to any questions I had, and I usually received a reply within a day of sending my email."

RESULTS AND SUMMARY

A few select customers are currently working with KEC to use their problems as a testing ground for the new service. The team is refining the simulation process for these customers' specific applications and comparing the simulated results with the actual equipment being tested. Response is proving extremely positive, and KEC will soon be offering the service as part of their regular product line.

"There are many benefits to including EM simulation in the typical cable harness design process that reach beyond the added value to our customers," Dyson said. "In the EMC interconnect arena, the usefulness of EM simulation is just being discovered.

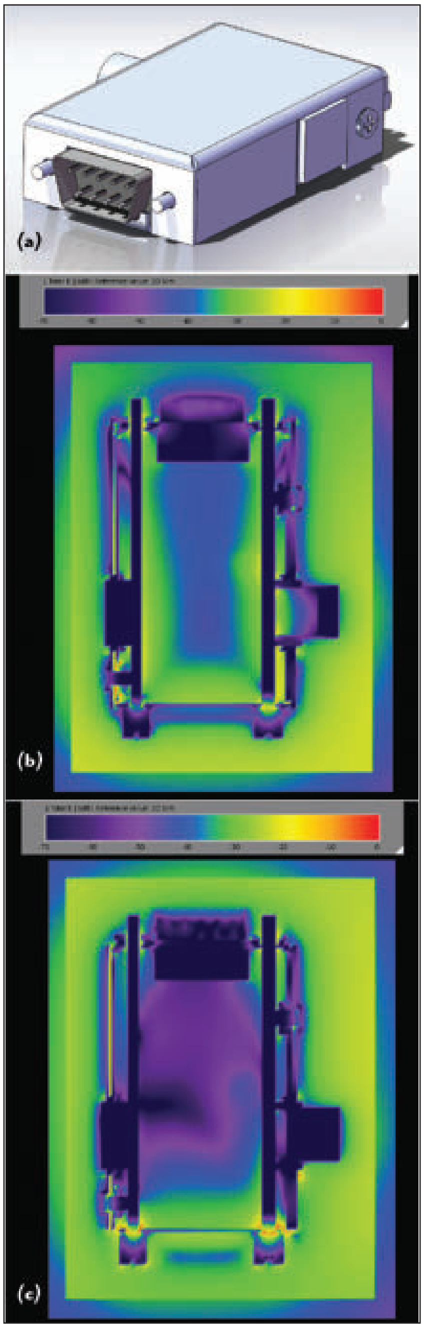

Fig. 2 Design of folded metal backshell (a), analysis of first configuration (b) and analysis of second configuration (c).

It is our hope that by demonstrating the value of in-situ testing before proceeding to EMC trials, we will be at the forefront of wider industry adoption." ■

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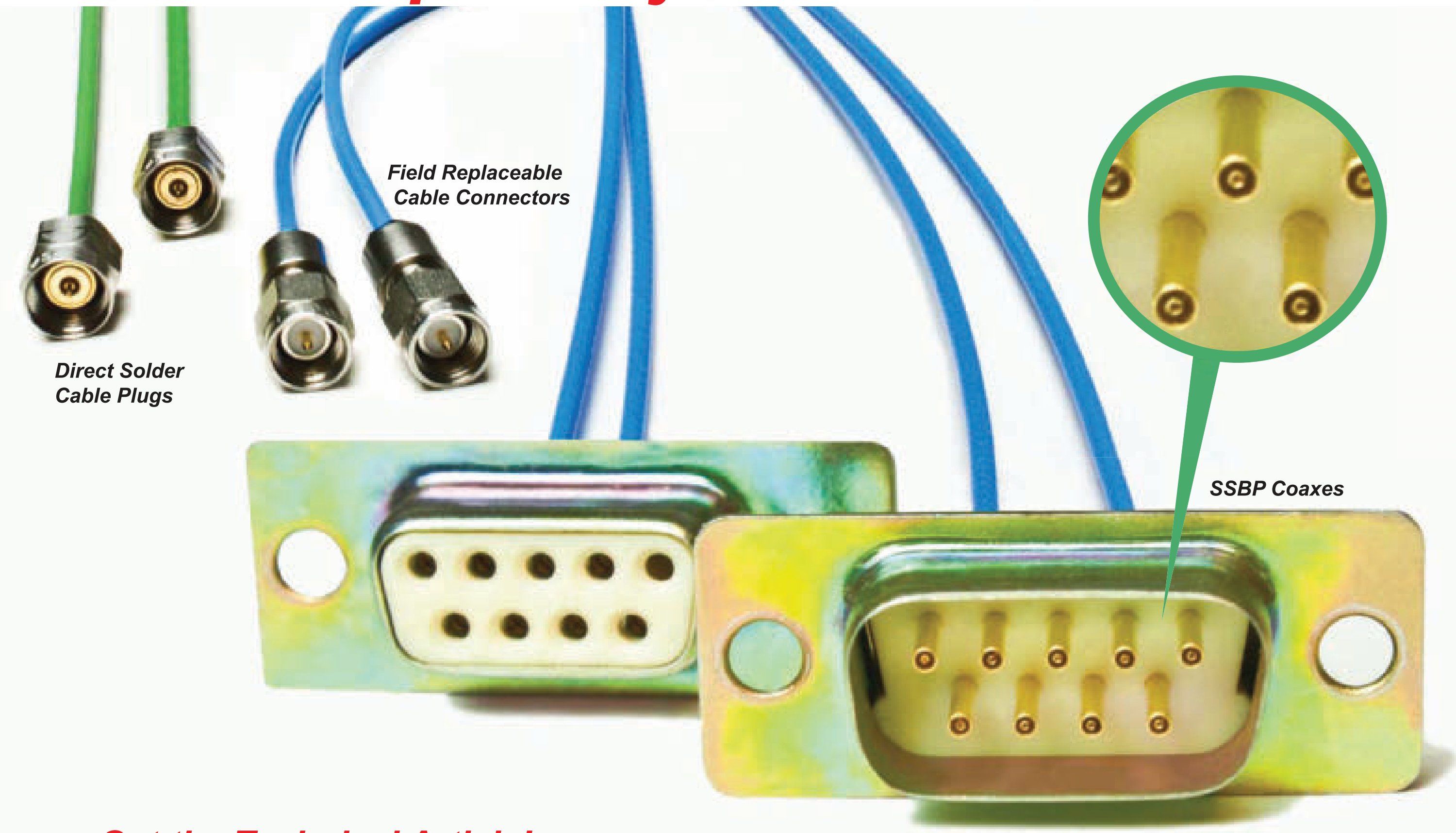

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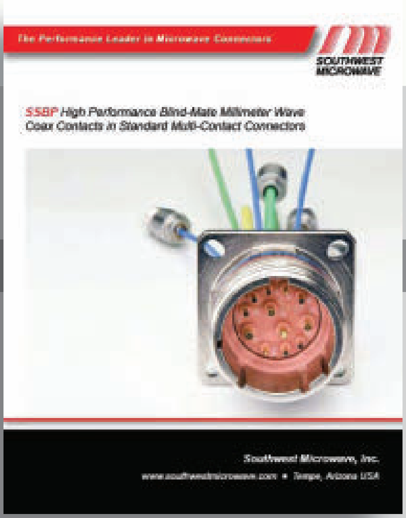
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SOUTHWEST MICROWAVE

What's All This PIM Stuff Anyways?

Wireless network operators upgrading to next generation systems such as LTE must ensure low passive intermodulation (PIM) in order to achieve bandwidth optimization and maximum Quality of Service (QoS). PIM represents third-order mixing products (in-band) generated by two distinct frequencies co-located within a system. These "ghost" signals act as interference for the cellular receiver and consume system capacity as well as causing false phone calls.

PIM can be caused by a number of characteristics, including the effects of corona generation, current saturation and the nonlinear characteristics of certain materials, all of which can be introduced by the cable assemblies used to interconnect the network's modules and components for effective signal flow.

Specific connector design features are meant to lower PIM. For instance, connectors designed for high RF power levels typically employ chamfered transitions to avoid localized ionization. To further minimize PIM, mating conductive surfaces should have smooth surface finishes at all component and connector/cable transitions, with optimum mating force maintained between conductive surfaces. Hard versus soft materials within press fits and the use of strong wiping action between mating center contacts can mechanically break down oxide layers and generate a clean conductive path, also helping to minimize the generation of PIM.

A new white paper from San-tron discusses the causes of PIM and its impact on next generation wireless networks as well as the design features in the company's eSeries connector products designed to mitigate PIM and is available on the Microwave Journal website at www.mwjournal.com/SantronPIM.

VENDORVIEW

San-tron Inc.,
Ipswich, MA,
www.santron.com.

3.5 mm Precision Quick Test Adapter Speeds Connections

Quick Test adapters, also commonly referred to as push-on adapters, quick connect adapters, quick-lock adapters and snap-on adapters, have been used by the microwave industry for years at low frequencies. While adding a level of convenience not found in traditional RF connectors, these adapters suffered from a degraded electrical performance, poor repeatability and reduced life. As such, adapters of this type were often avoided by those seeking a reliable connection.

In response to customer demands for high-frequency, extremely repeatable, long life precision push-on adapters, Maury Microwave invented the precision push-on/pull-off 3.5 mm adapter, the QT3.5mm™. The QT3.5mm is a patented design, based on Maury's metrology and precision adapter technology and is compatible with SMA, 3.5 and 2.92 mm connectors. The QT3.5mm is available in four configurations: no nut, 3/8" diameter nut, 9/16" diameter nut and guide sleeve.

Fig. 1 No nut quick-test adapter.

NO NUT

The no nut quick-test adapter (see ***Figure 1***) enables push-on/pull-off operation and allows for a full 360 degree rotation after connection is made, greatly increasing the flexibility of installations. With a rated life of over 3000 connect/disconnect cycles, the no nut QT3.5mm maintains a S-parameter repeatability of over 40 dB.

3/8" AND 9/16" DIAMETER NUT

The 3/8" and 9/16" diameter nut quick-test adapters (see ***Figure 2***) not only act as quick-test adapters with push-on/pull-off operation, but also have the increased accuracy of a threaded connection. With only a 1.5-turn rotation, the threaded nut will engage and prevent accidental slippage during use. Machined wrench flats allow the use of torque wrenches for metrology and calibration applications. With a rated life of over 3000 connect/disconnect cycles, the 3/8" and 9/16" diameter nut QT3.5mm maintains a S-parameter repeatability of over 50 dB when hand- or wrench-torqued.

GUIDE SLEEVE

The no nut quick-test adapter allows for a full 360 degree rotation after connection is made, greatly increasing the flexibility of installations. The additional guide sleeve (see ***Figure 3***) enables self-alignment making it ideal for automated test stations. With a rated life of over 3000 connect/disconnect cycles, the no nut guide-sleeve QT3.5mm maintains a S-parameter repeatability of over 40 dB.

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Fig. 2 3/8" and 9/16" diameter nut quick-test adapters.

AVAILABLE MODELS

No nut, 3/8" diameter-nut, 9/16" diameter-nut and guide-sleeve models are available to adapt with Type-N connectors to 18 GHz, 7 mm connectors to 18 GHz and 3.5 mm connectors to 26 GHz with excellent insertion loss and VSWR. Ruggedized 3.5 and 2.4 mm NMD options are also available for use on test ports (see ***Table 1***).

Fig. 3 No nut quick-test adapter with guide sleeve.

INDEPENDENT TEST RESULTS

Independent testing was carried out on the 8006Q1 QT3.5mm guide sleeve adapter at 3000 connect/disconnect cycles. While rated with a re-

TABLE I

AVAILABLE MODELS FOR QT3.5MM LINE

Model	Adapts: Side A	Adapts: Side B
8006B1	QT3.5mm™ (m) with no nut	7mm
8006B11	QT3.5mm™ (m) with 3/8" diameter nut	
8006B21	QT3.5mm™ (m) with 9/16" diameter nut	
8006C1	QT3.5mm™ (m) with no nut	NMD3.5mm (f)
8006C11	QT3.5mm™ (m) with 3/8" diameter nut	
8006C21	QT3.5mm™ (m) with 9/16" diameter nut	
8006E1	QT3.5mm™ (m) with no nut	3.5mm (f)
8006E11	QT3.5mm™ (m) with 3/8" diameter nut	
8006E21	QT3.5mm™ (m) with 9/16" diameter nut	
8006F1	QT3.5mm™ (m) with no nut	3.5mm (m)
8006F11	QT3.5mm™ (m) with 3/8" diameter nut	
8006F21	QT3.5mm™ (m) with 9/16" diameter nut	
8006G1	QT3.5mm™ (m) with no nut	Type N (f)
8006G11	QT3.5mm™ (m) with 3/8" diameter nut	
8006G21	QT3.5mm™ (m) with 9/16" diameter nut	
8006H1	QT3.5mm™ (m) with no nut	Type N (m)
8006H11	QT3.5mm™ (m) with 3/8" diameter nut	
8006H21	QT3.5mm™ (m) with 9/16" diameter nut	
8006K1	QT3.5mm™ (m) with no nut	NMD2.4mm (f)
8006K11	QT3.5mm™ (m) with 3/8" diameter nut	
8006K21	QT3.5mm™ (m) with 9/16" diameter nut	
8006Q1	QT3.5mm™ (m) guide sleeve	3.5mm (f)

[1] *Slightly reduced VSWR specs to 34 GHz.*

turn loss repeatability of better than 40 dB without use of a torque nut or wrench, independent testing proved a repeatability better than 56 dB to 10 GHz, 49 dB to 20 GHz and 47 dB to 26.5 GHz after 3000 connect/disconnect cycles. Similar results surpassing rated specifications were achieved for insertion loss magnitude repeatability, with a low variance of 0.03 dB to 10 GHz, 0.04 dB to 20 GHz and 0.06 dB to 26.5 GHz after 3000 connect/disconnect cycles, without use of a torque nut or wrench. As with magnitude, insertion loss phase repeatability surpassed specifications with a low variance of only 0.16 degrees to 10 GHz, 0.31 degrees to 20 GHz and 0.45 degrees to 26.5 GHz after 3000 connect/disconnect cycles, without use of a torque nut or wrench. Maximum life was noted as 10,000 connect/disconnect cycles.

INDUSTRY USE/APPLICATIONS

The convenient push-on/pull-off connector offers excellent repeatability, a long operating lifespan and increased throughput (up to 10× faster than mate-torque-demate) making it ideal for use in high volume test/production environments such as those found in component manufacturers (filters, attenuators, cables, couplers, etc) and those testing device assemblies in high volume (cell phones, radios, medical RF devices, etc). Commercial and military field operations can also benefit from a push-on/pull-off connector where using a torque wrench might not be convenient or even possible.

Maury Microwave,
Ontario, CA
(909) 987-4715,
www.maurymw.com.

Frequency Range (GHz)	Maximum VSWR (GHz)
DC to 18.0	DC to 4.0 ≤ 1.04 4.0 to 18.0 ≤ 1.08
DC to 26.5[1]	DC to 16.0 ≤ 1.08 16.0 to 26.5 ≤ 1.12
DC to 26.5[1]	DC to 16.0 ≤ 1.05 16.0 to 26.5 ≤ 1.08
DC to 26.5[1]	DC to 16.0 ≤ 1.05 16.0 to 26.5 ≤ 1.08
DC to 18.0	DC to 4.0 ≤ 1.05 4.0 to 18.0 ≤ 1.08
DC to 18.0	DC to 14.0 ≤ 1.05 4.0 to 18.0 ≤ 1.08
DC to 26.5[1]	DC to 16.0 ≤ 1.08 16.0 to 26.5 ≤ 1.12
DC to 26.5[1]	DC to 16.0 ≤ 1.05 16.0 to 26.5 ≤ 1.08

Multiport Connectors for Harsh Environments

Durability and high performance of components are key factors that determine the functionality of the overall installation. Often, connectors, cables and harnessing are mounted in hard to reach areas, making replacement or troubleshooting difficult and costly. Also, in rough and harsh environments connectors and cables will be charged to the limit, so any unwanted signal interruption will result in high repair costs. To address these issues HUBER+SUHNER is able to design and produce customized RF cable assemblies.

MULTICONNECTIONS

The series offers the facility to connect and disconnect microwave cables in one single activity rather than mating every single contact individually. Thus, these robust, compact, lightweight multiport connectors not only provide a high performance connection but also save space and time, resulting in reduced costs.

Due to its design and size, the series is particularly suitable for use in confined spaces; ***Figure 1*** shows the connectors used in a communication center of sensors. Installation is also simplified by the fact that intelligent mechanical coding on the MIL-DTL-38999 connectors eliminates any confusion.

HARSH ENVIRONMENTS

The multiconnectors have an aluminum alloy shell and olive green cadmium plating, and can withstand 500 mating/demating operations. Their durability and high performance means that they are particularly suitable for harsh environments. They are moisture proof, waterproof and robust enough to withstand a high level of vibration.

The MIL-DTL-38999 connectors are available with either four or eight coaxial connections and are particularly equipped for heavy and long usage. They are designed for communication terminals and testing systems in dirty, oily and dynamic environments with significant temperature changes. The multiport connectors address a temperature range of -65° to 175°C, with mated connectors meeting the altitude immersion requirements of MIL-C-38999.

HUBER+SUHNER AG
Herisau, Switzerland

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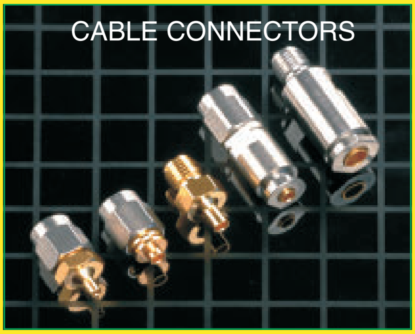

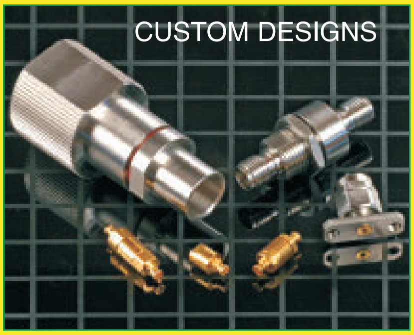

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1.85mm	DC-65 GHz	2.92mm	DC-40 GHz	7mm	DC-18 GHz
2.4mm	DC-50 GHz	3.5mm	DC-34 GHz	SSMA	DC-40 GHz

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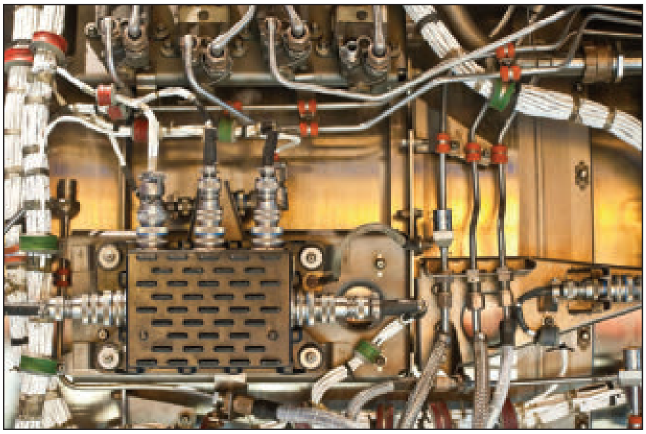

Fig. 1 MULTIPORT MIL-DTL-38999 connectors are suited to confined spaces such as this communication center of sensors.

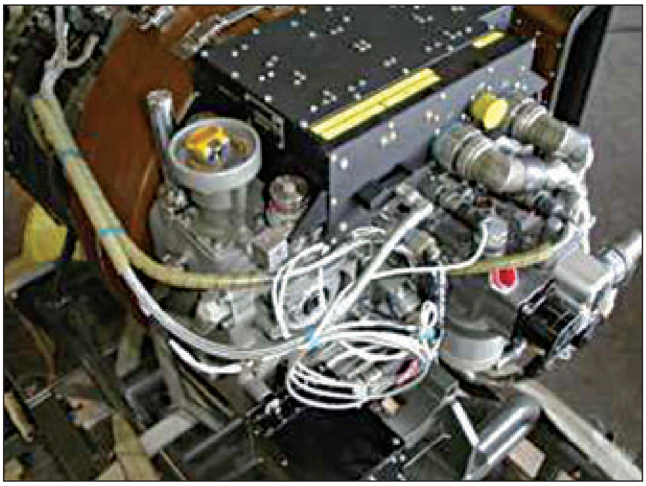

Fig. 2 The multiport connectors can withstand aharsh environments and vibrations enabling them to be used for landing gear.

They can be used for railway, aviation, defence, industrial technologies, onboard communications and radar for the transmission of RF signals for fast analog and digital signals. They are suitable for all types of rail and road vehicles, aircraft (***Figure 2*** shows their use for landing gear), ships, tanks and industrial applications.

The MULTIPORT MIL-DTL-38999 series of connectors offers easy quick and safe connection via one compact, robust multiport connector that can be fitted into confined spaces. The series is particularly suitable for harsh environments and for a wide range of applications.

They are compact, lightweight, robust and resistant to vibration. The connectors can operate over a wide temperature change and exhibit a high resistance to dust, water and high humidity. All of which make the series a cost-effective, time-saving option for installation engineers.

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Astrolab’s patented minibend® cable assemblies provide an excellent commercial-off-the-shelf (COTS) solution for your cable assembly needs. The perfect low profile design solution for making point-to-point interconnections between RF modules. minibend® cable assemblies are readily integrated into virtually any commercial, military, or space application.

minibend® cable assemblies are engineered to meet or exceed applicable industry and military standards. They’re triple shielded, bend-to-the-end and easily outperform competitive semi-rigid or semi-flex cable. All minibend® assemblies are 100% tested and are superior replacements for custom pre-formed semi-rigid cables.

If your company uses RF cables, you need to talk to us. We’ll work with you to supply a minibend® solution that will deliver proven superior performance. Contact our customer service department to experience the minibend® difference.

ASTROLAB® INC.
Tel: 732.560.3800
Email: sales@astrolab.com
www.astrolab.com

New Strain Relief Extends Cable Assembly Life

Teledyne Storm Products–Microwave has developed an improved strain relief that significantly extends the life of cable assemblies used in test applications requiring frequent flexure behind the connector. Hard-To-Hurt™ strain relief technology was developed in response to a common industry problem: early failure in cables with "standard" strain reliefs when repeatedly flexed behind the connector.

Since no industry-standard flexure test exists, Storm developed an accelerated life test to evaluate strain relief designs using a cable flexing device capable of testing up to six cables simultaneously. Connectors are held static while the flexer deflects the cable behind the connectors 30° to the right and 30° to the left. An integrated counter tracks the number of cycles (± 30° per cycle) that the cables have been flexed (see video on the company's website).

During flexing, the cables are connected to a network analyzer and monitored for insertion loss and VSWR. Every 1000 flexures, the movement is stopped, and each cable's performance is measured and recorded to determine when a cable starts to develop instability. Flexing is continued until cables fail to meet insertion loss or VSWR requirements. To establish a baseline, Storm evaluated cable assemblies with standard strain reliefs, and then alternate designs and materials were evaluated until the Hard-To-Hurt design was selected.

Available on two of Storm's most popular test cables, True Blue® 205 and Accu-Test® 200, Hard-To-Hurt technology increases their flex life by nearly four times over standard strain relief.

Teledyne Storm Products, Woodridge, IL, www.teledynestorm.com/microwave.

Quick-Lock Test Cable Mates with SMA Connector

The Mini-Circuits QBL Series Coaxial Cables include a Quick-Lock connector that mates securely with a standard female SMA connector with a simple sliding lock feature. These cables are ideal for use in test lab applications, with superior strain relief for lasting durability and flexibility for tight access locations. The FEP jacket supports operation to 105°C and protects a double shielded cable construction for minimum signal leakage.

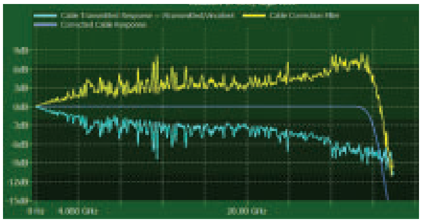
The Quick-Lock system is as simple as push, slide and click to make a repeatable RF connection. The unique design of the QBL Quick-Lock connector mates directly with a standard female SMA connector, with a contact and guide structure that makes a secure connection to 18 GHz.

Supporting 25 dB return loss at 6 GHz and 19 dB up to 18 GHz, the QBL Series is ideally suited for testing a wide range of RF equipment while minimizing measurement degradation due to the effects of VSWR interactions. Capable of withstanding RF power of 270 W at 1 GHz and 47 W at 18 GHz (at sea level). The QBL Series is a great fit for a wide variety of test and installation applications operating from DC to 18 GHz.

Tested without performance degradation to over 20,000 flex cycles (flexed to stress both the cable and strain relief), the QBL Series is ideal for a wide variety of test applications. Typical applications include high volume production test stations, research and development labs, environmental and temperature test chambers, replacement for OEM test port cables, field RF testing and cellular infrastructure site testing.

VENDORVIEW

Mini-Circuits,
Brooklyn, NY (718) 934-4500,
www.minicircuits.com.



Why Engineers Ignore Cable Loss

Companies spend large amounts of money on test and measurement equipment. One of the largest purchases for high speed designers is a real time oscilloscope. As is the case with most instruments, oscilloscope vendors charge a premium for cutting edge bandwidths. Companies are willing to pay this premium to be able to know with certainty that the device they are testing is being represented properly by the oscilloscope. An oscilloscope with too little bandwidth will under report rise times and in many cases, over report jitter. This leads to eroding electrical margins and increasing costs and time to market for a project and design. The benefit of higher margins makes the bandwidth premium a worthwhile investment.

Despite its cost, an oscilloscope is only part of the entire measurement system and precious measurement system bandwidth can be lost through other links in the channel system. One potential bandwidth bottle neck includes the cabling and adapters. Despite this, the characteristics of such adapters tend to be ignored. Compared to the price of an oscilloscope, the cost of a cable is very minor. Yet cables can wreak havoc on any measurement system. Beyond losing the biggest portion of the investment (the bandwidth) because of cable loss, precious margins are now lost as well. Amplifying the problem, companies now use more links in their measurement channels including switches (to measure multiple channels), adaptors and fixtures. Similar frequency responses potentially could be found in each one of these components, all causing erosion of crucial margins and potentially wasting hundreds of thousands of dollars. Yet the underlying theme is that the loss is largely ignored.

Agilent Technologies has published an article covering cable loss and how to adjust for it. It is available on the Microwave Journal website at www.mwjournal.com/AgilentCableLoss.

VENDORVIEW

Agilent Technologies Inc.,
Santa Clara, CA (800) 829-4444
www.agilent.com.

High-Performance Surge Arresters

Frontlynk has developed a family of surge arresters that are designed to protect sensitive electronic facilities such as base stations or outdoor antennas from lightning damage and current surges. As well as solid surge arresters, the family includes a system whereby the surge of electric current enters the arrester and is diverted though a gas-tube to earth, thus protecting valued components throughout the system. The incorporation of a replaceable gas-tube into the design of specific arresters means that only a small component needs to be replaced rather than the complete arrester, offering an economic and green alternative.

The family includes a range of surge arresters, including the N type and also the 7/16 series, which can be used for higher voltage equipment such as base stations. Each surge arrester, irrespective of its design, comprises three in-series adapters: Plug-to-Plug, Plug-to-Jack and Jack-to-Jack. The company also offers the facility to modify the design in accordance with customer needs.

To optimize the performance and reduce the loss the company divides the surge arresters into two, according to the operating frequency: 0 to 3 GHz and 2 to 6 GHz. Both frequency ranges have a 50 Ω impedance, surge capability of 8/20 µs 1 time 20 kA and breakdown voltage (±20 percent) of 90, 230 and 350 V. The 0 to 3 GHz surge arrester has a maximum VSWR of 1.2 and a maximum insertion loss of 0.3 dB, while the 2 to 6 GHz surge arrester has a maximum VSWR of 1.3 and a maximum insertion loss of 0.5 dB.

Signal loss is not an issue and customers can select the specific arrester to suit the requirements of their particular systems. Importantly, the surge arresters are waterproof, meeting the environmental requirements of IP67, which, due to its special design, also applies to the gas-tube replacement version.

Frontlynk Technologies Inc.,
Tainan City, Taiwan
+8866-356-2626,
info@frontlynk.com,
www.frontlynk.com.

Lightweight Space Savings Interconnect

ITT Corp. has developed a rugged, lightweight, "no-profile" interconnect system designed specifically for wearable and portable military equipment used in modern warfare. The Nemesis Series Space Saver connector is a compact, lightweight solution that not only saves weight, but also helps effectively shrink the overall size of portable equipment.

The advanced Nemesis Series Space Saver connector system utilizes canted spring technology to provide blind mating and quick snap-on/rip-away coupling to prevent military personnel from being endangered should a cable snag. Other design considerations include the use of ribbed overmolding for secure grip under difficult conditions.

Extremely rugged and with a high degree of sealing, the Nemesis Series Space Saver connector is designed to withstand harsh conditions in the field and features an anti-reflective RoHS-compliant salt-spray resistant plating that is guaranteed for 500 hours.

The Nemesis Series Space Saver has superior EMI performance to ensure the integrity of high frequency signals, as well as pogo pin contact technology for enhanced contact durability. Its canted spring technology provides full 360-degree EMI protection.

Military personnel often carry in excess of 95 pounds of wearable equipment on long and arduous missions, so reducing this weight burden is now a top priority of defense departments. The "no-profile" connectors utilize ITT's proven Pogo Pin/Pad and breakaway technologies, which are designed to increase the maximum number of mating cycles, while enabling the connectors to be cleaned in the field.

Maximum current rating for the Nemesis Series Space Saver connector is 2 A, and the voltage rating is 50 V with a minimum insulation resistance of 5000 MΩ. The Nemesis Series Space Saver connector features an operating temperature ranging from –40° to +100°C with a life span of more than 2500 cycles. Applications include portable computers, weapons, vision systems, headsets, radios, GPS equipment and headsets.

**ITT Interconnect Solutions,
White Plains, NY,
www.ittcannon.com.**

Cost-Effective SMA Family

TE Connectivity has released its next generation of RF products – the KOAXXA RF interconnects product family. The redesigned SMA family offers RF connectors with customizable designs, faster lead times and compelling pricing. While the traditional RF interconnects are still available and very well suited for their applications, the KOAXXA RF interconnects meet the market's need for cost-effective RF connectivity with reduced sensitivity to future material and labor appreciation.

KOAXXA RF products supplement traditional RF connectors by providing alternative connectors designed for the right performance at a competitive price. The new SMA connectors are redeveloped as an extendable product platform for large-scale manufacturing and assembly automation. This enables mass customization and reduces lead time and sensitivity to rising material and labor costs.

To combat material headwinds, the new KOAXXA connector family design reduces material consumption and waste. Advanced plating puts the precious metals only where needed: selective tin plating in the solder region promotes easy soldering and selective gold in the contact region offers the performance and durability needed to meet industry standards. The product leverages TE's global standardized manufacturing footprint, allowing KOAXXA RF interconnects to meet global demands quickly.

As the first offering of the KOAXXA RF interconnects product family, the SMA product line is offered in the most popular configurations with frequency ranges and durability to help meet the market's needs. These include: PCB straight and right-angle board mounts; cable plugs and jacks with a variety of flexible, semi-rigid and conformable cable types; and panel mount. Additional SMA configurations are planned for subsequent release.

KOAXXA SMA connectors are designed to be fully compatible with IEC-169-15 interface standards and are qualified per the EIA-364 test standard.

**TE Connectivity,
Berwyn, PA,
www.koaxxa.com.**

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March Short Course Webinars

Technical Education Series

Mini-Circuits' Smart Portable Test Equipment
Presented by: Mini-Circuits
Live webcast: 3/13/12, 11:00 AM ET

Using Highly Integrated RF ICs to Optimize Your Infrastructure and PTP Designs
Presented by: Richardson RFPD/Analog Devices
Live webcast: 3/28/12, 11:00 AM ET

Besser Training Series

LTE Overview
Sponsored by: AWR and Anritsu
Live webcast: 3/27/12, 11:00 AM ET

Presented by: CST

Leading Technology Webinar Series

CST STUDIO SUITE 2012:

Update Webinar on MW&RF Simulation
Live webcast: 3/1/12, 2:00 PM ET

Update Webinar on EDA/EMC Simulation
Live webcast: 3/8/12, 2:00 PM ET

Update Webinar on Low Frequency Simulation
Live webcast: 3/22/12, 3:00 PM ET

Presented by: Agilent Technologies

Innovations Series

EDA

RF Power Amplifier Design Series: Part 2: End-to-End Design and Simulation of Handset PA Modules
Live webcast: 3/1/12, 1:00 PM ET

Network Analysis

Basics of RF Amplifier Test with the Vector Network Analyzer
Live webcast: 3/13/12, 1:00 PM ET

Pulsed IV Measurement with PNA-X
Live webcast: 3/27/12, 1:00 PM ET

Wireless Communications Series

IEEE 802.11ad PHY Layer Testing
Live webcast: 3/8/12, 1:00 PM ET

Aerospace/Defense Series

RF Streaming, Analysis and Playback in Aerospace & Defense Applications
Live webcast: 3/15/12, 1:00 PM ET

LTE Series

It's Time for TD-LTE
Live webcast: 3/22/12, 1:00 PM ET

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Technical Education Series

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- An Intro to Over-the-Air Device Performance Testing

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Cables & Connectors Supplement

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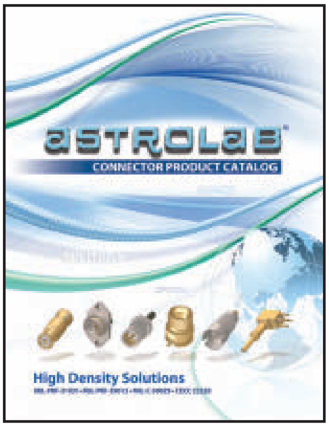


Product Catalog

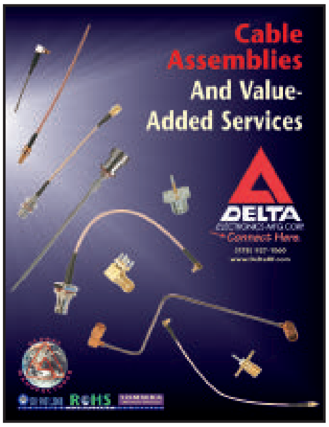
This catalog features the company's SMPM-T, the smallest threaded open source connector on the market offering unprecedented electrical and mechanical performance advantages. The catalog also showcases Astrolab's wide selection of SMP, BMZ, BMA, MCX and SMPM blind-mate connectors and coaxial contact product lines.

Astrolab Inc.,
Warren, NJ (732) 560-3800, www.astrolab.com.

Phase Adjusters

Check out Carlisle Interconnect Technologies latest sales sheet on its line of highly phase stable, low VSWR, precision phase shifters designed for high performance military communications (phased array antennas) and commercial applications. A precision mechanical movement provides continuously varying phase shifts, while maintaining a 50 Ohm impedance over the entire frequency range.

Carlisle Interconnect Technologies,
Cerritos, CA (866) 282-4708, www.carlisleit.com.



Product Brochure

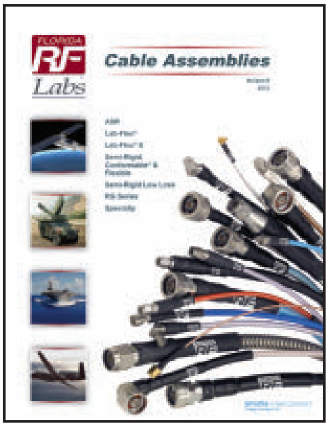
To assist customers who have a need to streamline their supply chain and logistics, Delta Electronics Manufacturing now offers a broad range of coaxial cable assemblies and other connector-related, value-added component subassemblies. Delta's cable assemblies, incorporating flexible, semi-rigid and hand-formable cables, range in size from micro-miniature to large, high-power types. They cover the spectrum of market needs from high volume, low cost assemblies to high performance, low volume categories.

Delta Electronics Manufacturing Corp.,
Beverly, MA (978) 927-1060, www.deltarf.com.

Product Catalog

Emerson Connectivity Solutions announces the latest version of the Trompeter catalog featuring products that align with military, aerospace, broadcast and telecommunications markets. Trompeter also offers a complete solution for any interconnect requirement, from standard to custom. Trompeter provides products that continually deliver the highest quality signal integrity for the most demanding applications.

Emerson Connectivity Solutions,
Bannockburn, IL (847) 739-0300,
www.emersonconnectivity.com.

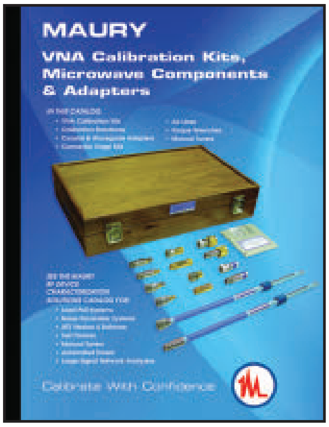


Product Catalog

VENDORVIEW

Florida RF Labs is a leader in the design and manufacture of high reliability microwave coaxial cable assemblies. This new catalog highlights the company's growing line of Lab-Flex® products and introduces its new line of Lab-Flex® S and ASR precision test port assemblies. The company also offers a full line of semi-rigid, semi-flexible and cost-effective flexible solutions.

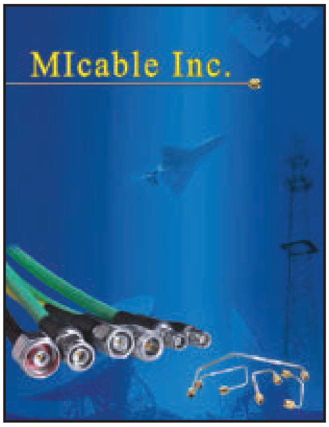
Florida RF Labs,
Stuart, FL (772) 286-9300, www.emc-rflabs.com.



Product Catalog

This 204-page catalog covers the entire Maury Metrology-Grade Precision Calibration Standards product line, including coaxial and waveguide VNA calibration kits, opens, shorts, loads, coaxial adapters, waveguide-to-coaxial adapters, coaxial connectors and cables, connector gage kits, torque wrenches and manual tuners. It is available in the original 2006 printed edition, and as a revised and updated 2010 PDF edition that can be downloaded from the Maury website at: www.maurymw.com.

Maury Microwave Corp.,
Ontario, CA (909) 987-4715, www.maurymw.com.



Product Catalog

MIcable Inc. is a designer and manufacturer of high-performance microwave coaxial cable assemblies for a variety of applications, including DC to 40 GHz test flexible cable assemblies, conformable cable assemblies and semi-rigid cable assemblies. In addition, the company designs and produces various precise coaxial stainless and copper connectors. Custom designed assemblies are also available. MIcable is your quality fast and low cost solution. Please e-mail sales@micable.cn.

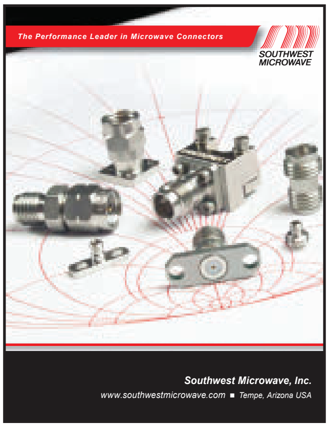
MIcable Inc.,
Fuzhou, Fujian, China +86-591-87382855, www.micable.cn.

IF/RF Microwave Signal Processing Components Guide

VENDORVIEW

Mini-Circuits' new 164-page catalog includes over 750 new products and is the industry's most comprehensive listing of RF/IF and microwave components and subsystems with more than 4100 products and over 25 product lines, including state-of-the-art amplifiers, mixers, VCOs, synthesizers, filters, test accessories and USB Power Sensors. Mini-Circuits' website provides additional data, application notes, design tools and its powerful YONI search engine, which searches actual test data on over thousands of units.

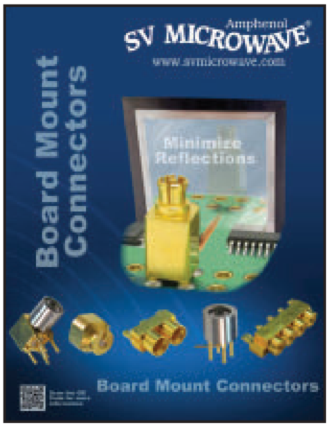
Mini-Circuits,
Brooklyn, NY (718) 934-4500, www.minicircuits.com.



Technical Paper

Southwest Microwave's technical paper "Optimizing Test Boards for 50 GHz End Launch Connectors" provides insights and guidelines to help assure the best transition using Southwest's end launch coaxial connectors to grounded coplanar waveguide and microstrip PCB lines. Via placement, line spacing and taper are discussed and concludes with a loss comparison between GCPW and microstrip. Southwest Microwave is a performance leader in microwave and millimeter coaxial interconnects by providing low VSWR, insertion loss and RF leakage.

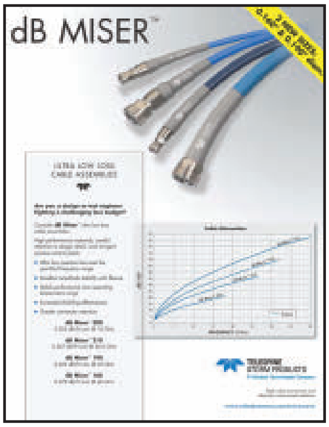
Southwest Microwave Inc.,
Tempe, AZ (480) 783-0201, www.southwestmicrowave.com.



Board Mount Connectors

SV Microwave introduces its next generation of push-on interconnects including single-port and multiport SMP, SMPM and SMPS edge launch, board mount and thru-hole connectors. They are ideal for high density applications. Additionally, the company offers custom PCB footprint design services, enabling the optimization of connector to PCB transitions through software simulation.

SV Microwave,
West Palm Beach, FL (561) 840-1800, www.svmicrowave.com.



Product Brochure

This expanded brochure introduces two new cables in the dB Miser™ line of ultra low loss assemblies: A 0.160" diam. cable (0.678 dB/ft nom. @ 40 GHz) and a 0.190" diam. cable (0.496 dB/ft nom @ 32 GHz), as well as new connector offerings. The clear choice for engineers facing challenging system gain or signal-to-noise requirements, dB Miser™ cables also exhibit excellent amplitude stability with flexure, stable performance over temperature, and exceptional connector retention.

Teledyne Storm,
Woodridge, IL (630) 754-3300, www.teledynestorm.com.

RF and Microwave Interconnects

TRU Corp. has created a short form capability catalog that outlines a wide variety of RF and microwave interconnect solutions. The catalog utilizes easy to use matrices to specify TRU brand cable and connector interface options for general purpose, commercial wireless and high performance test cable assemblies. A complete outline of RF receptacle design options as well as a full range of precision test and quick change adapters are included. This capability catalog discusses additional application driven design capabilities available from TRU Corp.

TRU Corp.,
Peabody, MA (978) 532-0775, www.trucorporation.com.

Cables & Connectors Supplement

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