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September 2011

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Microwave Journal (USPS 396-250) (ISSN 0192-6225) is published monthly by Horizon House Publications Inc., 685 Canton St., Norwood, MA 02062. Periodicals postage paid at Norwood, MA 02062 and additional mailing offices.

POSTMASTER: Send address corrections to *Microwave Journal*, PO Box 3256, Northbrook, IL 60065-3256 or e-mail mwj@omeda.com. Subscription information: (847) 291-5216. This journal is issued without charge upon written request to qualified persons working in that part of the electronics industry, including governmental and university installation, that deal with VHF through light frequencies. Other subscriptions are: domestic, $120.00 per year, two-year subscriptions, $185.00; foreign, $200.00 per year, two-year subscriptions, $370.00; back issues (if available) and single copies, $10.00 domestic and $20.00 foreign. Claims for missing issues must be filed within 90 days of date of issue for complimentary replacement.

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16 Sussex Street, London SW1V 4RW, England
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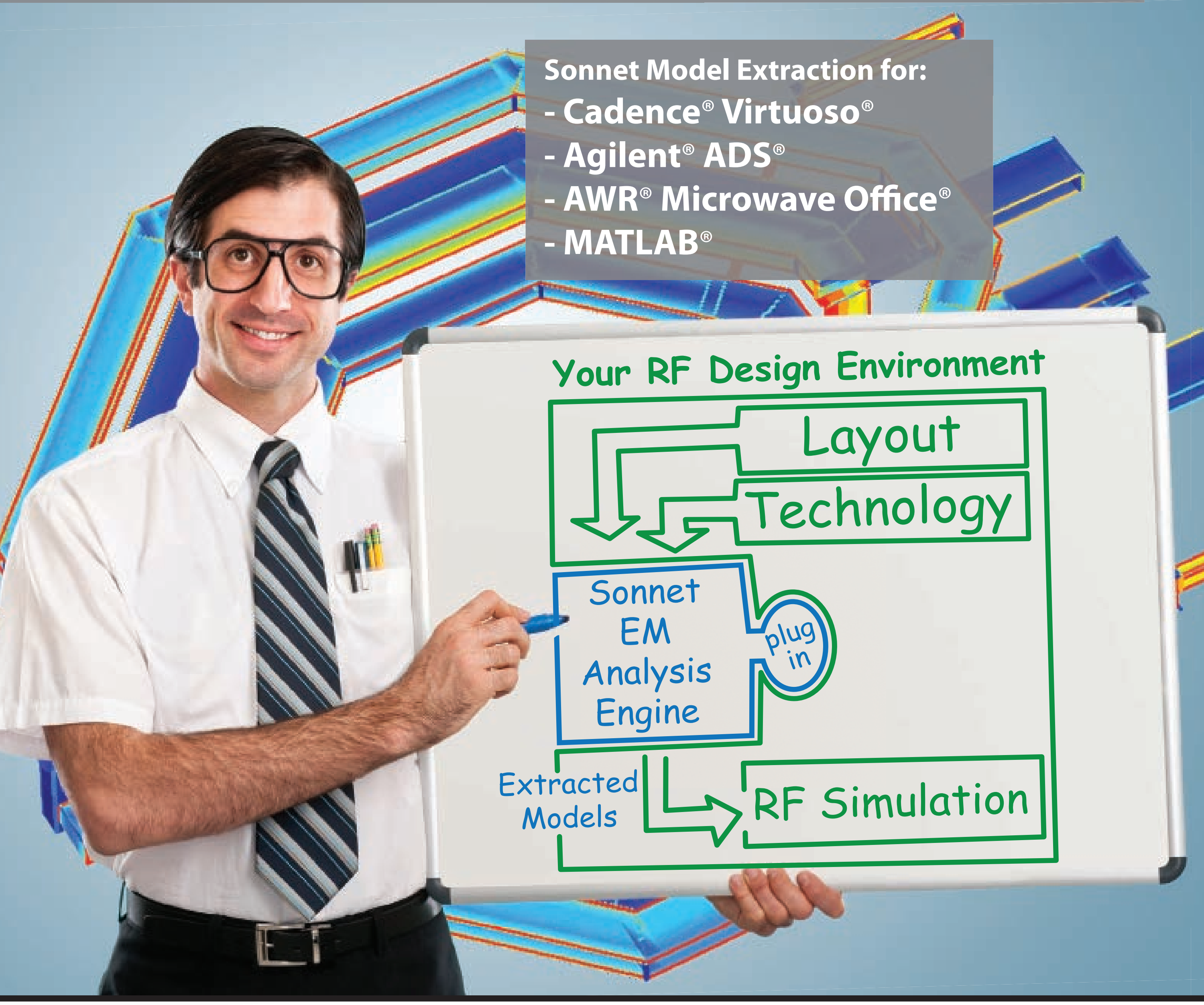

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TRENDS IN DEFENCE ELECTRONICS: TECHNOLOGICAL CONVERGENCE IN RADAR AND EW

Barry Trimmer will debate the issues raised in this article during his presentation at the EuMW Defence and Security Forum in Manchester on 12 October. To find out more and to register for the Forum visit: www.mwjournal.com/2011defenceforum

The history of military electronic Intelligence, Surveillance, Target Acquisition and Reconnaissance (ISTAR) since World War II has resulted in large single function systems with increasing performance levels achieved at longer and longer ranges (primarily to protect these expensive assets from evolving threats).[1] In almost all countries, successive budget reductions have increased the focus on cost-effective provision of ISTAR where traditional boundaries of militarily specific functions and command chains are called into question. The UK for example has recently imposed some of the most severe reductions consequent on its Strategic Defence and Security Review.

In addition, for airborne ISTAR, the advent of the unmanned aerial vehicle (UAV) has reversed the need for long-range sensor performance to give sensor platform protection.[2] These stand-in (partly) expendable systems, together with better, more reliable data links, open new possibilities for cost-effective ISTAR provision. This article will highlight some of the technological implications of these changes and the implications for microwave system requirements.

DRIVERS FOR CHANGE

For the ISTAR world, there are two change drivers. One is operational and budgetary "pull." The other is technological, opportunistic "push." So the question becomes – how can I address the changes in "pull" by taking advantage of the opportunities of technological "push?" The major change that will drive the use of new technology is budgetary. To understand the effects this will have, consider the principal sources of cost in the armed services. A whole life cost

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Thales Defence Mission Systems Business
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analysis of large programmes, such as the Watchkeeper Unmanned Air System, reveals that the major costs for the armed forces are in personnel and the associated Defence Lines of Development (DLOD).

Many of these DLODs can be assisted by technology. For instance, the training line can be made significantly more cost effective using forms of virtual reality – particularly where the training is for a semi-virtual operational role (e.g. UAV operator). However, some are fundamentally not amenable to this form of efficiency saving, because they are related to staffing or to equipment types required to satisfy the military need.

The tangible result of this budgetary pressure is a reduction in staffing (examples already being announced in the UK). Generally then, there will be less people in the services to make military functions work. Also, the threats against which national services must be prepared are also changing. The effect is often additive, so that the threat of, for instance, terrorism is added to the conventional threats between countries. It is not clear that this total is very much less onerous than the preceding set.

As a result of the pressures applied to the military budget while maintaining the required capability, a change in approach is demanded. The new environment requires technology to specifically answer the question: how can military capability be maintained with both less people in the services and with less money available for equipment purchase?

TECHNOLOGICAL OPPORTUNITIES

A principal result of change in technology over the development of electronic ISTAR has been the convergence of functions leading to lower staffing. For instance, while the earliest radar systems used people to tackle individual functions (such as, height finding and bearing of a target), rapid evolution of technology allowed the automatic combination of these functions. Generally then, the use of technology to achieve function combination is a normal evolution, particularly where no human decision-making is replaced by automation. What I see today is a continuation of this theme, but now the technological convergences will also provide an opportunity for sharing technology across military functions – sometimes between dissimilar platforms in different command chains.

There are two obvious convergences happening in military RF sensing at the moment, between RADAR and Electronic Intelligence (ELINT), and between ELINT and Communications Intelligence (COMINT). I will examine later how these can be used to provide one possible answer.

A second enabling issue is the advent of reliable communications, at least at the higher levels of command. This is also a continuing technological trend where access to a communications layer that connects peer military users makes possible the sharing of functions across formerly separate command chains without requiring significant changes in doctrine. It is reasonable to suppose that this trend will continue to provide normal IT-like connectivity (IP-based communications) right down to the tactical level.

As a result, this is a good time to move away from worrying about the provision of a communications layer, to thinking about what the military user would like to do to share military functions given universal addressing, a reliable carrier and an agreed language. This technology is likely to support the provision of co-operation advantages at higher bandwidths while maintaining the security of military communications in a physically distributed, mobile and at least partially wireless environment. This trend provides an alternative approach to reducing the cost of providing military functions. The two approaches are not necessarily in opposition, but are qualitatively different.

USING NEW TECHNOLOGY

Technology advances in many diverse areas and with many different methodologies. The key to successfully designing a complex multi-technology system is to understand where the "tipping" point occurs. As an example, the recent proliferation of UAV systems has been enabled by the maturity of automatic flight and mission control, reliable data link technology and persistence of air vehicles. The change wrought by these advances transforms the UAV from an asset of occasional use to one that is constantly in demand by the user. I believe that similar "tipping" points exist in the broader ISTAR world that will allow the user to easily take advantage of multiple technology applications to fulfill their military function.

COMMON CAPABILITY ACROSS MILITARY FUNCTIONS

I have already referred to the sharing of technology across command chains. It is reasonable to suppose that a doctrine can be evolved that reduces the number of people involved in providing that shared service. For instance, the UK MoD has decided to remove the Nimrod MRA4 from the inventory and is intending to take the ASTOR ground surveillance system out of service in 2015. These represent two unique capabilities to maintain maritime patrol and to provide long-range ground surveillance. It is a good thought experiment to consider how such capability could be created by one system using shared technology or by a combination of systems sharing functions across multiple platforms using the evolved communications backbone.

LOWER-COST PLATFORMS

Another thought experiment might be to consider how to use a large number of lower-cost platforms to substitute for a single large platform capability? Clearly, the history of electronic ISTAR has been to continue centralisation of functions in larger platforms that have become so valuable that they cannot be risked. This means that the platform has to be further away from the threat. Typically this has led to, for instance, large surveillance radar systems standing off some distance from the threat and having to manage the increase in power required to combat the well-known 1/R4 performance relationship.

Suppose I introduce stand-in platforms, such as UAVs that I am prepared to lose in combat, then the physics of the situation radically changes – potentially not needing the

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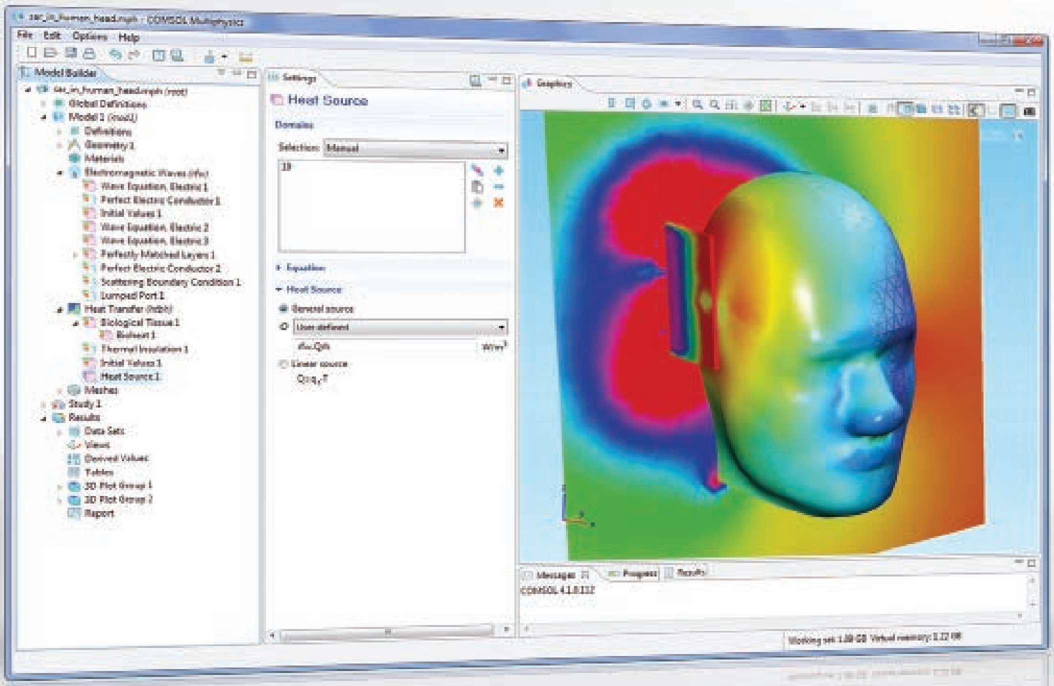

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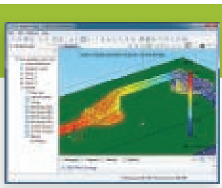

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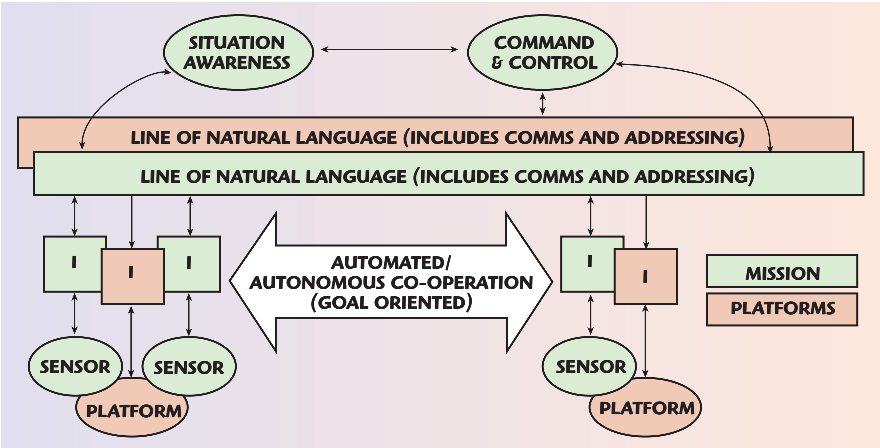
expensive, high power technologies. The combination of UAV technology, reliable data links and developing mission autonomy allows this form of system to be seriously considered (illustrated in ***Figure 1***[3]).

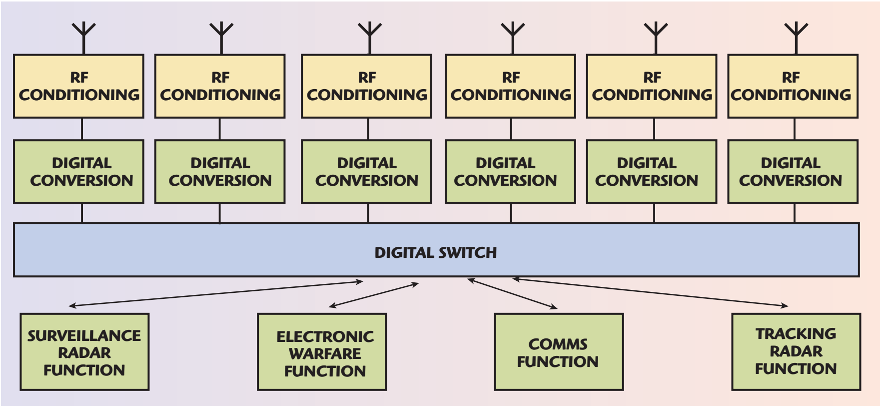
Two questions arise:

- The question for the technologists is what this distributed system needs in component terms and what are the total cost implications?
- The question for the user is what geographical coverage shape is really required by ISTAR operations now that coverage can move from the conventional circular shape to an arbitrary shape defined on the disposition of multiple smaller platforms? This would be a key to the cost comparison between approaches.

An interesting alternative example exists in Electronic Warfare where a function, such as Direction Finding (DF), is difficult to engineer in mobile platforms. In fact, the ideal function is geo-location, which is often approached by DF over a manoeuvre that, in turn, can be difficult to achieve. Multiple platforms offer alternative measurement techniques to achieve geo-location, such as Time Difference of Arrival (TDOA), that may be simpler to engineer on each platform.



▲ *Fig. 1 Automated/autonomous co-operation between platforms is enabled by a common communications layer, addressing and language.*



▲ *Fig. 2 The simplest possible architecture allows multiple functions to be simultaneously available.*

TECHNOLOGY BLOCKS

I referred to the technical convergences in the RF and microwave domain. I can see the evolution of the RF components to serve a very simple architecture where conversion to or from a digital representation happens very close to the front-end of a system (see ***Figure 2***[4]). There are already early examples of this type of architecture. The progress of conversion technology will simply move us further toward this architecture.

There are two reasons driving the adoption of the simple architecture:

- The overall cost of (nearly) commodity items substituting for bespoke design.
- The level of flexibility in the digital domain allowing complex signal processing to compensate for front-end behaviour.

The second reason is worth exploring to illustrate the change in system design and flexibility. Suppose I have an analogue receiver chain that leads to a detection process. If this chain is complex then I have to maintain a high degree of linearity to ensure that the relatively simple detection thresholding sees only the signal of interest and none of the potential artifacts generated by the receiver chain.

The alternative sees conversion to the digital domain happening early in the chain, with artefacts generated in the initial RF conditioning and in the conversion process. Subsequent processes, such as down conversion and filtering, are arbitrarily high quality at relatively low cost.

The key, however, is that the detection process can now be quite complex. For instance, the generation of unintended products is a known pattern that can be allowed for, corrected or filtered. This simple idea is fairly well established in non-coherent EW systems, but the latest coherent system designs point toward allowing this approach to be taken in both radar and EW. Effectively, this makes usable systems out of designs that would have looked impractical in earlier implementations.[5]

ANTENNAS

Antennas are the most closely coupled components to the real world and, therefore, are likely to be most affected by the commonality we choose to impose between functions. For instance, if I choose to combine a wideband EW function with a lower bandwidth radar function, then I impose a number of difficult simultaneous requirements that need satisfying. Typically, the radar function requires a fully filled array with spacing that approaches half a wavelength. By contrast, the EW function may not need the same spacing because it does not have to use angle as a fundamental resolution element. The EW function will, by contrast, require consistent behaviour over two or more octaves.

One technical convergence in antennas has to do with the increasing use of phase/amplitude interferometry arrays in EW. These do not need to have quite the same perfect amplitude responses required from conventional amplitude comparison DF, but rather have a combined aperture response which, in essence, is similar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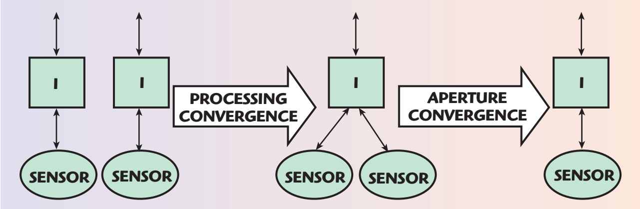
to the way a radar system would like antenna elements to behave.

Finally, there is an overarching question for antenna aperture design in a system context. Is the true technical trend defined by creating a single aperture, which is capable of all the required functions, or is it defined by information sharing between dedicated apertures, either on the same platform or between platforms?



▲ *Fig. 3 Alternative convergence routes depend on a cost, complexity and flexibility balance.*

This is an intensely platform and operational-use dependent question.

- If I think about a combat aircraft then the pressure on space for apertures is so great that a single aperture carrying out several functions is very attractive.
- By contrast for a surveillance asset, achieving a single aperture is probably not as important as maintaining the flexibility to change functions from mission to mission. For this case, the balance between cost, complexity and flexibility is much less clear (see ***Figure 3***). The jury is out on this question.

RF CONDITIONING

I am using the term "RF conditioning" to refer to the RF feed into a digital conversion process. I am also assuming that the requirement trends already discussed are likely to include the need for wideband high probability of intercept (POI) EW reception. This is a particularly acute example of the influence of RF components if I consider the convergence between radar-band EW and (relatively) narrowband radar functions.

The most obvious effect of the trend is the inability to filter out signals in the wide operating band, giving rise to a high dynamic range requirement. In particular, this leads to a need for high levels of device protection, inherently high dynamic range components and predictable behaviour as the RF conditioning is saturated.

Because we cannot provide RF filtering if we wish to maintain high POI, the likelihood of saturation is extremely high. This is particularly true for operation of these converged systems in the presence of very high power emitters, such as those found in naval task groups or in close proximity to civilian communication towers.

The first active component behind the antenna will receive all of this power and must not only survive, but continue to operate in a predictable way so that the presence of other signals (such as the radar return) can be established. This will require either very high speed limiting with the characteristics of "soft" limiting, or naturally higher dynamic range technologies, such as GaN.

The comment about predictable behaviour refers back to the discussion on detection processes. The evolution

of systems that utilise complex detection processes and assume knowledge of the distortions of the front-end can become vulnerable to errors in that knowledge, or, for array processing, errors in how that behaviour changes over the array. Repeatable and predictable behaviour as these components enter saturation becomes very important to achieving small signal detection in the crowded modern electromagnetic environment.

CONTINUING THE EVOLUTION

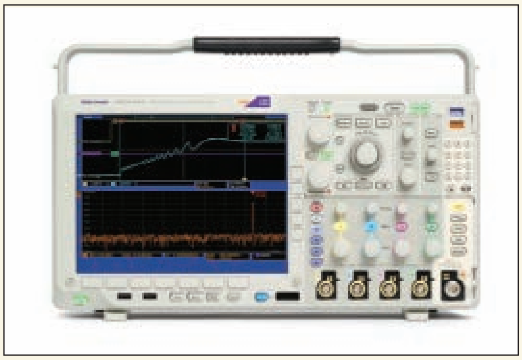
To conclude, I find it interesting to think about the two contrasting trends I have discussed in this article. On the one hand, we have convergence of functions enabled by the increasing ability to digitise close to the front-end of systems, and the evolution of the system architectures of EW and radar functions toward a single implementation.

On the other hand, we have the evolution of co-operation technologies that will allow dissimilar sensors to combine their activities to form a single, but distributed sensor net. This particular trend is likely to be fed by the commercial sector where co-operation technology is a fast-paced development domain. Which of these two trends will dominate or how they will combine in military ISTAR is an unknown, but fascinating topic. ■

Addendum

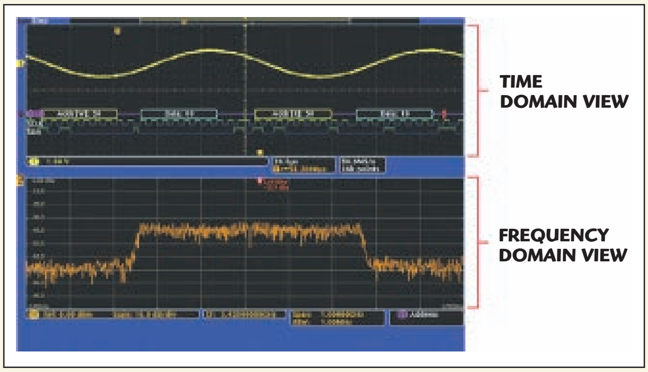
1. A typical example is the very long-range AEW provision using powerful radar to survey an airspace volume sufficiently large to exclude threats to the radar platform itself.
2. There are requirements for large area surveillance that may still need long-range detection, but the self-protection requirement is reduced.
3. The common "natural" language here is the enabler for co-operation, but each sensor/platform must be able to communicate in this natural language – the "I" function. This is becoming a normal, almost emergent capability, thanks to efforts on standardisation.
4. This simple architecture is the aim point. The degree to which current systems attain this level of simplicity is dictated by their critical requirements. For instance, the very high levels of dynamic range characteristic of the COMINT function will limit the current implementations of ELINT/COMINT convergence.
5. Taking care not to overload such techniques with too many undesired signals. Like all techniques there is always a limit of applicability.

Barry Trimmer *graduated in 1978 from Warwick University, UK, in physics, and in 1979, from Sussex University, UK, with a master's degree in astronomy. He joined the radiation laboratory at EMI Electronics, Hayes, UK, working on radar antennas for the Searchwater radar and naval ESM systems. During the 1980s, he developed RF and system modelling within EMI, leading to system design of ground surveillance, weapon locating and man portable radar systems. In the early 1990s, he participated in the development of combat radar systems and designs for multi-sensor military configurations of civil air platforms. Since 1992, he has led the design of airborne radar, EW, multi-sensor systems and air defence systems. More recently, he has been the Principal Designer for the Thales WATCHKEEPER UAV system. He has been awarded the Royal Academy of Engineering silver medal in recognition of his contribution to radar, ISTAR and UAV systems. He is presently Technical Director for the Defence Mission Systems Business of Thales UK, with particular responsibilities for Radar, Electronic Warfare and Unmanned Air Systems.*



TEKTRONIX DELIVERS TRANSFORMATIONAL NEW OSCILLOSCOPE CATEGORY

The Tektronix MDO4000 Series is the first and currently the only oscilloscope on the market with a built-in spectrum analyzer. It gives users the ability to capture time-correlated analog, digital and RF signals for a complete system view of their devices. It combines both the time and frequency domains in a single screen so engineers can view the RF spectrum at any point in time to find sources of noise, or to see how the spectrum changes over time or with device state. This capability represents a powerful new way to solve complicated design issues quickly and efficiently.



▲ *Fig. 1 The upper half of the MDO4000 Series display shows the Time Domain view of the analog and digital channels; the lower half shows the Frequency Domain view of the RF channel.*

Based on the Tektronix MSO4000B Mixed Signal Oscilloscope Series, the MDO4000 Series allows engineers to use their oscilloscope to look at the frequency domain rather than having to find and re-learn a spectrum analyzer. When both the RF channel and any analog or digital channels are on, the oscilloscope display is split into two views. The upper half of the display is a traditional oscilloscope view of the time domain. The lower half of the display is a frequency domain view of the RF input. Models are available with four analog channels with 500 MHz or 1 GHz bandwidth, 16 digital channels and one RF channel with either 50 kHz to 3 GHz or 50 kHz to 6 GHz frequency range and ≥ 1 GHz capture bandwidth.

As shown in ***Figure 1***, the spectrum displayed in the frequency domain view is taken from the period of time indicated by the short orange bar in the time domain view – known as the spectrum time. With the MDO4000 Series, spectrum time can be moved through the acquisition to investigate how the RF spectrum changes over time, correlated to the events monitored on the digital and analog channels in the time domain view. This can be done while the oscilloscope is live and running or on a stopped acquisition.

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FEATURES

- Broadband 50MHz to 4000MHz frequency range
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- Power supply (Icc < 1mA):
  - 5V for SA2013/SA3013
  - 3.3V for SA2023/SA3023
- SA2013/SA2023 Applications include: Cellular, 3G Infrastructure; WiBro, WiMax, LTE, Microwave Radio, High Linearity Power Control
- SA3013/SA3023 Applications include: Cable Modem, CATV, High Linearity Power Control

SPECIFICATIONS

Freq Range (MHz)	*Minimum Insertion Loss (dB)*	*Attenuation Range (dB)*	*IP1dB (dBm)*	*IIP3 (dBm)*	*Supply Voltage (V)*	*Package (mm)*	*Part Number*
50 to 4000	2.6	33	30	50	5.0	3 x 3 QFN	RFSA2013
50 to 4000	2.6	33	30	50	3.3	3 x 3 QFN	RFSA2023

SPECIFICATIONS

Freq Range (MHz)	*Minimum Insertion Loss (dB)*	*IP1dB (dBm)*	*CTB* (dBc)*	*CSO* (dBc)*	*XMOD* (dBc)*	*Attenuation Range (dB)*	*V_{DD} (V)*	*Package (mm)*	*Part Number*
50 to 3000	2.6	30	-78	-81	-79	33	5.0	3 x 3 QFN	RFSA3013
50 to 3000	2.6	30	-78	-81	-79	33	3.3	3 x 3 QFN	RFSA3023

*Note: 55.25MHz to 745.25MHz, 112 Channel, +39dBmV Input Flat Tilt

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FREQUENCY ALONE IS NO LONGER ENOUGH

It is estimated that more than 38 percent of embedded systems designs now have a wireless interface. In 2011 alone, more than one billion wireless networking enabled products will ship to consumers. This means engineers are now troubleshooting embedded system designs with integrated wireless modules, requiring them to work in both the time and frequency domains.

With oscilloscope and spectrum analyzer functionality integrated into a single instrument, design engineers can now test multiple points of their design at one time, looking at their serial and parallel buses, digital and analog signals, and RF signals in a single glance to quickly and efficiently troubleshoot system problems. Prior to the MDO4000, engineers who needed this insight had to attempt to capture RF on their spectrum analyzer and analog/digital signals on their oscilloscope. Those acquisitions are not time-correlated and it can take days of trial and error to capture exactly what is needed.

▲ *Fig. 2 The Spectrum Time display shows the frequency at 2.2202 GHz when the command arrives on the SPI bus, which tells the VCO/PLL the desired frequency.*

▲ *Fig. 3 Spectrum Time is moved 250 µs to the right, showing the final frequency that the VCO/PLL has settled on.*

CORRELATING ACROSS DOMAINS

The unique architecture of the MDO4000 Series provides a triggered acquisition system that is fully integrated with the RF, analog and digital channels. A single trigger event coordinates acquisition across all channels, allowing the user to capture a spectrum at the precise point in time where an interesting time domain event is occurring. A comprehensive set of time domain triggers are available, including edge, sequence, pulse width, timeout, runt, logic, setup/hold violation, rise/fall time, video and a variety of parallel and serial bus packet triggers. The RF power level of the RF input can even be used as a trigger source.

Because the MDO4000 Series captures a long time period of the RF signal, it can precisely calculate the RF spectrum at a specific point in time in the acquisition. This allows engineers to move spectrum time through their acquisition and see how the RF spectrum is changing in relation to their other signals.

A simple everyday application – tuning of a VCO/PLL – illustrates the value of connecting the time domain and frequency domain. ***Figure 2*** shows what can happen during the turn-on of a VCO/PLL. In this case, Channel 1 in yellow is probing a control signal that enables the VCO. Channel 2 in blue is probing the PLL voltage. The SPI bus, which is programming the VCO/PLL with the desired frequency, is probed

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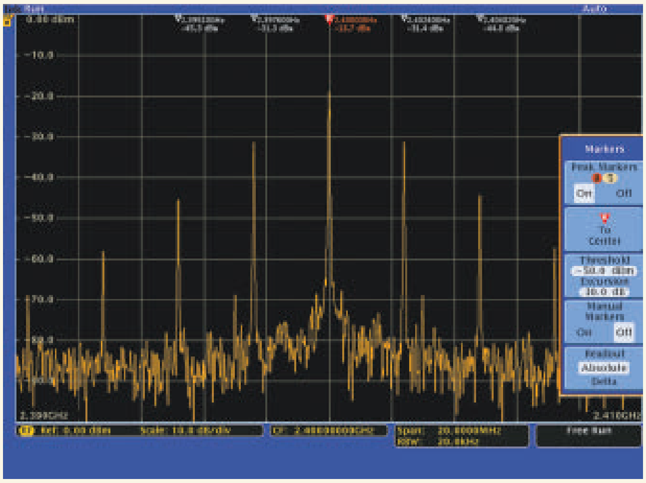
with three digital channels and automatically decoded. Initially, spectrum time was placed after the VCO was enabled and coincident with the command on the SPI bus telling the VCO/PLL the desired frequency. In ***Figure 3***, spectrum time is moved about 250 µs to the right. At this point, the VCO/PLL has settled to its desired frequency of 2.3987 GHz.



▲ *Fig. 4 Automated peak markers identify critical information.*

KEY MDO4000 FEATURES

The MDO4000 has a minimum RF capture bandwidth of 1 GHz. A FFT is performed on the acquired RF signal that can be converted to baseband I and Q vector data. This enables the MDO4000 Series to display three RF versus time traces on the time domain graticule derived from the data:

- Amplitude – The instantaneous amplitude of the RF input versus time
- Frequency – The instantaneous frequency of the RF input, relative to the center frequency versus time
- Phase – The instantaneous phase of the RF input, relative to the center frequency versus time
- Each of these traces may be turned on and off independently, and all three may be displayed simultaneously. RF time domain traces make it possible to understand what is happening with a time-varying RF signal and to easily measure system and RF latencies.

In a traditional spectrum analyzer, it can be a very tedious task to turn on and place enough markers to identify all the peaks of interest. As shown in ***Figure 4***, the MDO4000 Series simplifies this process by automatically placing markers on peaks that indicate both the frequency and the amplitude of each peak. The criteria used to determine what a peak is can be adjusted by the user.

In addition to outstanding bandwidth performance, minimum 1 GHz capture bandwidth and excellent noise performance (DANL typical -150 dBc/Hz), there are many additional advanced features in the MDO4000 Series Spectrum Analyzer. Advanced functionality includes spectrogram display, manual markers, automated measurements for occupied bandwidth, channel power and adjacent channel power ratio. Like a typical spectrum analyzer, the MDO4000 Series offers four user configured or automatic traces or views of the RF input including normal, average, maximum hold and minimum hold. Detection types include +peak, –peak, average and sample.

Signal input methods on spectrum analyzers are typically limited to cabled connections or antennas. But with the optional TPA-N-VPI adapter, any active, 50 Ω TekVPI probe can be used with the RF input on the MDO4000 Series. This increases flexibility when hunting for noise sources and enables easier spectral analysis by using true signal browsing on an RF input.

Based on the industry-standard MSO4000B mixed signal oscilloscope, the new MDO4000 Series oscilloscope is the industry's first to incorporate a spectrum analyzer. While the ability to make RF measurements from one instrument is convenient for the user, the real power is in its ability to correlate events in the frequency domain with the time domain. Mixed Signal Oscilloscopes have transformed embedded systems debug by allowing correlation across analog and digital signals to become a must have tool on the bench. The Mixed Domain Oscilloscope category will likely experience similar acceptance as wireless becomes more commonplace and design complexity continues to increase.

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OCTAVE BAND LOW NOISE AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA01-2110	0.5-1.0	28	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA12-2110	1.0-2.0	30	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA24-2111	2.0-4.0	29	1.1 MAX, 0.95 TYP	+10 MIN	+20 dBm	2.0:1
CA48-2111	4.0-8.0	29	1.3 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA812-3111	8.0-12.0	27	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA1218-4111	12.0-18.0	25	1.9 MAX, 1.7 TYP	+10 MIN	+20 dBm	2.0:1
CA1826-2110	18.0-26.5	32	3.0 MAX, 2.5 TYP	+10 MIN	+20 dBm	2.0:1

NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA01-2111	0.4 - 0.5	28	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA01-2113	0.8 - 1.0	28	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3117	1.2 - 1.6	25	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3111	2.2 - 2.4	30	0.6 MAX, 0.45 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3116	2.7 - 2.9	29	0.7 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA34-2110	3.7 - 4.2	28	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA56-3110	5.4 - 5.9	40	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA78-4110	7.25 - 7.75	32	1.2 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA910-3110	9.0 - 10.6	25	1.4 MAX, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA1315-3110	13.75 - 15.4	25	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3114	1.35 - 1.85	30	4.0 MAX, 3.0 TYP	+33 MIN	+41 dBm	2.0:1
CA34-6116	3.1 - 3.5	40	4.5 MAX, 3.5 TYP	+35 MIN	+43 dBm	2.0:1
CA56-5114	5.9 - 6.4	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6115	8.0 - 12.0	30	4.5 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6116	8.0 - 12.0	30	5.0 MAX, 4.0 TYP	+33 MIN	+41 dBm	2.0:1
CA1213-7110	12.2 - 13.25	28	6.0 MAX, 5.5 TYP	+33 MIN	+42 dBm	2.0:1
CA1415-7110	14.0 - 15.0	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA1722-4110	17.0 - 22.0	25	3.5 MAX, 2.8 TYP	+21 MIN	+31 dBm	2.0:1

ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA0102-3111	0.1-2.0	28	1.6 Max, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA0106-3111	0.1-6.0	28	1.9 Max, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-3110	0.1-8.0	26	2.2 Max, 1.8 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-4112	0.1-8.0	32	3.0 MAX, 1.8 TYP	+22 MIN	+32 dBm	2.0:1
CA02-3112	0.5-2.0	36	4.5 MAX, 2.5 TYP	+30 MIN	+40 dBm	2.0:1
CA26-3110	2.0-6.0	26	2.0 MAX, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA26-4114	2.0-6.0	22	5.0 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA618-4112	6.0-18.0	25	5.0 MAX, 3.5 TYP	+23 MIN	+33 dBm	2.0:1
CA618-6114	6.0-18.0	35	5.0 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA218-4116	2.0-18.0	30	3.5 MAX, 2.8 TYP	+10 MIN	+20 dBm	2.0:1
CA218-4110	2.0-18.0	30	5.0 MAX, 3.5 TYP	+20 MIN	+30 dBm	2.0:1
CA218-4112	2.0-18.0	29	5.0 MAX, 3.5 TYP	+24 MIN	+34 dBm	2.0:1

LIMITING AMPLIFIERS

Model No.	Freq (GHz)	Input Dynamic Range	Output Power Range Psat	Power Flatness dB	VSWR
CLA24-4001	2.0 - 4.0	-28 to +10 dBm	+7 to +11 dBm	+/- 1.5 MAX	2.0:1
CLA26-8001	2.0 - 6.0	-50 to +20 dBm	+14 to +18 dBm	+/- 1.5 MAX	2.0:1
CLA712-5001	7.0 - 12.4	-21 to +10 dBm	+14 to +19 dBm	+/- 1.5 MAX	2.0:1
CLA618-1201	6.0 - 18.0	-50 to +20 dBm	+14 to +19 dBm	+/- 1.5 MAX	2.0:1

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	Gain Attenuation Range	VSWR
CA001-2511A	0.025-0.150	21	5.0 MAX, 3.5 TYP	+12 MIN	30 dB MIN	2.0:1
CA05-3110A	0.5-5.5	23	2.5 MAX, 1.5 TYP	+18 MIN	20 dB MIN	2.0:1
CA56-3110A	5.85-6.425	28	2.5 MAX, 1.5 TYP	+16 MIN	22 dB MIN	1.8:1
CA612-4110A	6.0-12.0	24	2.5 MAX, 1.5 TYP	+12 MIN	15 dB MIN	1.9:1
CA1315-4110A	13.75-15.4	25	2.2 MAX, 1.6 TYP	+16 MIN	20 dB MIN	1.8:1
CA1518-4110A	15.0-18.0	30	3.0 MAX, 2.0 TYP	+18 MIN	20 dB MIN	1.85:1

LOW FREQUENCY AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure dB	Power-out @ P1-dB	3rd Order ICP	VSWR
CA001-2110	0.01-0.10	18	4.0 MAX, 2.2 TYP	+10 MIN	+20 dBm	2.0:1
CA001-2211	0.04-0.15	24	3.5 MAX, 2.2 TYP	+13 MIN	+23 dBm	2.0:1
CA001-2215	0.04-0.15	23	4.0 MAX, 2.2 TYP	+23 MIN	+33 dBm	2.0:1
CA001-3113	0.01-1.0	28	4.0 MAX, 2.8 TYP	+17 MIN	+27 dBm	2.0:1
CA002-3114	0.01-2.0	27	4.0 MAX, 2.8 TYP	+20 MIN	+30 dBm	2.0:1
CA003-3116	0.01-3.0	18	4.0 MAX, 2.8 TYP	+25 MIN	+35 dBm	2.0:1
CA004-3112	0.01-4.0	32	4.0 MAX, 2.8 TYP	+15 MIN	+25 dBm	2.0:1

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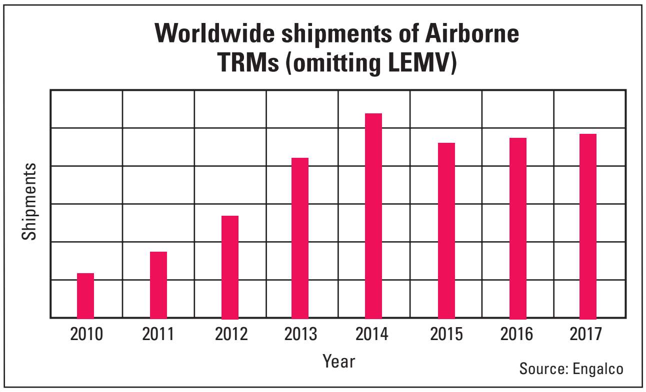
Dan Massé, Associate Technical Editor

Report Provides Data on Shipments and Market Values for Airborne AESAs

In spite of, and in several instances because of the cutbacks in defense expenditures, the avionics side of the industry is surviving almost unscathed and most parts of this segment exhibit growing markets. EW systems and radars will always be vitally important and, as well as new implementations, system upgrades are increasingly being installed on existing platforms. In order to reflect in detail the important changes during the past year, Engalco has pursued active research on airborne active electronically-scanned arrays (AESA) – the industry, technologies and markets – and has recently released its report on this subject: Airborne AESAs. This report provides extensive data on shipments and market values for the systems and the T/R-modules (TRM), including forecasts to 2017.

Major new aspects considered in detail reflect the significant impacts of the recent, typically harsh, national defense reviews and associated adverse economic environments – notably in the US and the UK (also affecting France). The implications of these reviews will result in decreased annual deployments of many platforms, ranging from the F-35 fighter to aircraft carriers. But set against this scenario, AESAs, such as Raytheon's RACR and Northrop Grumman's SABR, will be increasingly important for upgrading existing aircraft fleets. In addition to the F-35, the EA-18G (Growler), the Eurofighter Typhoon, France's Rafale – and UVs (UAVs and UCAVs) are all important. A further very significant program is the LEMV surveillance airship. In June 2010, Northrop Grumman was awarded the contract to develop this system and, more recently, this prime contractor has announced it is teaming with Hybrid Air Vehicles Ltd. of England and a team of technology leaders from three countries and 18 states in the US to build the LEMV. The prototype LEMV will have about 100,000 TRMs, while the final version will implement more than 7 million TRMs.

Engalco also provides details of Israel's CAEW system, status of the F-35 "Lightning II," systems going onto the EA-18G "Growler" and the ongoing upgrades of existing platforms, including F-15s and F-16s. It is clear that North American markets always lead this industry sector.



Raytheon Antenna Enhances US Capabilities to Locate Friendly Forces

Raytheon Co. has developed a miniaturized interrogation antenna capability to extend use of its Cooperative Target ID technology to soldiers and unmanned aircraft to help prevent fratricide. This effort builds upon an existing Raytheon antenna design and additional enhancements performed in concert with the U.S. Army CERDEC Intelligence & Information Warfare Directorate (I2WD). The new miniature antenna is approximately the size of an ice cube and weighs only a fraction of an ounce. It capitalizes on proven cooperative millimeter-wave technology, which has been certified at technical readiness level seven by the military for use on combat vehicles.

"This new miniaturized antenna... represents a technological breakthrough that can be of immediate benefit to our warfighters."

"This new miniaturized antenna is ideal to meet the constrained size and weight requirements posed by individual soldier and unmanned aircraft system (UAS) applications, and it represents a technological breakthrough that can be of immediate benefit to our warfighters," said Glynn Raymer, Vice President of Raytheon's Network Centric Systems' Combat Systems.

Raytheon's mini antenna development is the latest enhancement of its Cooperative Target ID technology successfully demonstrated to I2WD as part of the Light Vehicle Demonstration contract. This technology can be commonly applied to airborne platforms, ground vehicles and dismounted warfighters, providing air-to-ground and ground-to-ground mission capabilities. The technology is designed for ease of integration with surveillance, targeting and soldier systems.

"Raytheon's Cooperative Target ID technology has repeatedly demonstrated its mission effectiveness in locating friendly forces during numerous US government-sponsored ground and airborne field test exercises over the past seven years," explained Raymer. "It is easy to use by soldiers and pilots alike, and the feedback from test personnel has been uniformly positive."

During testing at the Bold Quest 2009 exercise, the radio frequency-based technology was mounted inside an F/A-18 Super Hornet fighter aircraft pod. Raytheon's combat ID solution provided an essential air-to-ground capability to reliably identify and locate "friendlies" equipped with the technology at typical tactical close air support ranges in real time and under all-weather and typical, obscured battlefield environments, including urban settings.

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Northrop Grumman Completes Successful Joint Strike Fighter Sensor Testing

Northrop Grumman Corp. has successfully participated in the 2011 Northern Edge joint military exercise by demonstrating key F-35 Joint Strike Fighter (JSF) sensor capabilities in a demanding operational environment. The AN/APG-81 active electronically scanned array (AESA) radar and AN/AAQ-37 Distributed Aperture System (DAS) were mounted aboard Northrop Grumman's BAC1-11 test aircraft during the exercise. The radar was tested featuring Block 3 and developmental software, and the DAS was tested with JSF Block 2 delivery software.

"The rigorous testing of both sensors during this exercise serves as a significant risk reduction step for the JSF program," said Commander Erik Etz, Deputy Mission Systems Integrated Product Team lead for the JSF Program Office. "By putting our systems in this operationally rigorous environment, we have demonstrated key warfighting capabilities well in advance of its scheduled operational testing."

Participating in the Northern Edge exercise for the second time, the AN/APG-81 radar demonstrated robust electronic protection, electronic attack, passive, maritime and experimental modes, and data-linked air and surface tracks to improve legacy fighter situational awareness. The AN/AAQ-37 DAS displayed its spherical situational awareness and target tracking capabilities during its operational environment debut at Northern Edge this year.

"The ability that DAS provides to track multiple aircraft in every direction simultaneously is something that has never been seen in an air combat environment before," said Chuck Brinkman, Sector Vice President and General Manager of Northrop Grumman's Targeting Systems Division.

"The ability that DAS provides to track multiple aircraft in every direction simultaneously is something that has never been seen in an air combat environment before."

The US Pacific Command, the Alaskan Command and the Joint Electromagnetic Preparedness for Advanced Combat organizations supervised the biennial exercise, which involved more than 6000 airmen, sailors and Marines. As the US's largest and most complex airborne electronic warfare environment, this exercise encompasses mass air combat scenarios conducted across diverse platforms to test their effectiveness within challenging environments.

European Antenna Reaches New Heights

The first European antenna that is part of the Atacama Large Millimetre/submillimetre Array (ALMA) was handed over to the European Southern Observatory (ESO) in April. The antenna, which was under contract from the ESO, was manufactured by the European AEM Consortium (Thales Alenia Space, European Industrial Engineering and MT-Mechatronics). Assembled at the Operational Support Facility at an altitude of 2900 m in the foothills of the Chilean Andes, it was equipped with highly sensitive detectors, which are cooled, and other necessary support electronics.

Since, one of the giant ALMA transporter vehicles has taken it 28 km to the Array Operations Site (AOS) location at 5000 m altitude. The AOS is the last port of call in a long journey that began when the component parts of the antenna were manufactured in factories across Europe. It is the 16th antenna of ALMA that will eventually be made up of 66 individual antennas.

John Richer, UK Project Scientist for ALMA, based at the University of Cambridge, UK, said, "Even with only 16 of the total 66 antennas in place, ALMA is a huge step forward for astronomy. The observatory is already much more sensitive than current instruments, and will allow us to study in great detail the faint radio waves emanating from young stars and distant galaxies. We hope these observations will answer some of the most fundamental questions about the way the Universe evolved from the Big Bang to the present day, and how our own Sun and planetary system formed."

The ALMA Antenna Project Manager at ESO, Stefano Stanghellini added, "It is great to see the first European ALMA antenna reach Chajnantor. It is from this arid plateau that these masterpieces of technology will be used to study the cosmos."

€7 B EU fund for Cutting-edge Research

In an effort to help Europe develop world-class research and close the innovation gap between the European Union and its main competitors, the US and Japan, the EU is making about €7 B available in the latest round of grants. This is part of the €53 B available through the current research funding programme for 2007 to 2013.

Key areas being targeted include nanotechnologies and information and communication technologies.

The call for research proposals also addresses the aims of the EU's Innovation Union policy. This flagship initiative of the Europe 2020 growth and job strategy will stimulate and speed up innovation in Europe, while removing bottlenecks that prevent good ideas from reaching the market.

Key areas being targeted include nanotechnologies and information and communication technologies. About 16,000 recipients will receive grants for research projects this year. About €1 B will be used to help small and medium-sized businesses innovate.

This funding is part of the EU's strategy for building up science and innovation. The EU wants to increase spending on research to 3 percent of gross domestic product by 2020 (from 2 percent in 2009). Achieving that target could create 3.7 million jobs and boost annual growth by about €800 B.

ETSI Specification Addresses NGN Services for Broadband Satellite Networks

The European Telecommunications Standards Institute (ETSI) has published the ETSI Technical Committee for Satellite Earth stations and Systems (TC SES) specification TS 102 855, which considers how broadband satellite multimedia networks can be integrated into the Next Generation Network (NGN) architecture. It explores the technical challenges for satellite networks to adopt this new network model.

...successful integration of satellite systems in new converged telecommunications networks...

The NGN concept standardized by ETSI presents an opportunity for satellites to take a more integrated role in global telecommunications networks. The NGN architecture can be used to provide seamless integration between fixed satellite networks and terrestrial networks as part of a wider fixed and mobile network convergence.

This new specification defines the integration and interoperability of Broadband Satellite Multimedia networks with the emerging terrestrial Next Generation Network architecture. The evolution of existing broadband satellite

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systems toward an NGN infrastructure will be crucial for the successful integration of satellite systems in new converged telecommunications networks.

One of the main characteristics of the NGN architecture is the uncoupling of services and underlying transport functions (i.e. network technologies), allowing services and transport to be offered separately and to evolve independently, with open interfaces provided between them.

Synergies Expert Group Makes Recommendations for FP7 Development

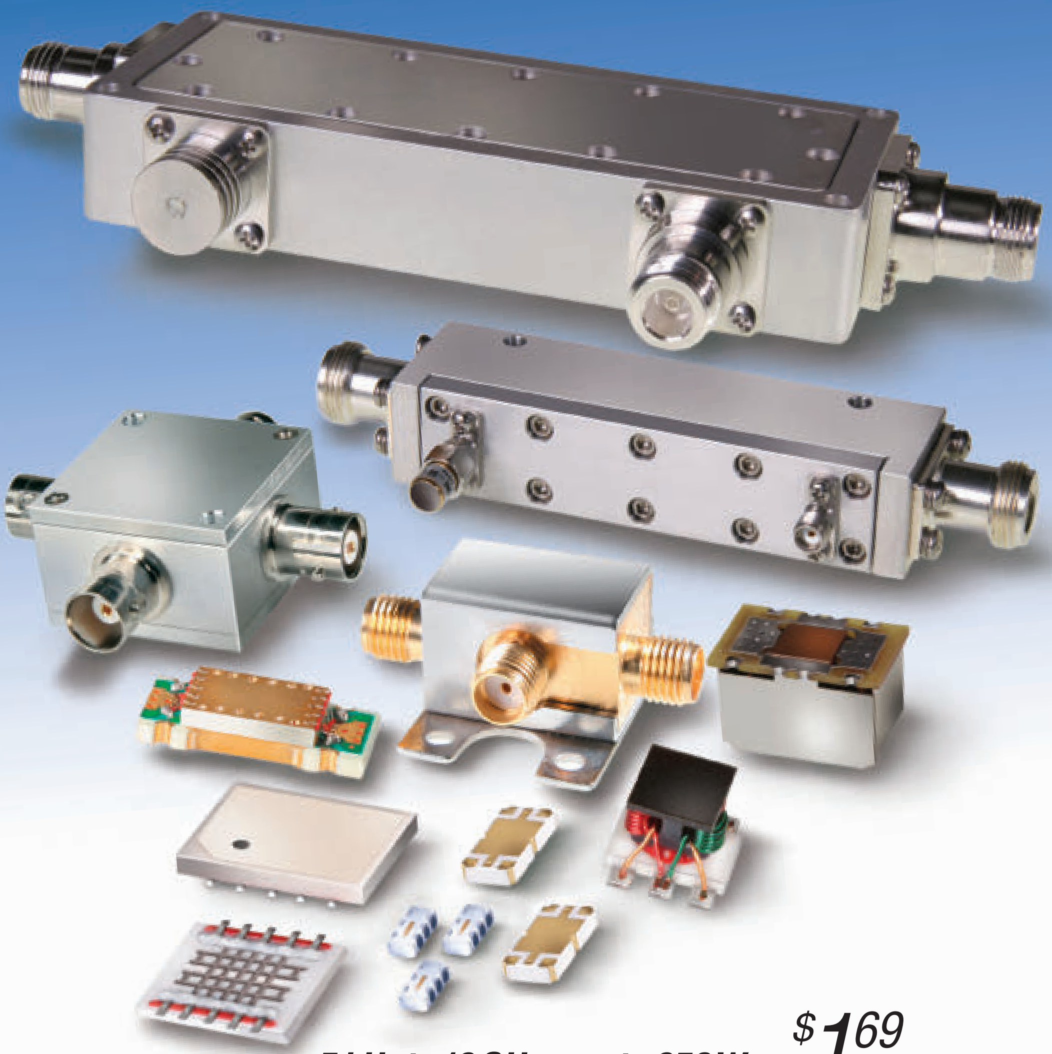
An expert group established as part of the Seventh Framework Programme's (FP7) has published a new report containing several key recommendations for the future of EU research policy. Since October 2010, the Synergies Expert Group (SEG) has been analysing how EU research policy should be aligned across the main European research policy framework programmes and actions.

With the keyword being "synergy," the taskforce set out to develop "synergies in practice" for the current programming period, as well as to explore how research and development (R&D) can be enhanced in the future. The philosophy behind synergy is one of joining the dots to ensure that policies are aligned and do not overlap.

In its report, the group found that innovation policies at EU level are fragmented and that coordination of research and innovation, as well as cohesion policies at European, national and regional levels, both within and between these levels, is suboptimal. Other problems include weak complementarities and compatibilities, as well as interoperability of policies and programmes, particularly regarding the regional dimension in research and innovation policy, and the research and innovation dimension in regional policy.

The philosophy behind synergy is one of joining the dots to ensure that policies are aligned and do not overlap.

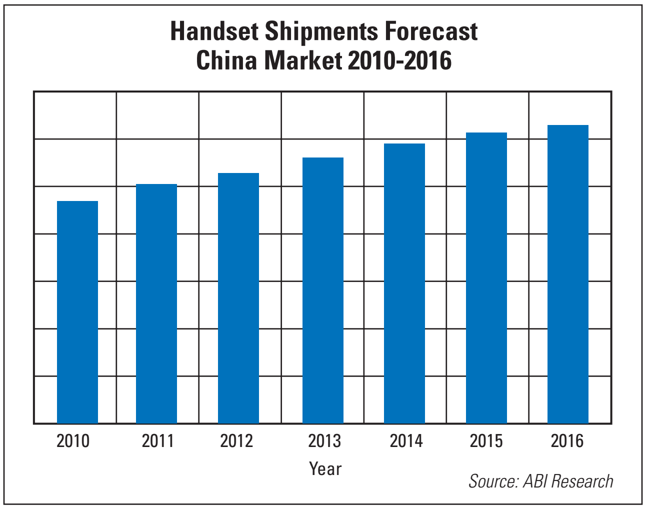
The group recommends that the Structural Funds could be better exploited for innovative public procurement and demonstrations projects, and thus for better support of the "smart growth" objective. In addition, they advise using the European Social Fund (ESF) to promote greater synergies between education and innovation programmes by making it more innovation oriented. Another key point of the SEG report is the need to ensure that the regional aspect of research remains at the top of the EU policy agenda.



2010 a Banner Year for China's Mobile Handset Markets; 3G Subscriptions Soar

2010 marked a year of outstanding growth for China's handset market – unit shipments saw a 17 percent increase from 2009, with smartphone shipments accounting for 11 percent of the total. The smartphone growth trend is expected to continue at least through the next five years. Entry-level smartphones retailing between $155 and $200 (US dollars) will be the driving force for this growth and for the attendant subscription rate growth among Chinese handset operators. This market surge is also reshaping the handset manufacturing and distribution business model in China.

China has successfully achieved the first phase of its 3G technology deployment, completing 3G network construction in most major provinces and cities. The total number of 3G subscribers in the country climbed to 47 million in 2010.



Broadcast RF Power Semiconductor Market Still Led Primarily by DTV

The global market for RF power semiconductors used in broadcasting is being driven by the current explosion in digital broadcasting, primarily from DTV. This market is expected to remain healthy and steady for the next decade.

Historically this market has been viewed as flat and not very exciting. That, it turns out, is an error. DTV and FM broadcasting are still expanding at a measured, but nevertheless positive rate. This market is being powered by the advance of digital broadcasting, both television and radio, but especially TV. The total demand for RF power semiconductors for broadcasting looks promising for the next 10 years. Regionally, growth will be driven by the phased switchover to digital TV as it occurs in different countries.

ABI Research's new report, "RF Power Semiconductors for Broadcast Applications" examines the major sub-segments of terrestrial broadcasting services for both sound and video, and drills down to show how the evolution of digital broadcast services will affect the RF power semiconductor devices that are used in transmitters for new and existing applications.

RFID Growth Potential Remains Strong Despite Apparel Rollout Slowdown

Despite the 2008-2009 economic setbacks, the RFID market rebounded nicely in 2010, growing slightly more than 14 percent to reach roughly $5.3 B. When automobile immobilization hardware is extracted from the total, the market grew almost 18 percent, capturing nearly $4.4 B. ABI Research's ongoing research and data collection efforts reveal a projected total market size of nearly $6 B in 2011, reflecting slightly more than 11 percent growth. The 2011 forecast without automobile immobilization is $5 B, growing in excess of 14 percent over 2010.

ABI Research foresees variation in demand and the pace of adoption between applications, verticals, regions and technologies, with the retail apparel sector in particular displaying something of a slowdown in growth this year. However, the bottom line is that across the market as a whole, continued strong growth is expected.

"The fastest-growing application between now and 2016 will be item-level tracking in supply-chain management."

"The fastest-growing application between now and 2016 will be item-level tracking in supply-chain management, which ABI Research estimates will exceed a 37 percent growth rate," notes Research Director Michael Liard.

"The fastest-growing verticals over our five-year forecast period (in descending order) will be retail CPG, retail in-store, healthcare and life sciences, diverse non-CPG manufacturing, and commercial services," says Liard.

More specifically, primary RFID applications can be broken down into "traditional" and "modernizing" types. The 2011-2016 CAGR for aggregated modernizing applications is expected to be double that of the traditional applications cluster.

Legislative Mandates, Grant Programs Driving Smart Meter Deployment

Global shipments of smart meters will exceed 100 million this year and forge ahead to more than 250 million by 2016, with Europe being the main constituent of this total installed base.

"Robust smart meter uptake in Europe is the result of mandates legislated by European central governments,

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coupled with heightened development in renewables," says ABI Research Industry Analyst Kelvin Chan. "North America is also experiencing a quickening deployment rate due to stimulus from the American Recovery and Reinvestment Act (ARRA) Grant Programs."

The Asia-Pacific region has recently also seen deployments of smart meters. Australia is in the forefront in AMI deployments and New Zealand seems to be moving towards development of a national smart metering initiative. The rest of Asia has also shown signs that smart metering is occurring. China announced in the 12th Economic five-year plan that AMI plays a key role in its economic vision. South Korea has also embarked on a Smart Grid Demonstration Project, encompassing various initiatives in the smart energy space. Singapore has also joined the bandwagon with its "Intelligent Energy System."

Smart meters play a significant role in rolling out energy efficiency initiatives due to the two-way communication that connects the utility and customer, facilitating the growing dynamic response and home automation markets. Practice Director Sam Lucero adds, "Consolidation is also continuing, with Toshiba – known for its power generation and grid transmission and distribution business segments – acquiring Landis+Gyr, a global pioneer in smart metering, networking and service products."

ABI Research's "Advanced Metering Infrastructure" study analyzes the market dynamics of Automated Metering Infrastructure (AMI) deployment on a global basis, encompassing the myriad of advanced communication technologies in conjunction with utility infrastructure and operations. In particular, the study examines the adoption of smart meters and its integration into key Transmission and Distribution (T&D) infrastructure elements, thereby forming the backbone of the smart grid. In addition, updates on smart metering activities in the Asia-Pacific region are highlighted. Also central is an examination of trends in the use of cellular wireless technologies. Market forecasts are provided through 2016.

Smart meters play a significant role in rolling out energy efficiency initiatives due to the two-way communication that connects the utility and customer.

INDUSTRY NEWS

Microsemi Corp. announced that it has acquired the millimeter-wave technology and related assets of privately held **Brijot Imaging Systems Inc.** Microsemi's product offerings will include the industry's first millimeter-wave wand solution for touchless pat downs and will also support customers who need solutions that prevent internal loss and promote workplace safety.

Tektronix Inc. announced the acquisition of **Veridae Systems Inc.** Founded in 2009 to commercialize research from the University of British Columbia, Veridae delivers three leading products for ASIC/FPGA prototyping debug, ASIC post silicon validation and FPGA-based system product validation into leading semiconductor and system product companies.

AWR Corp. announced that the merger with **National Instruments** (NI) is complete. As previously announced, AWR will continue to operate as a wholly owned NI subsidiary under the leadership of the existing management team. In related news, NI started construction over the summer for its R&D and operations facility in Penang, Malaysia. The facility is expected to be complete in 2012.

Agilent Technologies Inc. and the **University of California, Davis**, announced they will establish the Davis Millimeter Wave Research Center (DMRC). The DMRC will focus on advancing technology in millimeter-wave and THz systems for radar, imaging systems, sensors, communications and integrated passive devices found in electromagnetic metamaterials and antennae.

GigOptix Inc., a supplier of semiconductor and optical components that enable high speed information streaming, recently moved its headquarters from Palo Alto, CA, to 130 Baytech Road, San Jose, CA. The move came after GigOptix acquired **Endwave Corp.** over the summer.

Emerson & Cuming Microwave Products N.V. Belgium has moved. The new address is Bell Telephonelaan 2B, 2440 Geel, Belgium. Telephone (+32 14 56250) and fax number (+32 14 562501) remain unchanged. Emerson & Cuming Microwave Products is a worldwide supplier of absorbing materials, low-loss dielectrics and shielding materials.

The High Performance Foams Division of **Rogers Corp.**, located in Chicago, IL, has been awarded a Silver Performance Excellence Award for 2010 by **Boeing**. The Boeing Performance Excellence Award is given to Boeing suppliers for superior supplier performance over a year's time.

Richardson RFPD Inc. reports that, for the second consecutive year, it has received the "Top Distributor of the Year" award from **TriQuint Semiconductor Inc.**, a RF solutions supplier and technology innovator. The award recognizes Richardson RFPD's overall contribution to TriQuint's growth, including high level of responsiveness to customers, increasing design wins, and technical support.

Anritsu Co. announced that the IEEE Microwave Theory and Techniques (MTT) Society has presented **Bill Oldfield** with the 2011 Microwave Application Award. He received the award for developing high frequency coaxial microwave connectors in the 1970s and 1980s.

Centerline Technologies of Hudson, MA, has become certified to ISO 9001:2008. The ISO 9001:2008 standard, published by the International Organization for Standardization, is an international reference for quality management requirements and continuous improvement in business-to-business dealings.

Auriga Microwave has been awarded Phase II.5 for its Small Business Innovative Research (SBIR) N07-007 Solid-state High-efficiency Transmit Module. This Navy-sponsored two-year effort will build upon the Phase II development of C-Band power amplifiers and low noise amplifiers.

CONTRACTS

Raytheon Co. has been awarded the first competitive Public Safety Long Term Evolution (LTE) contract in the nation, as well as the first contract under the Broadband Technology Opportunities Program (BTOP), for recipients of the FCC 700 MHz Broadband Waiver. The $8.7 M contract will provide Adams County, CO, and the adjacent Denver community, with a 15-site LTE communications system that delivers the public safety user access to next-generation broadband capabilities, such as streaming video, remote data access and information sharing.

Phonon Corp., of Simsbury, CT, received a $6.5 M contract from Raytheon IDS to upgrade the Patriot ground radar system to Config-3. Phonon will provide SAW pulse compression delay lines, which are critical radar elements, to achieve this latest configuration. This contract continues Phonon's 20-year involvement in Patriot technology advances.

L-3 Telemetry-East (L-3 TE), a division of L-3 Communications, has been awarded an indefinite-delivery/indefinite-quantity (ID/IQ) contract to upgrade fielded telemetry ground receivers to incorporate the C-Band spectrum for the US Air Force. Over the past two years, engineers at Edwards AFB and L-3 TE have been testing a down-conversion scheme ensuring optimum functionality with no degradation to existing performance.

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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.

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NEW MARKET ENTRIES

RF Micro Devices Inc. announced its foundry services business unit has expanded its portfolio of process technologies to include two additional GaAs process technologies — RFMD's FD25 low noise PHEMT process and RFMD's FET1H switching PHEMT process. The two additional GaAs PHEMT process technologies are available immediately to foundry customers.

SemiGen Inc., an expert in RF/microwave hybrid assembly and testing, semiconductor evaluation and packaging, and automated PCB manufacturing, has a new facility and is expanding its RF/microwave assembly and test capabilities. To accommodate SemiGen's recent acquisitions and new product line repair business, SemiGen has relocated to 920 Candia Road in Manchester, NH. The new facility adds a second SMT line as well as a Class 10,000 ESD Zero clean room for RF microwave assembly, and SemiGen's newest capital acquisition, an MRSI605 Automatic Eutectic Die Bonder.

PERSONNEL


▲ *James L. Klein*

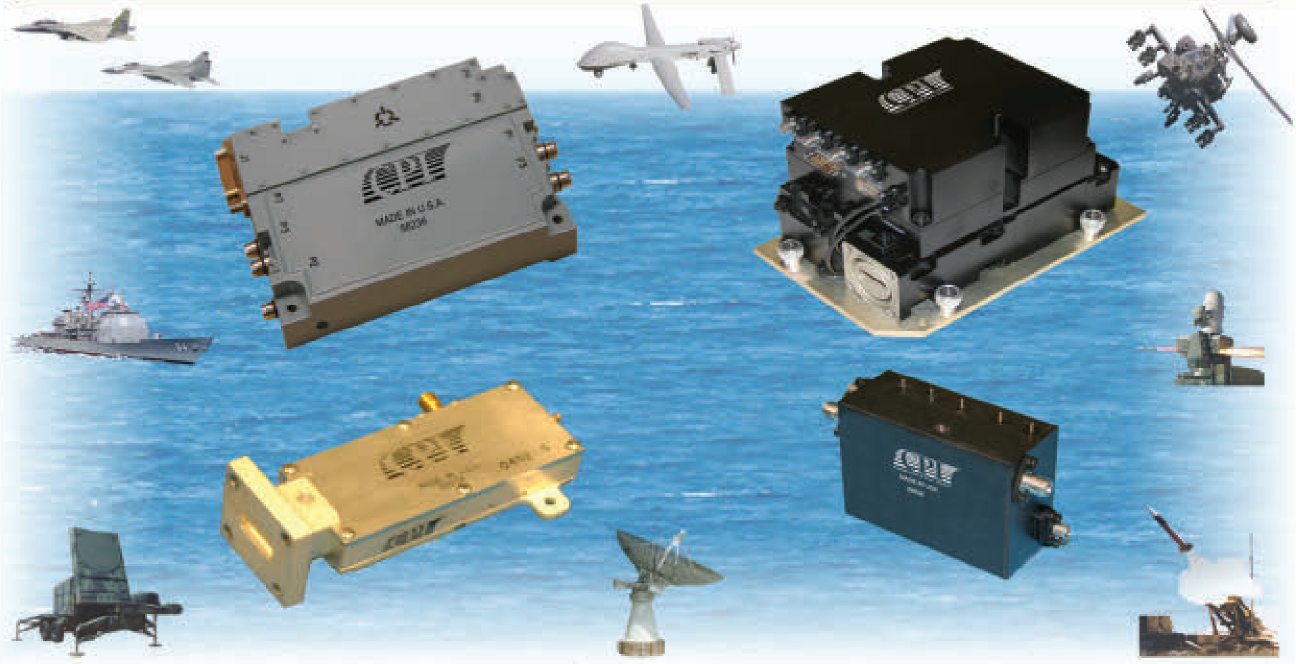
TriQuint Semiconductor Inc. announced that **James L. Klein** has joined the company as Vice President and General Manager of its Defense and Aerospace business. Klein was most recently with Raytheon in the Space and Airborne Systems division and responsible for design and manufacturing of advanced RF and microwave subsystems and components. He holds both bachelor's and master's degree in electrical engineering from Texas A&M University.

RF Industries announced that it has appointed Chief Financial Officer **James Doss** to the additional position of President. Howard Hill, RFI's CEO and former President, will continue in his current position as the company's Chief Executive Officer. After joining the company as Director of Accounting in February 2006, he was appointed Chief Financial Officer and Corporate Secretary in January 2008. Doss received his B.S. in finance and economics from San Diego State University in 1993 and completed graduate and advanced financial management studies, receiving his MBA from San Diego State University in 2005.


▲ *Tony Ieraci*

DYMAX Corp. has announced the appointment of **Tony Ieraci** as Marketing Communications Manager. Prior to joining DYMAX, Ieraci held positions as Marketing Communications Manager at Scapa North America and as owner of AIM Marketing Communications. He received his B.S. and M.B.A at Western New England College.

Integrated Microwave Assemblies



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Communications & Power Industries

Communications & Power Industries' Beverly Microwave Division (BMD) offers product technology that includes Integrated Microwave Assemblies and Control Components. BMD's broad experience and extensive capabilities in the areas of high power microwave component design for military and non-military radar, satellite, communications, and EW systems makes it uniquely suited to design and manufacture a wide range of components and multi-function assemblies in small, lightweight packages. Coupling that with our experience in other transmission lines and technologies gives us a technical capability that is unparalleled in the microwave industry.

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* Integral driver & associated electronics
* The industry's most extensive high power test facility

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REP APPOINTMENTS

Custom MMIC Design Services Inc. (CMDS), a fabless design company located in Westford, MA, announced the appointments of **Cain Technology**, **NWN Inc.** and **dBm Technical Sales** as its technical sales representatives. Cain Technology will represent CMDS in Southern CA, NWN Inc. will cover Northern CA and parts of NV, and dBm Technical Sales will cover the New England area.

Valpey Fisher Corp., a provider of high performance integrated products for timing and frequency control, announced the addition of **ATM Mid-Atlantic** and **Sertech Inc.** to its worldwide sales network of representatives and distributors. ATM Mid-Atlantic will be the authorized sales representative for Valpey Fisher frequency control products in MD, VA and DC. Sertech will be the authorized sales representative for all Valpey Fisher product lines in Eastern PA, Southern NJ and Delaware.

M/A-COM Technology Solutions recently named **Mouser Electronics** as an authorized global distributor. Mouser Electronics is a design engineering resource and global distributor for semiconductors and electronic components. Mouser Electronics, with its user-friendly "EZ Buy" online catalogue, enables customers to buy online for fast and efficient fulfillment of product orders for M/A-COM Tech's customers.

TRU Corp. of Peabody, MA, announced the appointment of **ProTEQ Solutions** as its representative for RF and microwave cable assembly and connector products in the New England territory. ProTEQ Solutions has a successful history of selling into the complex test and instrumentation market. ProTEQ recently merged with Hi-Peak Sales to form a new embedded products sales team for modules, PCBs and assemblies.

MITEQ Inc. announced the appointment of **MC Microwave** as the company's exclusive sales representative in Northern CA and NV and the appointment of **Technical Marketing Specialists** as the company's exclusive sales representative in NM and AZ. The two companies will represent MITEQ's Component division, which includes amplifiers, mixers, frequency multipliers, passive power components, switches, attenuators, limiters, phase shifters, IF signal processing components, oscillators, synthesizers, integrated multifunction assemblies and fiber optic products. MC Microwave can be contacted at sales@mc-microwave.com. Technical Marketing Specialists can be contacted at tms@tmssales.com.

WEBSITE

Engalco, which provides in-depth company analyses and market forecasts for commercial, industrial and military sectors, has a new website, www.engalco-research.com. Engalco is based in East Yorkshire, UK, and specializes in aerospace and defense.

HAND FLEX™ CABLES

Hand Flex Cables conform to any shape required.

from $8.69 IN STOCK ea. (qty.1-9) DC to 18 GHz

Get the performance of semi-rigid cable, and the versatility of a flexible assembly. Mini-Circuits Hand Flex cables offer the mechanical and electrical stability of semi-rigid cables, but they're easily shaped by hand to quickly form any configuration needed for your assembly, system, or test rack. Wherever they're used, the savings in time and materials really add up!

Excellent return loss, low insertion loss, DC-18 GHz. Across their entire bandwidth, Hand Flex cables deliver excellent return loss (>27 dB for up to 24" runs) and low insertion loss (0.2 dB typ at 9 GHz for a 3-inch cable). So why waste time measuring and bending semi-rigid cables, when you can easily install a Hand Flex interconnect?

Two popular diameters to fit your needs. Hand Flex cables are available in 0.086" or 0.141" diameters, with a turn radius of 6 or 8 mm, respectively. Straight SMA connectors are standard, and now we've added right-angle connectors to our Hand Flex lineup, for applications with tightly-packed components.

Standard lengths in stock, custom models available. Standard lengths from 3 to 24" are in stock for same-day shipping. You can even get a Designer's Kit, so you always have a few on hand. Custom lengths, or two-right-angle models, are also available by preorder. Check out our website for details, and simplify your high-frequency connections with Hand Flex! *RoHS compliant*

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U.S. Patents 7739260, 7761442

IF/RF MICROWAVE COMPONENTS

Welcome to European Microwave Week 2011

For complete coverage of the EuMW conference, event news, exhibitor product information and special reports from the editors of *Microwave Journal*, visit our Online Show Daily at www.mwjournal.com/eumw2011 starting September 22nd.

Manchester was at the heart of the industrial revolution in the 19th century and the city will again be a hub of activity as the RF and microwave industry takes the opportunity to demonstrate its current invention and productivity during European Microwave Week 2011, which will be held at the Manchester Central Convention Complex from Sunday 9 October to Friday 14 October. Since hosting EuMW in 2006, the complex has undergone a £28 million refurbishment that has resulted in a spacious, modern venue in the heart of the city.

Proud of its history, Manchester is now a prosperous post-industrial city and a centre for commerce, the arts and education that has prompted EuMW 2011 to adopt the slogan, *Wave to the Future*. The slogan epitomises the fact that the Week has, at its core, the traditional and established focused conferences, alongside Europe's premier RF and microwave exhibition, yet is also looking forward and innovating.

It is the leading microwave event in Europe and brings together the microwave community from around the world. The Week is organised around three conferences: the 41st European Microwave Conference (EuMC), the 6th European Microwave Integrated Circuits Conference (EuMIC) and the 8th European Radar Conference (EuRAD). Delegates will be able to experience a very broad range of technical subjects, from semiconductors and nanotechnology through to wireless and radar systems. More than 1000 papers were submitted from more than 50 countries and above 375 papers will be presented in technical sessions, 200 in posters and 195 in workshops and short courses.

A significant first is that the Opening Ceremony will be presented by Professor Konstantin S. Novoselov FRS, from the University of Manchester, who received the Nobel Prize for his discovery of graphene and its extraordinary properties.

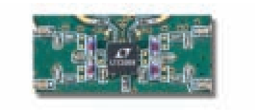
Add to that, special sessions that will run in parallel with the conference sessions. These include a focused session on Advances in Nanoelectronics in Radio Frequency Technology and a joint APMC-EuMC session. A special half-day Microwaves inside Asia session will provide an overview of some of the most significant research and development currently

Ian Hunter
General Chair, EuMW 2011
Ivar Bazzy
President, Horizon House Publications

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

1-800-4-LINEAR

LINEAR TECHNOLOGY

in Asia, and the popular Women in Engineering event is again on the agenda.

In its effort to *Wave to the Future*, EuMW recognises the importance of encouraging and nurturing students. The EuMW 2011 Student Challenge aims to bridge the gap between university and industry by challenging students and young researchers to test their technical and application-oriented innovation skills. The competition complements the 2011 Tutorial Seminars for Young Engineers aimed at stimulating and encouraging the next generation. New initiatives this year are the Doctoral School in Microwaves aimed at early stage Ph.D. students and the Filter Design Competition, which is open to postgraduate and undergraduate students.

Design, innovation and the application of technology to the commercial market will be at the forefront of the three-day 2011 European Microwave Exhibition, which a number of the 250 or so exhibiting companies will target to launch new and significant products. The exhibition is a microcosm of the RF and microwave industry with companies large and small, established and embryonic, and from all over the globe.

Over recent years, the Exhibition has developed to be much more than just a show floor. For example, this year, for the first time, the exhibition hall will play host to the Microwave Application Seminars (MicroApps) at EuMW 2011. Taking place for the entire three days of the exhibition, the intent of this open forum is to highlight and elaborate on products and techniques useful to engineers in their day-to-day design work. Interactive Poster Sessions will be prominent in the exhibition hall on all three exhibition days, enabling authors to demonstrate their work face to face.

Important recent initiatives continue. In particular, the success of the inaugural EuMW Defence/Security Executive Forum at EuMW 2010 in Paris has prompted the organisers to expand European Microwave Week's coverage of the Defence/Security sector and instigate the full-day EuMW Defence and Security Forum. It offers delegates the opportunity to benefit from the expertise and experience of representatives from government defence agencies and leading defence/security contractors who will provide insights into how their organizations view future threats to global safety, security and defence, and the role of technology in addressing these risks.

A social highlight of the Week is the EuMW Welcome Reception, which epitomises the organiser's ongoing endeavours to encourage the interaction between industry and academia that is both convivial and conducive to networking. Indeed, mixing business and pleasure can be enjoyed throughout the week through the strong calendar of social events that has been organised.

To bring all of the initiatives mentioned to fruition takes time and effort and the Local Organizing Committee would like to express its gratitude to the Technical Programme Committees of the three conferences, along with the 350 volunteer reviewers of the technical papers. A special mention goes to Prof. Matthias Rudolph for his great efforts in running the TPMS paper submission software.

We would also like to acknowledge all the organisers of workshops, special sessions and student events. Thanks also goes to the Horizon House staff assigned to EuMW for their invaluable support in organising this major international event, as well as their contribution to the staging of a world-class exhibition. Last but not least, we acknowledge the financial and in-kind sponsorship of many industrial enterprises and other organisations.

We are sure that you will have a great experience at EuMW 2011 and we look forward to meeting you in Manchester.


Ian Hunter


Ivar Bazzy

Welcome from Ian Hunter, General Chairman, EuMW 2011, and Ivar Bazzy, President, Horizon House Publications. ■

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EuMW 2011 — Wave to the Future

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MAAL-010705	500 - 1600	21.0	-21.0	32.0	0.5	4	2 mm PDFN
MAAL-010706	1400 - 4000	17.5	-19.0	34.5	0.6	4	2 mm PDFN

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ATTENDING EUROPEAN MICROWAVE WEEK 2011

Professor Wolfgang Heinrich, President of the European Microwave Association (EuMA) explains the Association's history, structure and aims, and outlines the role that it plays in the global RF and microwaves industry.

Executive Interviews

After five years, European Microwave Week returns to Manchester and the UK. At the heart of the Industrial Revolution, the city was the site of the world's first passenger railway station and a dynamic centre for free trade. Its industrial past and subsequent regeneration make it the ideal home for EuMW 2011 and have prompted the adoption of the slogan, *Wave to the Future*.

Fig. 1 Manchester Central Convention Complex.

From 9 to 14 October, the event is expected to attract an estimated 4500 attendees (delegates, visitors and exhibitors) to the new Manchester Central Convention Complex, formerly known as GMEX and the Manchester International Conference Centre (see ***Figure 1***). It is located right in the heart of the city, and provides more space and award-winning facilities than in 2006 for both the conference and exhibition.

Now firmly established as the premier event in the RF and microwave calendar in Europe, European Microwave Week offers a broad platform for the industry to showcase and discuss the latest technology, exchange ideas, network and do business. The conferences reflect the groundbreaking and innovative work being undertaken in the RF, microwave, integrated cir-

RICHARD MUMFORD
Microwave Journal *International Editor*

cuit, wireless and radar sectors, while the commercial reality of that research and development will be highlighted during the European Microwave Exhibition. The exhibition will feature more than 250 exhibitors spread over more than 7000 m^2 (gross).

The official European Microwave Week opening ceremony on Tuesday morning is open to delegates from all conferences and will feature a presentation by the Nobel Laureate, Professor Konstantin S. Novoselov. Tuesday evening sees the Manchester Central Exchange Hall stage the EuMW Welcome Reception, which has become a highlight of the week. The evening will begin with a cocktail reception at 18.30, when guests will be addressed by the 2011 EuMW Chairman, who will hand over to the 2012 EuMW Chairman for Amsterdam, followed by Platinum Sponsor Agilent Technologies, after which a seated buffet will be served.

The following quick reference guide is designed to complement the Conference Programme and Exhibition Show Guide, where you will find more detailed information.

THE CONFERENCES

Each with their own dedicated time slots throughout the week are the three focused conferences:

- The 6th European Microwave Integrated Circuits Conference (EuMIC) takes place on Monday 10 and Tuesday 11 October
- The 41st European Microwave Conference (EuMC) extends from Tuesday 11 to Thursday 13 October
- The 8th European Radar Conference (EuRAD) spans Thursday 13 and Friday 14 October

The conferences encompass a wide range of subject areas including: microwave, millimetre-wave and submillimetre-wave systems, antennas and propagation, wireless technologies, telecommunication (RF, microwave and optical), ICs, semiconductor materials and packaging, radar architectures, systems and subsystems, sensors and remote systems, and test and measurement.

Registration, sponsored by Rohde & Schwarz, opened online on 6 June 2011 and will remain open up to and during the event until 14 October. Onsite registration is available from Saturday 8 October (16.00 to 19.00) and from 07.30 each morning from Sunday 9 October to Friday 14 October. Registration at one conference does not allow any access to other conference sessions, but those who wish to register for two or more conferences will receive a discount.

THE EUROPEAN MICROWAVE INTEGRATED CIRCUITS CONFERENCE

The EuMIC is the successor of the well known GAAS application symposium, which was first held in Rome in 1990. Since 2007, EuMIC has been organised under the umbrella of both the European Microwave Association (EuMA) and GAAS® Association. More than 100 technical papers have been selected, distributed across 16 EuMIC sessions, 11 joint EuMC/EuMIC sessions and two poster sessions. There will be also 13 workshops

and two short courses and there are a significant number of joint sessions and workshops, organised with the EuMC, which highlight the strong interaction between these conferences.

On Monday, the plenary session will feature two speakers. Dr. Tahir Ghani, Intel Fellow and Director of Transistor Technology and Integration, Intel Corp., will consider challenges and innovations in nano-CMOS transistor scaling. Professor Masahiro Yamaguchi, Director of Electromagnetic Theory Division, Tohoku University, Japan, will discuss trends and the future of on-chip RF magnetic technology.

The programme has been formulated to be of interest both for industry and academia, with many sessions ranging from basic process and device physics to integrated circuit theory based on different compounds in a number of different application domains. A special session on foundry services on Tuesday will bring together UMS, OMMIC, GCS, TriQuint Semiconductor and WIN Semiconductors to discuss trends and the applications of various semiconductor materials and devices.

Prizes and Awards

To acknowledge the high quality of papers presented the EuMIC technical programme committee and the EuMA general assembly will award a Best Paper Prize and a Best Student Paper Prize. In addition, the GAAS Association will award three postgraduate student fellowships to recognize the valuable work of students and to support them in the first steps of their technical and scientific career.

THE EUROPEAN MICROWAVE CONFERENCE

EuMC is Europe's leading forum for presenting microwave and related technologies and every effort has been made to deliver a comprehensive and varied programme. It comprises 42 European Microwave Conferences and 15 joint Technical Sessions, 15 workshops, two short courses, three special sessions, a Special Event, the Doctoral School in Microwaves, aimed at early-stage PhD students, and the established EuMW 2011 Student Challenge.

This year, with the European Conference on Wireless Technology (EuWiT) being integrated into EuMC, there is a greater emphasis on wireless-related topics and this is evident in the various technical sessions and workshops. Also, a new Special Session on Friday will focus on a specific geographical region; under the title, Microwaves inside Asia, invited speakers from China, Hong Kong, Taiwan, South Korea, Japan, Singapore, Thailand and India will showcase microwave technologies from within Asia.

Prizes and Awards

On Thursday afternoon, the closing session will feature an award ceremony for the EuMC Microwave Prize, and EuMC Young Engineers Prizes, sponsored by EADS/Cassidian, for the best papers written and presented by young engineers.

THE EUROPEAN RADAR CONFERENCE

Over the past eight years, EuRAD has grown to be one of the largest Eu-

▲ *Fig. 2 Manchester Central exhibition hall.*

ropean and world-wide radar events, offering high quality papers, workshops and focused sessions. There are 81 paper presentations, which have been organised into 19 sessions, covering four main areas: radar subsystems and phenomenology, signal processing, architectures and systems, and applications, complemented by 35 poster papers.

The paper sessions are enhanced by expert workshops, covering advanced areas of radar, including micro-Doppler analysis, multi-static and passive radar and phased array radar. Also, in a first for EuRAD, the impact of wind farms on radar systems will be addressed, including looking at the fundamentals of radar and wind farms, to give the non-radar expert insight into this increasingly important topic.

Prizes and Awards

There is one EuRAD Conference Prize and two Young Engineer Prizes. The EuRAD Prize is sponsored by Raytheon as is one Young Engineer Prize. The second Young Engineer Prize is sponsored by EADS/Cassidian. Both are awarded to young engineers or researchers who have presented an outstanding paper at the conference.

EXHIBITION

This FREE to enter exhibition is the largest trade show dedicated to RF and microwaves in Europe (see ***Figure 2***). The exhibition is a vibrant shop window for companies large and small, established and developing from all over the world. Each year, the EuMW host country attracts local interest with smaller companies and distributors banding together to give them a collective presence. In fact, the success of last year's event in Paris is being carried over to Manchester via the French Pavilion. To find out which companies will be at Manchester Central see the latest exhibitor list, starting on page 82. Exhibitor workshops continue to be a feature of EuMW, offering attendees the opportunity to gain hands-on experience and guidance.

This year, for the first time, the exhibition hall will also play host to the Microwave Application Seminars (MicroApps) at EuMW 2011. It will also house the Interactive Poster Sessions, which will enable authors to present their results interactively, the Publisher's Corner, and host the conference session coffee breaks for the three days.

EXHIBITION OPENING HOURS

Tuesday: 09.30 to 17.30 (followed by Welcome Reception)

Wednesday: 09.30 to 17.30
Thursday: 09.30 to 16.30

CST is sponsoring a Cyber Café located within the Exhibition Hall for all delegates, exhibitors and visitors to use, as well as free WiFi access to emails for delegates in all conference areas.

GETTING TO MANCHESTER CENTRAL

The venue has excellent transportation via rail link from Manchester airport and there are more than 2500 hotel rooms within a five minute walk of the Complex. Located in the centre of the UK, Manchester is served by strong road, rail and air links, making it an easily accessible location for visitors from all over the world.

By Air

Manchester airport is a major international air traffic hub with frequent scheduled flights to the majority of key UK, European and international destinations. It is nine miles (14.5 km) outside the city centre, taking approximately 25 minutes by taxi. Alternatively, there is a direct half-hourly express rail service to the city centre, which takes approximately 20 minutes.

By Rail

Manchester has direct rail connections to all major UK cities – London is just over two hours away. Services come into the city at either Piccadilly or Victoria station, both of which connect to the Metrolink light-rail system. You can also take advantage of the free Metroshuttle bus that travels between the two stations across the city centre. For information on train services to Manchester, visit www.nationalrail.co.uk.

Metrolink

The extensive Metrolink tram service covers the city centre and areas of Greater Manchester. To reach the venue, follow signs for Metrolink from either Piccadilly or Victoria, purchase a City Zone ticket on the platform and take a tram heading for Altrincham or Eccles, alighting at St. Peter's Square. Manchester Central is then a five-minute walk away behind the Midland Hotel.

By Road

Manchester is at the heart of the Northwest's motorway network with easy access from all directions onto the M60, the city's orbital motorway. Once on the M60, exit at Junction 12 and join the M602 sign posted towards the city centre. Follow the A57 straight on from the end of the M602, passing under a railway bridge before taking the left exit to merge onto the A56 Bridgewater Way. Turn right onto Whitworth Street West at Deansgate station and then turn left onto Albion Street. The entrance to the Manchester Central Car Park is through the next set of traffic lights on the left, opposite The Bridgewater Hall. If using Satellite Navigation/GPS, type in M2 3GX.

HOTEL RESERVATION

European Microwave Week 2011 has teamed up with Hotelzon to offer a wide range of accommodations to suit every budget at competitive rates for the event. To do so, visit Hotelzon's Booking Page at www.hotelzon.com/uk/exhibitions/eumw2011/ and

make your reservation or email exhibitions@hotelzon.co.uk.

SIGHTSEEING

Manchester has embraced change wholeheartedly, restoring its industrial landscape and combining that heritage with contemporary urban design to create a cityscape that blends the best of the old and new. Modern day Manchester is a vital and sophisticated urban capital that influences the world in science, business, fashion, style, music and culture.

Bristling with pubs, bars and clubs, the city centre truly does offer a friendly welcome with everything from a pint of local ale to a sophisticated cocktail. The city continues to be recognised as a thriving nightspot. Dining in Manchester is a real cosmopolitan culinary experience with a host of quality restaurants to choose from, whether it is British, Chinese, Russian, Thai or Brazilian.

Manchester has a wealth of shopping outlets from large department stores to independent boutiques and high end fashion to value-for-money purchases. Prestigious designer stores can be found on King Street and St. Anne's Square and along Deansgate. There are well-known department stores and independent stores along Market Street and in the Arndale (said to be Europe's largest city centre shopping mall).

For culture, there are about 90 museums in and around Manchester, while the city's art galleries house collections that range from the classical to the contemporary. Most museums and galleries offer free admission. For a show visit, the Palace Theatre, Royal Exchange and Opera House. Alternatively, there is the Library Theatre on the basement level of the city's beautiful, circular Central Library. For more information visit: www.manchestercentral.co.uk or www.visitmanchester.com.

In advance, take time to familiarise yourself with the event and plan your visit by logging onto the show website: www.eumweek.com. The website offers information about the conferences, registration, social activities and more. *Microwave Journal* will feature the EuMW 2011 Online Show Daily web page with up-to-date news, new products, photos, videos, exclusive articles and more at www.mwjournal.com/eumw2011.

For complete coverage of the EuMW 2011 conference, event news, exhibitor product information and special reports from the editors of *Microwave Journal*, visit our Online Show Daily at www.mwjournal.com/eumw2011 starting September 22nd.


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The 2011 EuMW Defence and Security Forum

This is a full-day event addressing Safety, Security and Defence issues and featuring the EuMW Defence and Security Executive Forum. Attendance is FREE and open to all EuMW 2011 conference delegates, exhibitors and visitors.

Wednesday, 12 October 2011, 08.30 to 18.30, Room Charter 1

Manchester Central Convention Complex, Manchester, UK

The defence and security sector is evolving to reflect the economic and threat realities of the early 21st century. Pressures on public spending and funding are having a significant impact and while the ability to defend sovereignty, resolve regional conflicts and fight global terrorism need to be addressed, new issues have emerged. These include border control and security, such as the detection of weapons and explosives, methods to control cross-border trafficking and anti-piracy measures.

The 2011 EuMW Defence and Security Forum aims to put these issues into context from the perspective of those researching and developing the latest technology, defence/security contractors and government defence agencies and open them up for analysis and debate.

There is a full-day programme this year, expanding on the success of the inaugural EuMW 2010 Defence/Security Executive Forum evening session in Paris that attracted more than 200 attendees last year. The format comprises a Morning Session, Lunch & Learn, an Afternoon Session and the evening Executive Forum.

Morning Session

The day will begin by focusing on Safety and Security and consider the application of the microwave technology that is being developed to increase security and address safety issues. World recognized experts will give tutorials and presentations on active and passive RF detection and imaging techniques applied to short range stand-off surveillance and through-wall and buried sensing.

Lunch & Learn

Over lunch, Strategy Analytics will provide market analysis of the defence and security sector and look at: The impact of budget constraints on future defence technology investment. Their experts predict the desire for technology differentiation will lead to continued opportunities for electronic systems in emerging platforms and this will be supplemented by a focus on upgrading existing capabilities.

Afternoon Session

After lunch, the session will consider – Radar (and EW) Challenges for the 21st Century: An Industry Perspective – which will focus on the application of microwave technology to provide security and counteract threats. A keynote will set the scene and consider technology convergence, then industry experts will outline the development of the technology required to meet current and future challenges. The approach of industry to such challenges will be the focus of a panel session that will feature experts from Agilent Technologies, NXP Semiconductors, RFMD and and TriQuint Semiconductor.

Richard Mumford
Microwave Journal *International Editor*

▲ *Fig. 1 Speakers and panel members of the 2010 EuMW Defence/Security Executive Forum (photo courtesy of Shmuel Auster).*

EXECUTIVE FORUM

In the early evening, the Executive Forum, like in 2010, will offer delegates the opportunity to benefit from the expertise and experience of representatives from government defence agencies and leading defence/security contractors who will provide insights into how their organizations view future threats to global safety, security and defence and the role of technology in addressing these risks. It will conclude with an open panel discussion with questions from the floor. The Executive Forum will keep its established early evening time slot and be preceded and complemented by morning and afternoon sessions.

Figure 1 shows the speakers and panel members of the 2010 EuMW Defence/Security Executive Forum: Back row from left - Dr. Barry M. Alexia, Director Strategy Technology; Rockwell Collins, Frank van den Bogaart, Director Research TNO Defence, Security and Safety and Forum Moderator; Asif Anwar, Program Director for Strategy Analytics; Hans Brugger, Vice President CASSIDIAN; and Pierre Fossier, VP and Technical Director, Thales. Front row from left - Attila Simon, R&T Project Manager, European Defence Agency (EDA); Dr. Massimo Piva, Senior Vice President of Large Systems Business Unit, Selex Sistemi Integrati; Francois Murgadella, Direction Generale pour L'Armement (DGA) & Agence Nationale de la Recherche (ANR); and Major General Roger Renard, NATO RTA Deputy Director.

Attendance is FREE and open to all EuMW 2011 conference delegates, exhibitors and visitors as a selected option of the normal registration process. However, those wishing to attend the 2011 EuMW Defence and Security Forum are asked to register specifically for the Forum and can do so online at: www.mwjournal.com/2011defenceforum or www.eumweek.com.

AGENDA

Morning Sessions

Safety and Security

08.30 – 09.10 Millimetre-wave Imaging - Roger Appleby, Queen's University, Belfast
09.10 – 09.45 A Terahertz Imaging Radar for Concealed Object Detection – Ken Cooper, JPL
09.45 – 10.20 Passive Sub-Millimetre Wave Technology for Weapon and IED Detection
Arttu Luukanen, MilliLab
10.40 – 11.20 Ultra-wideband Radar for the Detection of Buried Threats – David Daniels, Cobham
11.20 – 11.55 Ultra-wideband Radar Imaging – Alex Yaravoy, Technical University, Delft
11.55 – 12.30 Real Time Imaging at 250 GHz - Chris Mann, ThruVision, UK

Lunch & Learn

Defence Market Watch

12.30 – 13.30 The Impact of Budget Constraints on Future Defence Technology Investment
Asif Anwar, Strategy Analytics

Afternoon Sessions

Radar (and EW) Challenges for the 21st Century: An Industry Perspective

Keynote:

13.45 – 14.15 Technological Convergence in Radar and EW – Barry Trimmer, Thales

14.15 – 14.45 The Hidden Decisions Behind Covert Surveillance
Steve Williamson, Cambridge Consultants

Industry Panel Session:

15.00 – 16.30 – Radar Challenges & Solutions

- Providing a New Level of Realism in the Testing and Evaluating of Advanced Radar and Electronic Warfare Systems – Elizabeth Ruetsch, Agilent Technologies
- Selecting the Right Technology for High Power Military Applications – Mark Murphy, NXP
- Reliable High Power GaN Amplifiers for RADAR Applications – Kal Shallal, RFMD
- GaN and GaAs MMIC and Module Technology Supporting the Needs of Phased Array Radars
Dean White, TriQuint Semiconductor

Defence & Security Executive Forum:

17.00 – 18.30 – Trends in Future RF/Microwave Technology for Defence

Special Guest Panelist and Opening Remarks:

Dr. Eli Brookner, Principal Engineering Fellow, Raytheon

Industry and Agency Speakers:

Shane Rouse, ISTAR Capability Advisor, UK MoD DSTL
David Fudge, VP Engineering and Projects of Selex Galileo (UK)
Vincent Mifsud, VP for Technology for Cobham Worldwide
Dr. Barry Alexia, Director Strategic Technology Center, Rockwell Collins
Dr. Farina of Selex Sistemi Integrati as a Guest Panelist

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Microwave Journal

EuMA European Microwave Association

2011 EuMW Exhibitor List

The following list is complete as of August 18, 2011. Exhibitors in bold have an ad in this issue.

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APC-Novacom 229
AR Europe 417
AR/RF Microwave Instrumentation 417
Arlon - MED 23
Artech House 35
Aselsan 144
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Chin Nan Precision Electronics Co. Ltd. 117
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SSBV 545
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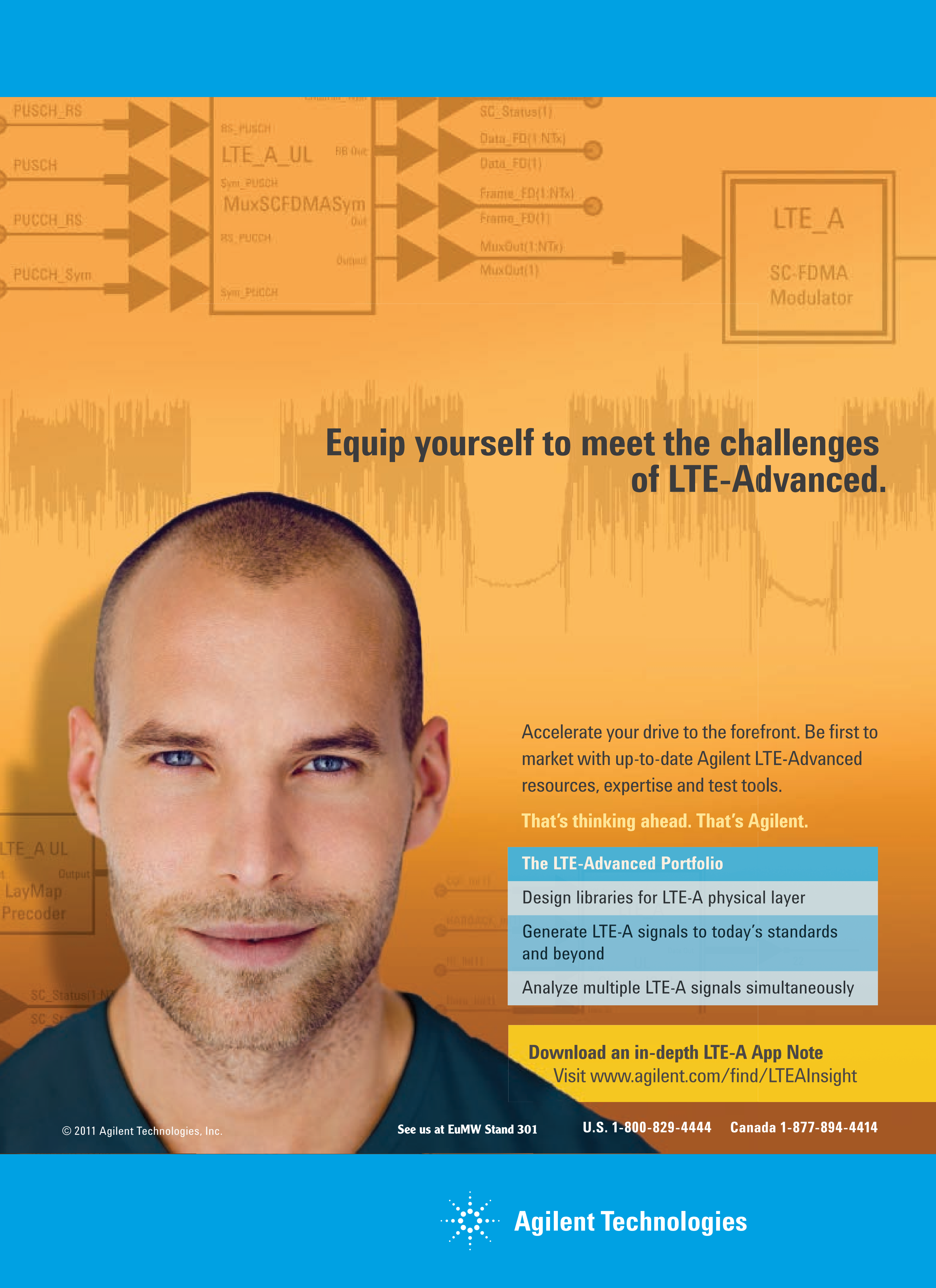
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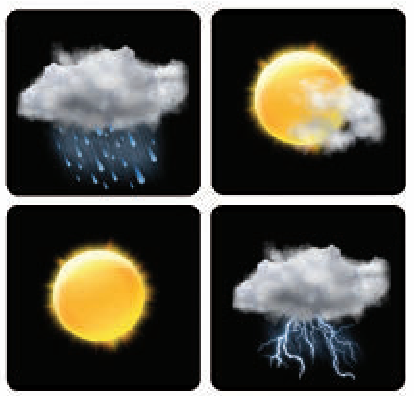


MICROWAVES IN EUROPE: THE CURRENT CLIMATE

In times of plenty, it is easy to view the fruits of success as a given and make hay while the sun shines. The good times included the boom in the mobile communications sector in the late 1990s, subsequent periods of full order books and expansion through growth and acquisitions and the promise of the virtually untapped potential of emerging markets, such as China and India.

Is the European RF and microwave industry feeling the heat? Will the current economic drought starve the industry of essential funding and investment or can focused and targeted innovation harvest demand and stimulate growth in established and developing sectors of the market?

In hindsight, this was the calm before the storm when the recessionary cloud rained without discrimination on the parade of industry, agencies, research institutes and academic institutions in most regions of the world. Through quick and decisive actions, reorganisation and a realistic assessment of capabilities and targets, the fortunate were able to shelter themselves from the worst, while others were washed away by the sheer force and suddenness of the economic downturn.

Few regions of the world have survived unscathed and the economic difficulties of some European countries are well documented. Greece, Ireland and Portugal have received economic bailouts from other Eurozone members and the International Monetary Fund, while Italy and Spain also have to manage significant debt. Interestingly, China has pledged to buy billions of Euros of European debt to support the single currency – a move that may not be entirely unselfish as China sees a strong European market as being essential for exports.

Even with outside help, maintaining a strong European Market is going to be challenging as individual governments get to grips with economic reality. For many nations, austerity is the watchword with a squeeze on funding, both from government and the banks, cutbacks in services and a rationalization of resources. The results have been limited investment, job insecurity and reduced disposable income to pump back into the economy.

It is against this background that the European RF and microwave industry has to operate, evolve and plan for the future. Since the downturn, R&D, both commercial and academic, has had to become streamlined and focused, as have the mechanisms for funding and collaboration. Being fitter and leaner can have its advantages and the RF and microwave industry has the benefit of being at the forefront of technologies that are desired, play a significant role in everyday life and can thus create new opportunities for economic development.

The public's voracious appetite for information anytime, anywhere, allied to the boom in social networking has created the smartphone revolution, which is putting greater demands on mobile and wireless communications. As a result, networks and spectrum are being stretched and it is engineers and researchers in our industry whose expertise and endeavour can make a real difference – be it materials and semiconductor/IC development, at component, subsystem and system level, from infrastructure to mobile backhaul or test and measurement.

RICHARD MUMFORD
Microwave Journal *International Editor*

"…China sees a strong European market as being essential for exports."

Europe's skills base in the RF and microwave sector has traditionally been strong and it is perhaps now when that depth of knowledge and expertise really needs to be tapped into and exploited. Everyone yearns to find that Killer App, but maybe all we need is a small number of less aggressive apps that together can take a significant chunk out of the market.

As EuMW in Manchester demonstrates, European research and development is making a significant contribution. For instance, European research groups pioneered graphene science and technology and are at the cutting edge of other emerging technologies, such as RF MEMS and THz.

The work on metamaterials is significant too with research projects based on novel materials and nanoscience concepts looking to develop a new generation of nanoelectronic devices and systems with improved electro-thermal-mechanical properties that yield higher integration densities. Driven by commercial applications, the desire for higher system functionality and performance is impacting on areas such as high frequency communication, sensors and radar.

Europe has historically been strong in defence and security and that continues, although there is a change in emphasis. With a general decrease in military spending, the search is on for lower cost and higher performance with a greater focus on civilian and non-conventional military applications. These include border control and security, encompassing the likes of imaging to detect weapons and explosives, air traffic control systems, anti-piracy measures and marine radar.

However, having detected what is on the radar with regards to viable options for research and development, does Europe have the organisation and systems in place to fully exploit such potential and bring it to market? Following is an overview of the initiatives and funding that the EU has put in place over recent years, highlighting new initiatives and long-term programmes.

EUROPEAN INITIATIVES

The European Union is an amalgamation of diverse Member States, each with its own endemic industry, educational system, infrastructure, economic framework and political agenda. Meeting the objectives of all and drafting effective common policy can be a challenge, but when there is consensus and mutual goals, the EU can be a significant driver for development.

In particular, the Union has been, and continues to be, effective in instigating, driving, funding and supporting research and technological development in association with industry to bridge the gap between research and the market. At times when individual government funding agency budgets are being cut, European Union initiatives continue to have the resources to distribute funding to a collaborative blend of industry, national research centres and academic institutions across the continent.

Having been forged over time and become established and robust, these initiatives are a key weapon in Europe's armoury in the battle to recover from the downturn, stimulate research and development and provide future growth. At a time when individual companies, research institutes, agencies and governments tend to be understandably cautious in their approach, these EU programmes provide cross-border, interdisciplinary structure and motivation toward tangible, common objectives.

Particularly significant is the European Research Area (ERA), which addresses all research and development activities, programmes and policies in Europe which involve a transnational perspective. ERA's activities operate at regional, national and European level and are designed to enable researchers, research institutions and industry to circulate, compete and cooperate across borders. Its stated aim is to provide access to a Europe-wide open space for knowledge and technologies in which transnational synergies and complementary activities are fully exploited. A number of ERA organisations have long been established, such as the European Space Agency (ESA), but more recent additions that impact on R&D and industry are the European Research Council, the Joint Technology Initiatives and the European Institute for Innovation and Technology.

However, the most significant driver has been the European Framework Programmes that were launched in 1984 and have played a lead role in funding multi-disciplinary research and cooperative activities in Europe and beyond ever since. The current initiative, the Seventh Framework Programme for Research and Technological Development (FP7), is a mechanism for all research-related EU initiatives to stimulate growth, competitiveness and employment, alongside the Competitiveness and Innovation Framework Programme (CIP) and Education and Training programmes.

"…FP7 has been a catalyst for research and development…"

In recent years, FP7 has been a catalyst for research and development in the RF and microwave sector, enabling research industries, academia and companies to pool expertise, experience and resources to develop new technology that is entering the marketplace and contributing to everyday lives. Successful programmes have demonstrated their ability to harness engineering/research expertise in order to target and meet real needs (specific examples and programs are mentioned in later sections).

Also significant is Europe 2020, which is the EU's growth strategy for becoming a smart, sustainable and inclusive economy. Of its seven flagship initiatives, two are of particular interest to our industry. A Digital Agenda for Europe is a strategy for a flourishing digital economy by 2020 that aims to speed up the roll-out of high speed internet and capitalise on the benefits of a digital single market. The Innovation Union aims to improve framework conditions and access to finance

for research and innovation so as to ensure that innovative ideas can be turned into products and services that create growth and jobs. It uses public sector intervention to stimulate the private sector and eliminate the barriers that prevent ideas from reaching the market, such as lack of finance, fragmented research systems and markets, under-use of public procurement for innovation and slow standard setting.

In the latest phase of the Innovation Union rollout, the European Research, Innovation and Science Commissioner announced, in July 2011, the release of nearly €7 B for stimulating European innovation through research funding. As the biggest ever European Commission funding package, it is hoped that this money will help create around 174,000 jobs in the short term, as well as 450,000 jobs and nearly €80 B in gross domestic product (GDP) growth within the next 15 years.

"…it is hoped that this money will help create around 174,000 jobs…"

The funding boost, part of the FP7, will take the form of grants awarded to 16,000 recipients comprising companies and agencies, European universities, research organisations and industry specialists, with a particular focus on small and medium-sized enterprises (SME).

The EU also supports the international Cooperation in Science and Technology (COST) programme, which was set up to expand and coordinate nationally funded research on a European level. COST implements networking activities for researchers, contributing to ERA, goals and participates in the delivery of the Europe 2020 agenda. COST is presently used by the scientific communities of 36 European countries to cooperate in more than 250 research networks (called COST Actions) that leverage national research funds. That funding has been greatly enhanced by the European Commission's announcement in May 2011 to allocate an additional €30 M to COST and this additional funding raises the total budget for COST to €240 M for FP7.

Although its focus is primarily within Europe, the EU also recognises that international cooperation enhances European competitiveness. So, it established the Strategic Forum for International Cooperation (SFIC) whose mandate is to share and pool information and knowledge, identify common priorities, coordinate similar activities undertaken by the member states and the EU, propose joint initiatives and promote networking among the science counsellors of the EU and the member states in major partner countries. The SFIC has already put in place a pilot initiative with India, while others are being launched with China and the USA.

Recognising that web-based and mobile technologies are enabling interactive dialogue and that access to social media is now the norm for many, the Community Research and Development Information Service (CORDIS) has embraced the medium with the launch of a new Partners Service.

Designed to be an interactive platform, this free online service can help individuals to promote their expertise and organisations, find business or research partners, create groups, join networks and find the right components for funding bids and proposals. Acting as a speed-dating service for industry and academia, the resource offers the possibility for users to form partnerships.

Such compatibility and interaction are critical if there is to be a strong and successful collaboration between R&D and industry. The next section of this report illustrates how this relationship is developing both technologically and in the marketplace by identifying specific areas of activity and growth.

Sector Overviews & Initiatives

The chairmen of the three 2011 European Microwave Week conferences – the European Microwave Conference (EuMC), the European Microwave Integrated Circuits (EuMIC) Conference and the European Radar Conference (EuRAD) – offer an insight into key areas of development and identify future trends. To illustrate specific European activity in these sectors, examples of recent FP7 and other relevant EU initiatives are outlined.

RF & MICROWAVES

Sector overview by Stepan Lucyszyn, EuMC 2011 Conference Chair

The US and Asia are recognised for directing large budgets to independent world-leading groups within both the industrial and academic sectors, for R&D activities in areas of strategic importance, such as health care and defence. In contrast, European Union initiatives put a stronger emphasis on distributing funding to a collaborative blend of industry, national research laboratories and university partners located across Europe; at a time when individual government funding agency budgets are being reduced.

A good example of this can be seen in the area of RF microelectromechanical systems (RF MEMS). In the early days, DARPA injected many tens of millions of dollars into RF MEMS technologies, enabling the US to take the early lead. As the Editor of the new Eurocentric book titled, *Advanced RF MEMS*, a deliverable from AMICOM (a European Union 'Network of Excellence', funded under its FP7 programme), I believe that RF MEMS has now matured enough to be taken seriously; there are now many solutions to the issues of packaging and reliability that thwarted this technology in the past. Also, with attention now turning to bringing down manufacturing costs there will soon be an accelerating migration of applications that embrace this new technology.

"...RF MEMS has now matured enough to be taken seriously..."

The reason for this is that the higher performance advantages, from new RF MEMS-based architectures, will compete more favourably in terms of overall cost with the more traditional

solid-state solutions. To this end, Europe is currently taking a leading role within world-class research institutes that include IMEC (Belgium), FhG-ISiT and EPCOS AG (Germany), VTT (Finland), CEA-LETI and CNRS-LAAS (France).

In security and defence, Europe has historically been and currently still is in a strong position. For example, across Europe and within Israel, there is growing activity in unmanned aerial vehicle (UAV) technologies for policing, border control and military applications. Within the UK, ThruVision Systems has marketed what is claimed to be the world's first commercial stand-off passive imaging system.

Operating at 250 GHz, it is capable of detecting metals, plastic, liquids, gels, ceramics and narcotics concealed beneath a person's clothing. The UK also has a strong reputation for submillimetre-wave satellite remote sensing, with Astrium Ltd. In addition, TeraView Ltd. is one of the world's leading suppliers of commercial equipment for close-in active imaging and spectroscopy at THz frequencies.

It has been suggested that the global THz market will be $400 M by 2017. BCC Research predicts that this market will be $521 M by 2018. According to the Thintri Inc. market study for 2010, the current annual sales for THz equipment amounts to only $25 M worldwide, with a growth of 10 to 15 percent in 2010, but a predicted growth of 50 to 80 percent by 2015.

Within the security sector, the THz market is likely to exceed $300 M worldwide by 2020. Within the manufacturing/process control sector, material inspection remains the most promising market opportunity for THz technology, with a predicted forecast of $500 M worldwide by 2020.

For the domestic mobile phone market, carriers are now advertising 4G networks with faster download speeds. The UK is one of the global leaders for base station filters, with companies such as Radio Design and Filtronic at the forefront in this area. Also, in the commercial sector, 2010 saw more than 1 million microwave point-to-point radios being sold for backhaul applications or extending networks wirelessly; with 75 percent of these having 1 Gbit/s true data throughput. For multi-gigabit transmission, the 60 and 70/80 GHz bands remain the growth market segment.

Indeed, for both the domestic and commercial markets, a number of working groups have published standardizing specifications for the unlicensed 60 GHz band, including the following: ECMA-387 for high data rate wireless personal area networks (WPAN); IEEE 802.15.3c representing a millimetre-wave extension to the IEEE 802.15.3 WPAN standard; and WirelessHD for existing, commercially available, wireless video area networks (WVAN) based on IEEE 802.15.3c. More recently, the Wireless Gigabit (WiGig) Alliance has been working with the IEEE 802.11ad group to extend the IEEE 802.11 WLAN specification to the 60 GHz band, for publication next year.

Emerging enabling technologies, such as graphene, RF MEMS and THz are redirecting engineers and

scientists from areas including material science, mechanical engineering and applied sciences, respectively, into the RF and microwave sectors. In addition, metamaterials appear to have stolen the limelight (metaphorically, or should that be metaphysically speaking?). From Star Trek's Romulan War Bird Cloaking Device to Harry Potter's Invisibility Cloak, even school children are being drawn into technologies that may one day turn fiction into fact. In conjunction with exciting new applications ranging from GPS tracking to intelligent transportation systems to pervasive wireless sensor networks, such examples are helping to inspire and create the next generation of RF and microwave engineers.

FP7 PROJECTS

The aim of the €4.7 M Beyond Next Generation (BuNGee) project is to achieve a tenfold increase in mobile broadband infrastructure capacity. Planned to continue through June 2012, it will draw upon collaboration among consortium members comprising European service providers, technology equipment vendors, universities and research organisations. The consortium's objective will be to increase the overall mobile network infrastructure capacity density to beyond what is promised by current technologies, targeting the challenging goal of 1 Gbit/s per square kilometre. The project will identify network deployment strategies especially suited for dense urban environments where the demand for wireless broadband access is highest.

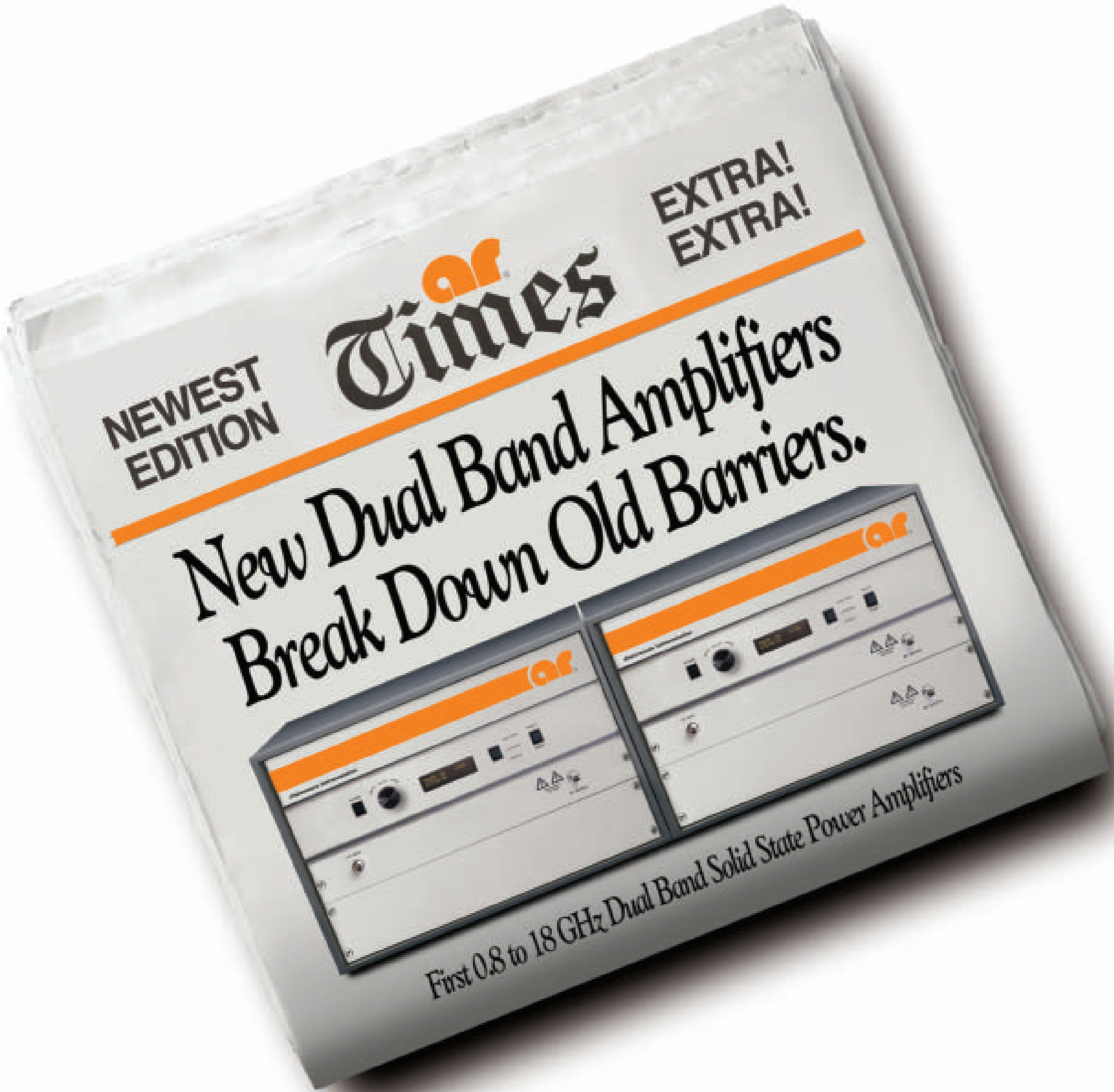
Also concerned with wireless mobile networks is the Energy Aware Radio and Network Technologies (EARTH) project that will adopt an approach that considers the energy efficiency of mobile networks at a comprehensive system level rather than focusing on discrete network elements. The consortium members will research approaches to allow for unprecedented energy savings in the area of wireless networks, their components and its radio interfaces. Based on this, EARTH will develop a new generation of energy-efficient network equipment and components, craft energy-oriented deployment strategies, and conceive energy-aware network management solutions.

In the automotive arena, the DRIVE C2X Project, with a total budget of €19 M, aims to create the transport system of the future, in which cars communicate with each other, receive real-time information about traffic, and also gather and forward information. The three-year project, which commenced in January 2011, follows on the work of the PRE-DRIVE C2X Project that was completed in June 2010.

ICS & SEMICONDUCTORS

Sector overview by Ali A Rezazadeh, EuMIC 2011 Chairman (In collaboration with John Atherton, Co-Chair EuMIC 2011)

Semiconductor materials, devices and ICs are essential components of today's microwave and millimetre wave subsystems for many applications, such as telecommunication, defence,



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automotive, space and imaging systems. These devices and ICs require not only different technological processes, but also advanced modelling, simulation and characterization in order to predict the performance of individual technology and its successful route to exploitation. European microwave companies and research centres produce, develop and are involved in research that covers a broad range of technologies, which play an increasingly significant role in everyday life and open up new opportunities for economic development.

"Silicon technologies are steadily improving their operating frequency …"

Silicon technologies are steadily improving their operating frequency and their level of integration. In particular, the scaling of Si MOS technology has led to phenomenal growth in transistor density and performance during the past few decades. This growth was primarily driven by traditional device scaling from lithography improvements to power supply scaling.

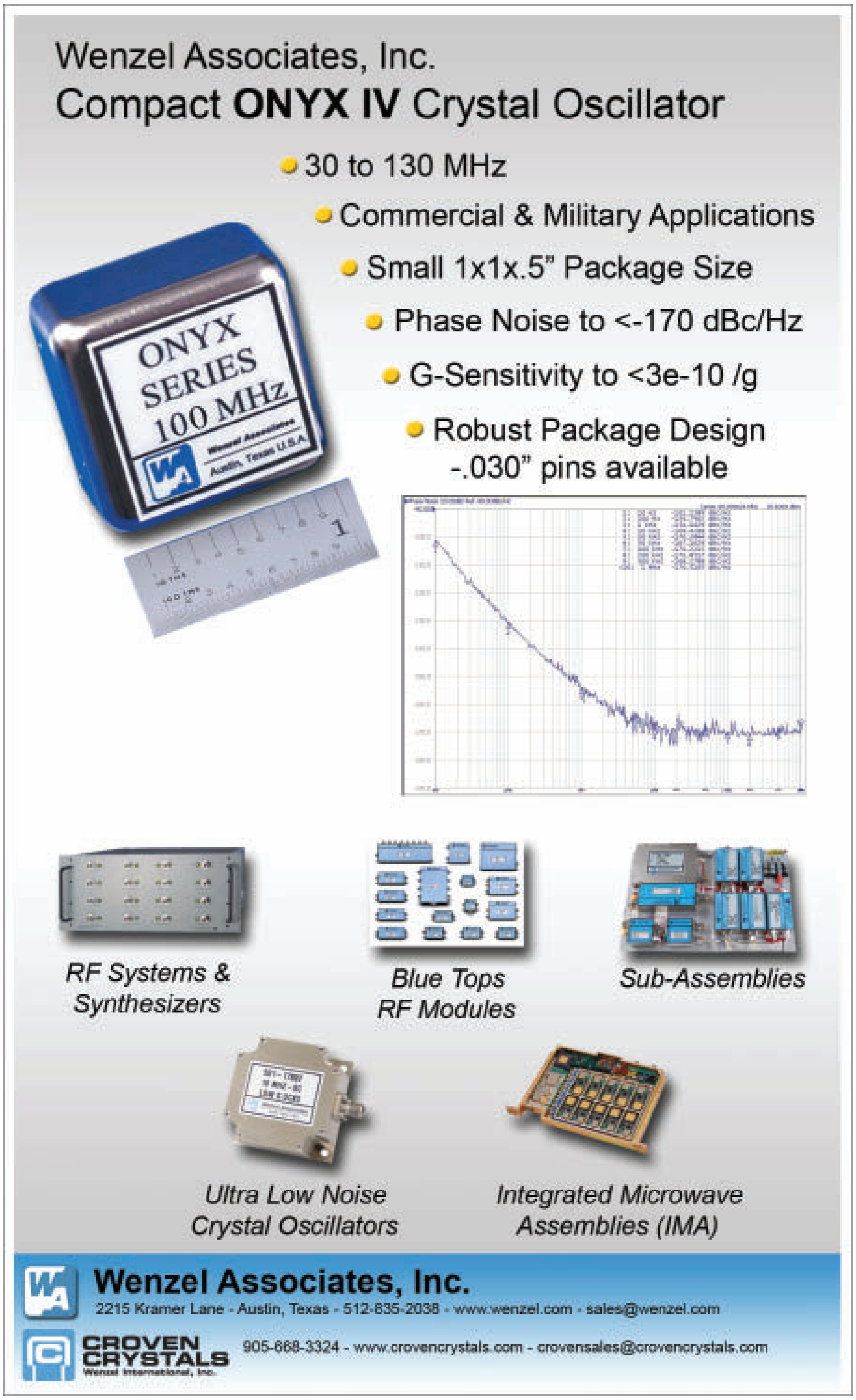
However, the industry began to experience fundamental barriers at 90 nm in achieving historical performance gains through traditional scaling such as High K material plus metal gate technology. The convergence of new semiconductor transistor structures and materials along with a better fundamental understanding of carrier transport in new materials will be the key to successfully scaling transistors to beyond 10 nm nodes.

GaAs devices for defence applications continue to be the driving force in many of the microwave applications. GaAs remains a key enabling technology in military and defence systems, covering radar, communications, electronic warfare and smart munitions. However, the demand for wider bandwidth, higher frequency and higher power favours emerging technologies, such as GaN and SiC. These devices require higher DC bias voltages and more critically, new designed bias circuitry, as well as modelling and packaging to deal with very high power density in these devices. There is currently dynamic academic research and industrial development in the wideband semiconductor devices sector.

The future of RF/microwave technology will be fundamentally influenced by nanoelectronics, which will provide substantial improvements in the integration of RF electronics, sensing, energy harvesting, computing and communication systems. Driven by technology and market requirements, semiconductor electronics has already found its way into nanoscale dimensions.

Currently, a multitude of research projects based on novel materials and nanoscience concepts are being developed to pave the way for a new generation of nanoelectronic devices and systems, yielding not only higher integration densities but also substantially improved electro-thermal-mechanical properties. Many of the nanoscale materials and devices exhibit their most interesting properties over a broad range of applications and operating frequencies up to the THz region.

Many applications, such as high



frequency communication, radar and sensors, require higher system functionality and performance. Driven by commercial applications, however, cost issues become most important. Monolithic integrated circuits based on GaAs and InP materials with high performance are currently available and the requirement for elaborate chip mounting and interconnection technologies has emerged. Due to the relatively high cost per area for GaAs and especially InP based ICs, hybrid integration techniques are currently being considered. In addition, monolithic integrated circuits have to deliver increasing functionality with smaller chip size. These requirements can be fulfilled by multifunctional chips, which integrate different circuit functions or multi-chip modules where different ICs, often with different semiconductors, can be integrated.

These are some of the current and future directions of ICs and semiconductor devices. However, it should be emphasized that advanced simulation and modelling are key factors in achieving the optimum performances of circuits and systems.

EU FLAGSHIP INITIATIVE

A coordination action on graphene will be funded by the European Commission to develop plans for a 10-year, €1,000 M Future and Emerging Technology Flagship (FET). This is a large-scale visionary research initiative, aimed at a breakthrough for technological innovation and economic exploitation based on graphene and related two-dimensional materials.

"...plans for a 10-year, €1,000 M Future and Emerging Technology Flagship (FET)."

The research effort of individual European research groups pioneered graphene science and technology, but a coordinated European level approach is needed to secure a major role for the EU in this ongoing technological revolution. The Graphene Flagship aims to bring together a large, focused, interdisciplinary European research community, acting as a sustainable incubator of new branches of ICT applications, ensuring that European industries will have a major role in this radical technology shift over the next 10 years. An effective transfer of knowledge and technology to industries will enable product development and production. The pilot phase coordination action started in May 2011 and the Graphene Flagship already includes over 130 research groups, representing 80 academic and industrial partners in 21 European countries.

RADAR

Overview of European radar activities by Tony Brown, EuRAD 2011, Conference Chairman

EuRAD 2011 is the eighth in the conference series. The event continues to be at the forefront of radar application, design and implementation and reflects current activity across the broad area of radar and related disciplines. In general, the European radar industry is evolving and encompassing new applications in the civilian, military and

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security sectors. The continued development of lower cost components and processing is impacting a broad range of solutions. As one of the conference's keynote speakers points out, this trend to lower costs and higher performance marks the beginning of an exciting era with new technologies, such as graphene-based devices offering the hope of dramatic changes in the future price/performance of microwave radar.

"…the European radar industry is evolving and encompassing new applications …"

We have yet to see the end of Moore's Law and that increasing capability of digital processing impacts both radar and communications. This is leading to interesting developments between the disciplines. The use of MIMO and OFDM in radar are examples of this, with UWB communications and location finding techniques drawing on radar experience.

As military spending is under increasing pressure, there is greater emphasis on civilian and non-conventional military applications for radar. Anti-piracy and related border control issues are one market driver; safety and the environment are others. We are seeing a renewed interest in air traffic control systems, in marine radar, in imaging for security applications and, of course, in automotive applications, which are now moving confidently into the next generation.

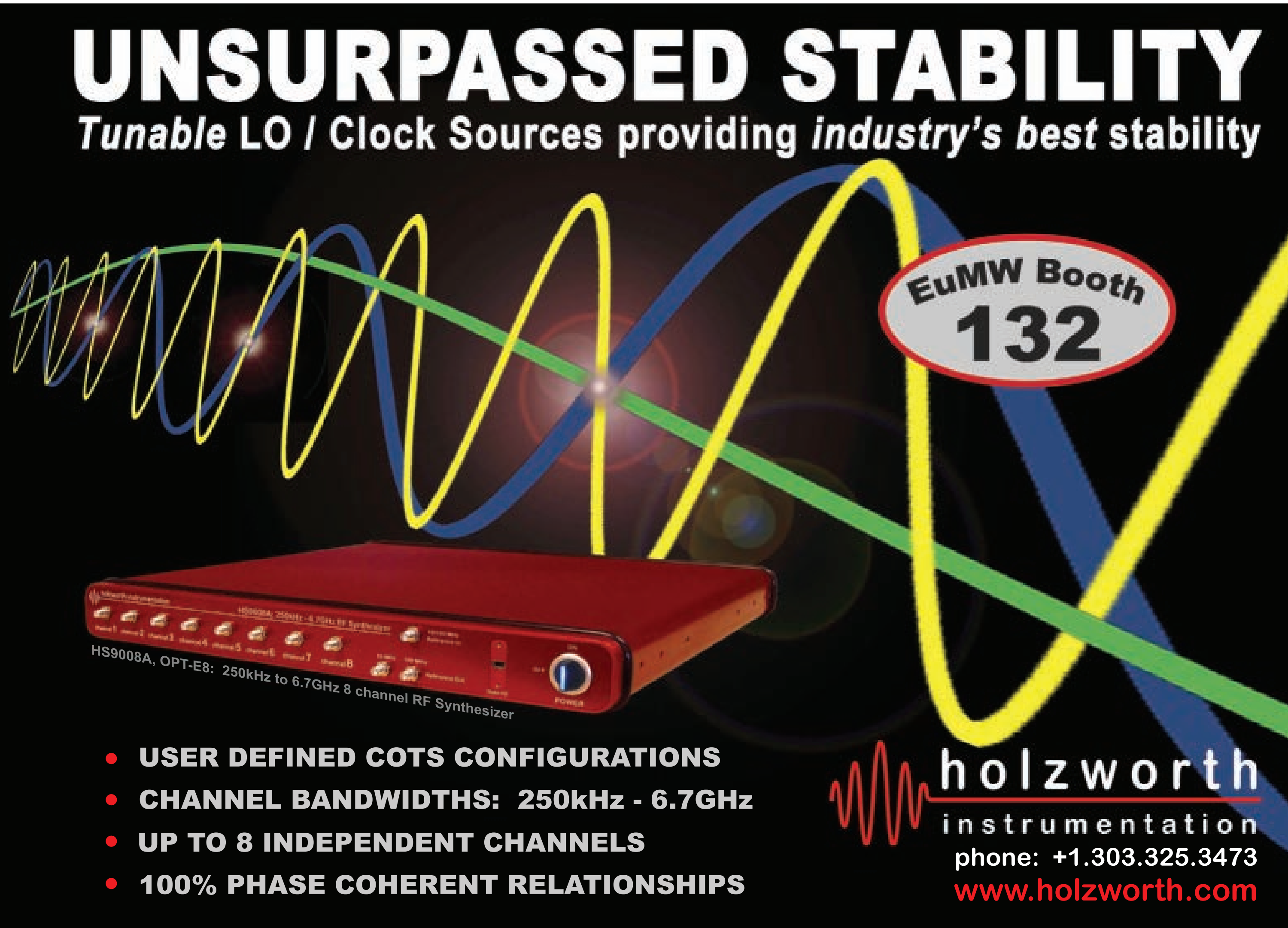
At a technology level, interest in wide bandwidth radar continues to grow, recognising the inherent resolution and interference resilience these systems can bring. There is also continued strong interest in micro-Doppler and related target identification techniques and phased and digital beam-forming arrays continue to produce innovative approaches to serve military and civilian needs.

One problem that is of growing importance worldwide, and which is attracting interesting system solutions, is the potential impact of wind farms on a wide variety of radar. Across Europe and the USA, different solutions are being proposed from improved tracking and signal processing through to high resolution "fill in" radars and the design of low RCS wind turbines. This problem continues to challenge radar designers for robust and cost-effective solutions.

Overall, the radar community is maintaining vibrancy, despite the economic climate and by innovative use of technologies, looks set to continue to address both existing and new application challenges.

FP7 PROJECT

The Protection of European BoRders and Seas through the IntElligent Use of Surveillance (PERSEUS) project has been instigated to provide protection of the European seas and borders with the smart use of technologies. The project, with a budget of €43.7 M and an execution period of four years, addresses the call for an integrated European system for maritime border control. Its purpose



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is to build and demonstrate an EU maritime surveillance system integrating existing national and community installations and enhancing them with innovative technologies.

PERSEUS will incorporate technological innovations regarding detection and analysis applied to maritime security, particularly for the detection of low flying targets and small vessels. Multiple sensors and sources of information will be incorporated into the system, which will also employ technologies and capabilities under development by other EU projects, including other segments such as Space.

CONCLUSION

As the title signals, this report focuses on the current climate of the RF and microwave industry in Europe. As recent years have demonstrated, just like the weather, the prevailing market conditions can change suddenly and unexpectedly, severely testing the strength of the industry's foundations and the framework that supports it.

The cloud still hanging over all enterprises, academic and commercial, cannot be ignored but, as has been outlined in this report, there are rays of optimism to brighten the gloom. As the sector overviews demonstrate Europe does have the skills and knowledge to develop those technologies that consumers and society not only crave, but demand. Add to that some blue sky thinking, which is producing research that has the potential to take developments to a brave new world.

Such creativity has to be backed up with systems and support that can bring these ideas to fruition and to market. This often cannot be done by individual companies, research agencies, large corporations or even governments. This is where the coordinated action of EU initiatives that can connect, support and fund the right skills, at the right time and at the right level – regional, national or pan-European – are making a difference.

Through long-term, forward-thinking structured co-operation and coordination, the significant initiatives that have been put in place during the last decade are now reaping rewards. In particular, the EU's Competitiveness and Innovation Framework Programmes are identifying, promoting and stimulating competitiveness, while the 7th Framework Programme and the associated Networks of Excellence Programmes are encouraging the involvement of industry alongside academia to address Europe's traditional weakness in commercialising the results of research, and identifying the market potential of new technology.

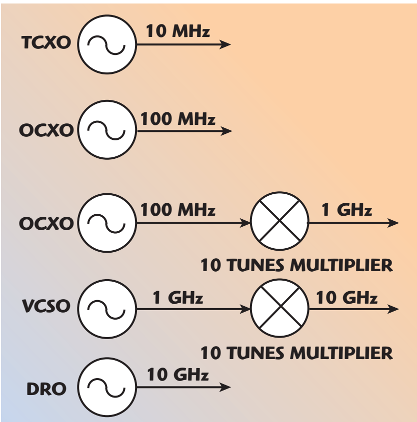
Significantly too, at a time when companies, governments and agencies have to watch the Euros, the European Commission is able to pool resources, take a long-term view and provide substantial funding and backing.

While identifying the positives, optimism has to be tempered with the reality that the marketplace is far from stable, economic recovery is slow, if not comatose, and although significant efforts are being made, the European RF and microwave industry cannot guarantee its day in the sun just yet. ■

ADAPTIVE MODE-COUPLED HARMONICALLY TUNED HIGH-Q ULTRA LOW PHASE NOISE SOURCES

Historically, synthesizer developers have relied on a crystal based multiplied 1 GHz reference oscillator featuring excellent phase noise performance at frequencies of 3 GHz and above. A frequency multiplier crystal oscillator can offer low phase noise performance at frequencies of 1 GHz and above, but at the cost of larger size, higher noise floor and higher power-consumptions.[1-7] The most dramatic change will occur when optimum loop bandwidth extends to a few megahertz, where reported adaptive mode-coupled harmonically tuned voltage controlled SAW oscillator (VCSO) noise performance supersede the performance of the conventional VCSOs and dielectric resonator oscillators (DRO), including the multiplied crystal oscillators at 3 GHz and above.

Various reference oscillator schemes are possible as shown in ***Figure 1***.[5] A 10 MHz temperature-compensated crystal oscillator (TCXO) provides small size and low cost benefits for low-to-moderate performance applications, but higher multiplication factors can degrade the noise floor significantly. Improved stability and phase noise performance can be achieved by using a 100 MHz oven-compensated crystal oscillator (OCXO), but at the cost of size and power consumption. It is worth noting that higher frequency OCXO (for example, 100 MHz instead of 10 MHz) can potentially result in a improved synthesizer jitter and phase noise performance. Frequency multipliers are used to extend synthesizer operating frequency bands, but at the cost of phase noise and spurs, which are degraded at 20logN, where N is the multiplication factor. Therefore, a designer's main concern is to minimize the degradation of phase noise using self-injection and noise filtering techniques, and the most effort is toward the realization of developing fundamental low phase noise high reference signal sources.[7] ***Figure 2*** shows the measured phase noise plots for a 128 MHz VCXO circuits (VCXO #1, Vtune=2 V; VCXO #2, Vtune=5 V; VCXO #3, Vtune=2 V; VCXO #4, Vtune=5 V) to provide a brief insight about the phase noise characteristics.



▲ *Fig. 1 Typical reference frequency generation topology.*

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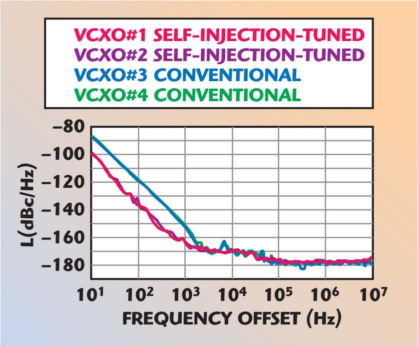


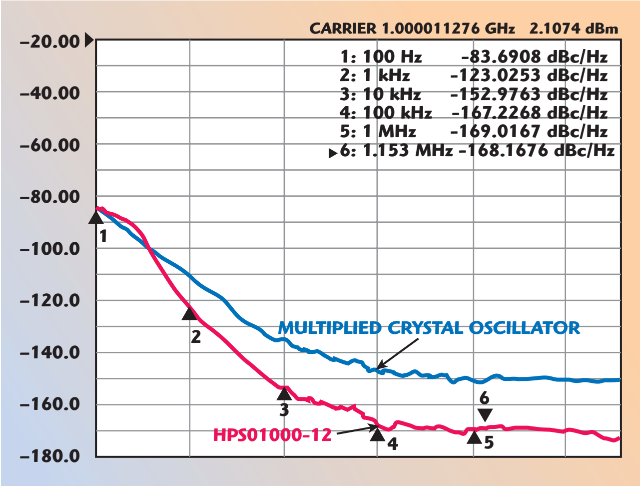
▲ *Fig. 2 Measured phase noise plots of 128 MHz VCXO circuits.*

As shown in Figure 2, self-injection feature adjusts the phase of the resonator tank for providing optimum group delay, thereby improving the phase noise below 1 kHz offset from the carrier. Further improvement in phase noise performance at far offset (<1 kHz) can be achieved by an adaptive self-tuning filter network that introduces the required delay to generate a feedback signal for far out phase noise reduction.[3-7]

MULTIPLIED FREQUENCY CRYSTAL OSCILLATOR CIRCUIT

As briefly discussed, designers have often relied on multiplying a low-noise crystal oscillator to achieve higher frequency 1 GHz and higher output signals. The harmonic frequency crystal oscillator approach can provide excellent phase noise, but tends to consume a great deal of power, generate high levels of noise, and are large in size. Commercially available crystal oscillators at 100 MHz and below are available with phase noise of −160 to −176 dBc/Hz offset 20 to 100 kHz from a 100 MHz output.

When multiplied 10 times to obtain a 1 GHz frequency source, the phase noise of crystal oscillators translates to −140 to −156 dBc/Hz offset 20 to 100 kHz from 1 GHz but can degrade the noise floor by as much of 20 dB. The availability of low cost, low noise voltage-controlled saw oscillators (VCSO) clears the way for small, low noise synthesizers. Part of using these sources involves modeling the surface acoustic wave resonators under large signal drive conditions for better insights about noise dynamics at close-in phase noise, then developing manufacturable methods for producing high-purity and temperature stable oscillators in chip form.



▲ *Fig. 3 Performance comparison between a 1 GHz VCSO and a multiplied crystal oscillator.*

Figure 3 compares a fundamental 1 GHz VCSO (HFSO1000-12) phase noise at 1 GHz to that of a commercially available multiplied crystal oscillator circuit. It can be seen that a fundamental 1 GHz VCSO supersedes the phase noise performance as much as 20 dB at 100 kHz offset from the carrier as compared to commercially available multiplied 1 GHz VCXO. The primary drawback of VCSOs is their inability to be tuned by means of tuning varactor diode; therefore, they are unable to compensate the frequency drifts due to aging and changes in operating temperature for reference source applications. Accordingly, there is a need for frequency agile SAW resonators for VCSO applications.

In this article, new techniques using degenerated adaptive mode-coupling and regenerative noise filtering are being incorporated to achieve excellent spectral performance at fundamental frequencies of 3 GHz and

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SPST								
0.2 – 2	SW1-002020RN1NF	1.7	70	1.6:1	10/10	20	35	35/70
2 – 8	SW1-020080RN1NF	2	80	1.7:1	10/10	20	35	35/70
4 – 12	SW1-040120RN1NF	2.2	80	1.7:1	10/10	20	35	35/70
2 – 18	SW1-020180RN1NF	3	80	2:1	10/10	20	35	35/70
1 – 18	SW1-010180RN1NF	3	70	2:1	10/10	20	35	35/70
SP2T								
0.2 – 2	SW2-002020RN1NF	1.5	70	1.6:1	10/10	20	35	60/60
2 – 8	SW2-020080RN1NF	1.8	80	1.7:1	10/10	20	35	60/60
4 – 12	SW2-040120RN1NF	2.2	80	1.7:1	10/10	20	35	60/60
2 – 18	SW2-020180RN1NF	2.8	80	2:1	10/10	20	35	60/60
1 – 18	SW2-010180RN1NF	3	70	2:1	10/10	20	35	60/60
SP3T								
0.2 – 2	SW3-002020RN1NF	1.6	70	1.6:1	20/20	150	180	85/85
2 – 8	SW3-020080RN1NF	1.9	80	1.7:1	20/20	150	180	85/85
4 – 12	SW3-040120RN1NF	2.4	90	1.7:1	20/20	150	180	85/85
2 – 18	SW3-020180RN1NF	3	80	2:1	20/20	150	180	85/85
1 – 18	SW3-010180RN1NF	3.1	70	2:1	20/20	150	180	85/85

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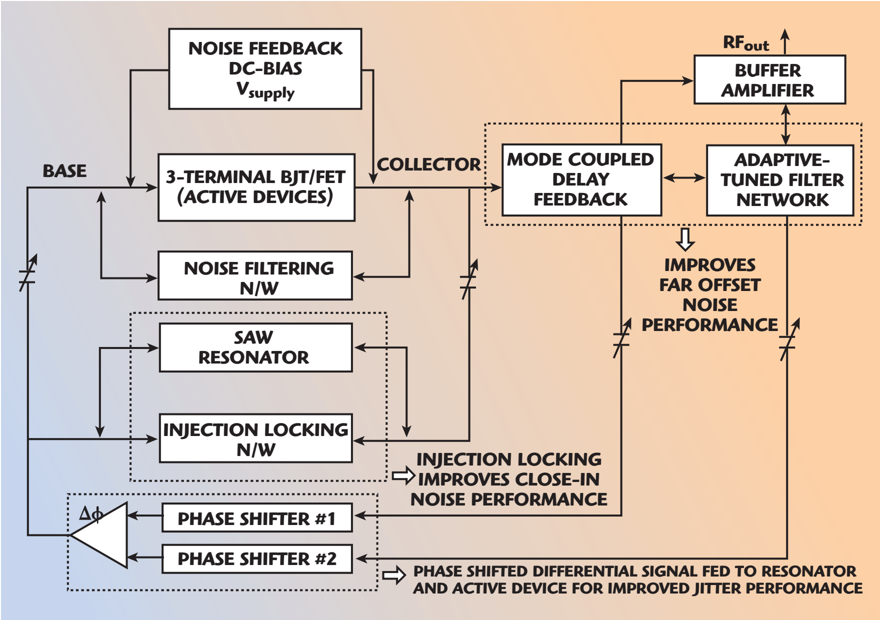

▲ *Fig. 4 Block diagram of an adaptive mode-coupled, harmonically toned VCSO.*

above. The novel approach includes a methodology to enhance the mode-injection locking range using delay feedback techniques and to reduce or eliminate the amount of filtering needed to suppress sub-harmonics and higher-order harmonic products. The approach also reduces the susceptibility to microphonics while retaining low phase noise and a moderate tuning range to compensate for short-term and long-term effects of thermal drift and aging.[2] The reported reference sources are ideal for use as clock translators for high speed analog-to-digital converters (ADC) and direct-digital-synthesizer (DDS) clocks, offer superior figure-of-merit (FOM) in terms of performance, price, and product delivery to satisfy both the technical and current business needs of designers and buyers.

ADAPTIVE HARMONICALLY TUNED REFERENCE SIGNAL SOURCE TOPOLOGIES

High Q factor resonator (RF-MEMS, Crystal, SAW, Ceramic) based oscillators are widely used in wireless applications because the technology features very low phase noise at fixed frequencies through about 1 GHz. However, a reference signal source operating above 1 GHz is generally realized using a multiplier approach, which is power hungry, large in size and has degraded phase noise performance. ***Figure 4*** shows the typical block diagram of the ultra low phase voltage-controlled oscillator using an adaptive mode-coupled harmonically tuned mechanism enabling more than 500 kHz tuning for compensating the thermal drift without using a heating device and fabricated in tiny SMD packages (0.5" × 0.5").

The typical measured phase noise of a harmonically tuned (5th harmonic) 1 GHz SAW resonator at 10 kHz offset from the 5 GHz carrier is –138 dBc/ Hz, with RMS jitter less than 10 femto sec. The reported harmonically tuned 5 GHz VCSO offers about 10 to 15 dB superior phase noise performance as compared to commercially available SAW and crystal multiplied sources for a given size, cost and power consumption.

TUNABLE SAW RESONATOR FOR VCSO CIRCUITS

The resonant frequency of the SAW device is set by the distance between the electrode "fingers" (see ***Figure 5***). Quartz, $LiTaO_3$ and $LiNbO_3$ are common substrates for such devices. Initial accuracy is dependent on the accuracy of the printing of the "fingers." Initial accuracy can be in the ±50 to 200 ppm range. The approximate temperature constant of quartz is 0.03 ppm/^{0}C^2 and -20ppm/^{0}C^2 for LiTaO3.

Generally, it is highly desirable for reference frequency sources to exhibit ultra low phase noise characteristics. This is usually accomplished by us-

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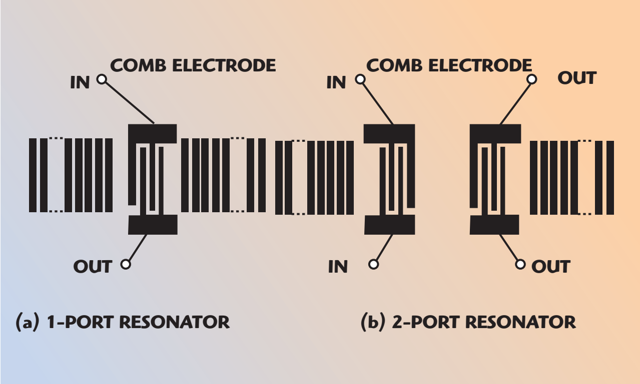
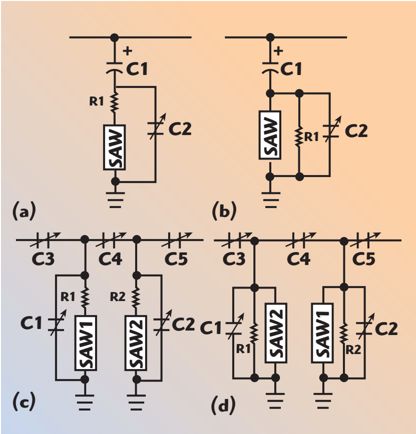
ing high Q quartz crystals and SAW resonator devices. Unfortunately, SAW resonator based oscillators have several disadvantages, including a limited operating temperature range and limited tuning range (which limits the amount of correction that can be made to compensate for the tolerances of other components in the oscillator circuitry). Coupling a varactor diode or other capacitive element to a high Q-factor frequency controlling element, such as SAW device, does not result in a tunable, low phase noise VCSO circuit. To overcome this limitation, VCSO have been implemented that couple together two or more SAW devices to achieve a wider tuning range and low phase noise. The simplified approach is to reduce the quality factor of the SAW by introducing series or parallel loss resistors. However, the use of multiple SAW elements increases the complexity and the cost of the VCSO circuits.

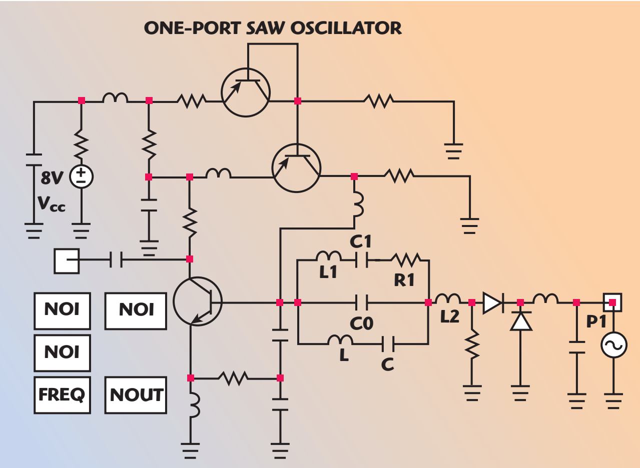


▲ *Fig. 5 Typical representation of SAW resonator (a) one-port saw and (b) two-port saw.*



▲ *Fig. 6 Arrangements of tunable SAW resonator networks.*

Figure 6 shows the arrangement of tunable SAW resonator network based on the design trade-offs between the phase noise and the tuning characteristics of the VCSOs. Although the frequency of VCSO can be changed over a fairly wide range by means of varying the capacitances (C_1 to C_5), the parameters of the oscillator circuit are changing drastically. Figure 6 shows the arrangements of tunable SAW resonator networks: (a) series resistance in conjunction with SAW resonator, (b) parallel series resistance in conjunction with SAW resonator, (c) series resistance in conjunction with capacitively coupled SAW resonator, and (d) parallel resistance in conjunction with capacitively coupled SAW resonator.



▲ *Fig. 7 Schematic of a typical SAW resonator oscillator.*

This creates serious problems in terms of phase noise and tuning linearity. For low phase noise, it is necessary to keep the reactance slope as steep as possible by maximizing the phase derivative and group delay ($\partial\varphi/\partial\omega$) of the coupled SAW resonator network. For tuning linearity, it is necessary to keep the reactance slope as straight as possible over the desired

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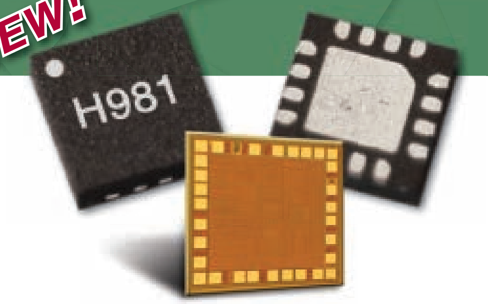

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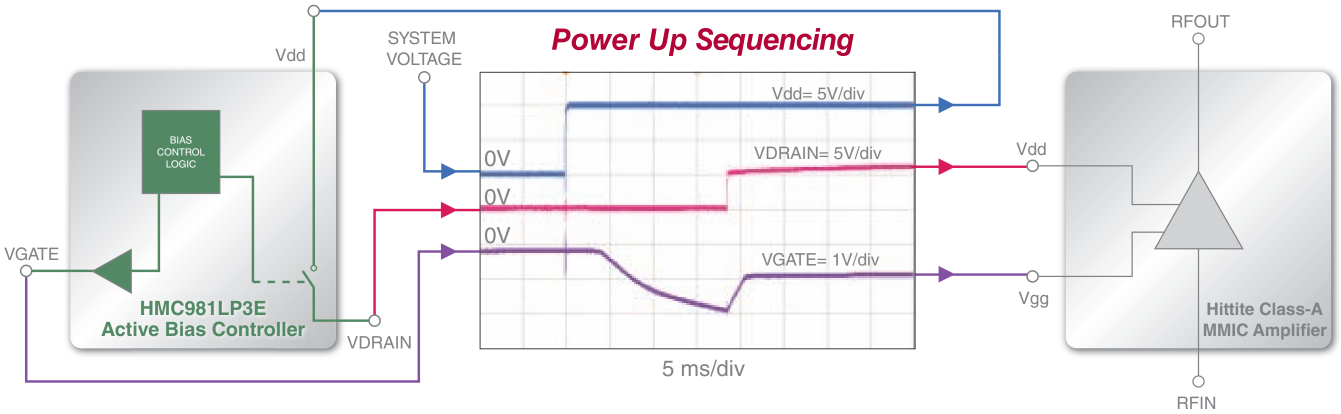

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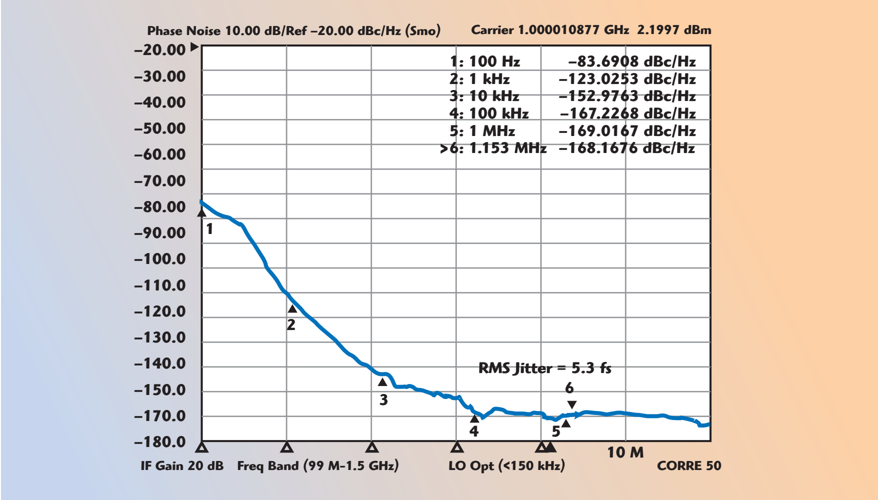

▲ *Fig. 8 Phase noise of a cascaded mode-coupled, harmonically tuned SAW resonator oscillator (999 to1001 MHz).*

operating frequency range. If the reactance curve is too shallow, the oscillator circuit becomes susceptible to noise and stability perturbation. Furthermore, the straighter the reactance curve is, the greater is the tuning linearity in the desired frequency range. To overcome these problems, a novel technique is to incorporate additional inductor (L) parallel to the SAW resonator that resonates with the C0 (the internal and package capacitance of SAW resonator) as shown in ***Figure 7***. Additionally, the value of inductor L2 and C is adjusted in order to shift the resonance to that of intrinsic SAW resonator (without insertion of L and C) frequency (i.e. 1 GHz). This enables the reactance curve linear and steep over the operating frequency range from 999.3 to 999.8 MHz.

An objective of this design is to improve the tuning characteristics (on the order of ±400 ppm) of the SAW resonator without compromising phase noise performance by cascading the mode-coupled harmonically tuned network to compensate the frequency drift caused due to change in operating temperature (–40° to +85°C). The drive to maximize the phase noise performance using a mode-coupled harmonically tuned network in the compact space is particularly demanding on the RF/microwave communication systems. The cascaded mode-coupled harmonically tuned VCSO circuit minimizes the phase noise with more than 2 MHz tuning, resulting in a cost-effective solution. The typical measured phase noise is –152 dBc/Hz at 10 kHz offset from the carrier with jitter less than 6 fs, this is the reasonably low phase noise solution for this class of inexpensive VCSO solutions (see ***Figure 8***).

ULTRA LOW PHASE NOISE SIGNAL SOURCE DESIGN METHODOLOGY

The oscillator design methodology is being traded simultaneously by an increase in operating frequency, bandwidth and a decrease in physical size. The result is that the physical design layout challenges faced by circuit designers are rapidly increasing, while choices for how these challenges should be best-addressed are kept aside. In addition, oscillator design technology did not earn its reputation as black magic for no reason.

Unlike other microwave circuits, oscillators do not behave in a totally predictable way, so "tweaking" has been an accepted mainstay of the signal sources design flow. Fortunately, high frequency commercial CAD design tools (Agilent, Ansoft, AWR, MS Office, MathCAD, etc.) have dramatically improved so that tweaking of prototype circuits is much less common, and today's designers have powerful CAD tools that can make meaningful sense of the black magic.

For high Q factor resonator based oscillator applications, noise dynamics place stringent conditions on these reference frequency sources owing to inherent high noise figure and low dynamic range caused by the uncontrolled nonlinearity at large-signal

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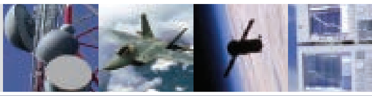

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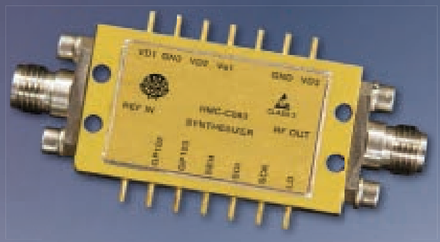

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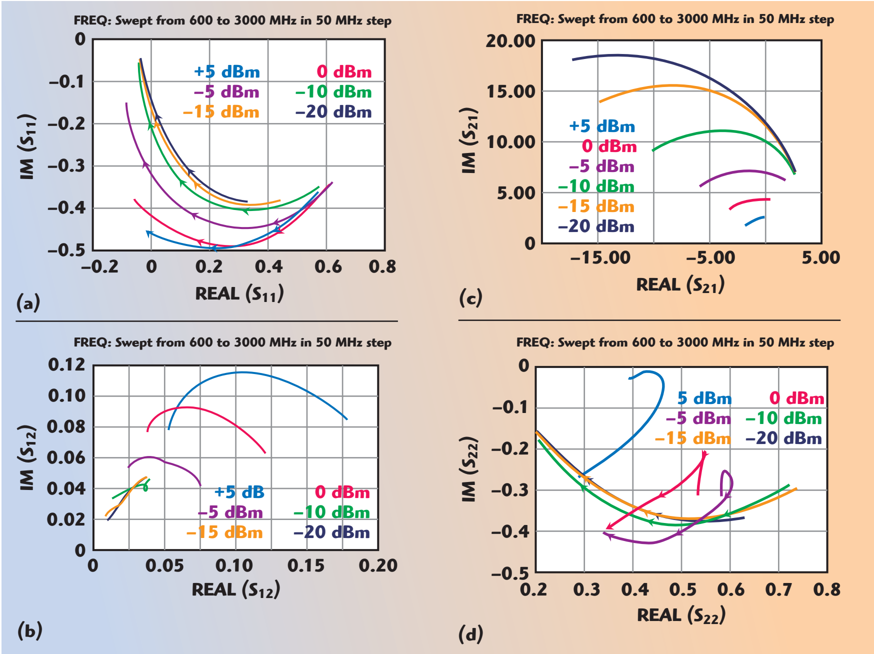
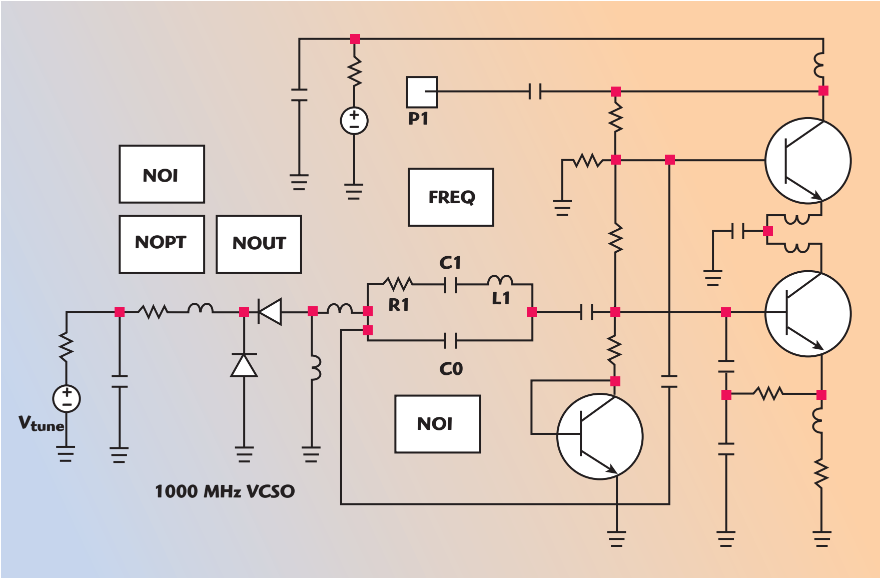


▲ *Fig. 9 Measured large-signal S_{11} (a), S_{12} (b), S_{21} (c) and S_{22} (d) of the bipolar transistor.*



▲ *Fig. 10 Schematic of typical tunable mode-coupled 1 GHz SAW resonator oscillator.*

drive-level conditions. In addition, these problems become critical at high frequency when active devices (bipolars/FETs) are technologically scaled to obtain higher cut-off frequency. Historically, nonlinear devices have been represented in simulation by compact empirical or analytical SPICE models that operate in the time domain. The linear portion of the network is being analyzed in the frequency domain and the nonlinear components in the time domain, resolving the two through an iterative technique called harmonic balance. However, most device parameters are extracted from linear 50 Ω S-parameters and DC I/V (static and pulsed) data. Their ability to predict behavior under extreme nonlinear conditions or non-50 Ω terminations, especially for autonomous circuits, is questionable.

The definition of S-parameters in large-signal environment is ambiguous compared to small-signal S-parameters. When driving an active device with an increasingly higher level, the output current consists

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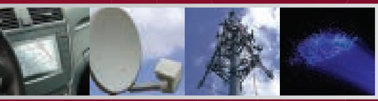

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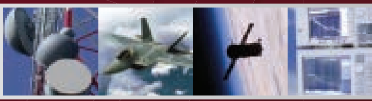

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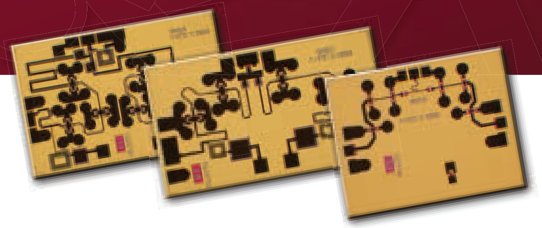

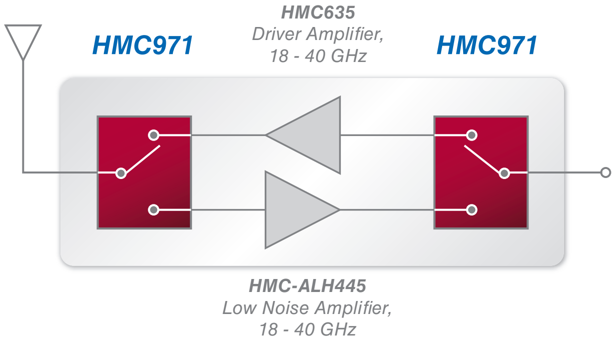

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DC - 8	SPDT, High Isolation	1.5	45	26	0 / -5V	C8	EAR99	HMC234C8
DC - 8	SPDT, High Isolation	1.2	48	23	0 / -5V	MS8G	EAR99	HMC270MS8GE
DC - 8	SPDT, High Isolation	2	44	23	0 / -5V	C8	EAR99	HMC347C8
DC - 8	SPDT, High Isolation	2.2	35	23	0 / -5V	G8 Hermetic	EAR99	HMC347G8
DC - 12	SPDT, High Isolation	1.5	55	27	0 / -5V	LP4	EAR99	HMC232LP4E
DC - 14	SPDT, High Isolation	1.7	44	23	0 / -5V	LP3	EAR99	HMC347LP3E
DC - 15	SPDT, High Isolation	1.4	50	26	0 / -5V	Chip	EAR99	HMC232
DC - 15	SPDT, High Isolation	1.7	60	26	0 / -5V	Chip	EAR99	HMC607
DC - 20	SPDT, High Isolation	1.7	45	23	0 / -5V	Chip	EAR99	HMC347
DC - 20	SPDT, High Isolation	1.8	47	23	0 / -5V	LP3	EAR99	HMC547LP3E
8 - 21	SPDT, PIN MMIC, 2W	1.2	40	33	-10 / +1.5 (30mA)	Chip	EAR99	HMC970
18 - 40	SPDT, PIN MMIC, 2W	1.4	40	34	-10 / +1.5 (30mA)	Chip	EAR99	HMC971
2 - 50	SPDT, PIN MMIC, 0.5W	0.9	45	27	-10 / +1.5 (30mA)	Chip	EAR99	HMC975
55 - 86	SPDT, PIN MMIC	2	30	-	-5 / 5V	Chip	5A991.h	HMC-SDD112
DC - 8	SP8T	2.3	40	23	0 / 5V	LP4	EAR99	HMC321LP4E
DC - 8	SP8T	2.5	25	23	0 / -5V	LP4	EAR99	HMC322LP4E
DC - 8	SP4T	1.8	42	21	0 / -5V	Chip	EAR99	HMC344
DC - 8	SP4T	2	45	26	0 / -5V	LC3	EAR99	HMC344LC3
DC - 8	SP4T	1.8	40	21	0 / -5V	LP3	EAR99	HMC344LP3E
DC - 8	SP4T	2.2	32	21	0 / 5V	LP3	EAR99	HMC345LP3E
DC - 10	SP8T	2	38	23	0 / -5V	Chip	EAR99	HMC322
DC - 12	SP4T	1.8	42	27	0 / -5V	LH5 Hermetic	EAR99	HMC344LH5
DC - 18	SP4T	2.1	42	24	0 / -5V	Chip	EAR99	HMC641
DC - 20	SP4T	2.1	42	23	0 / -5V	LC4	EAR99	HMC641LC4
DC - 20	SP4T	2.3	45	22	0 / -5V	LP4	EAR99	HMC641LP4E
23 - 30	SP4T	2.8	35	25	0 / -3V	LC4	EAR99	HMC944LC4
DC - 8	Transfer	1.2	42	26	0 / +5V	LP3	EAR99	HMC427LP3E

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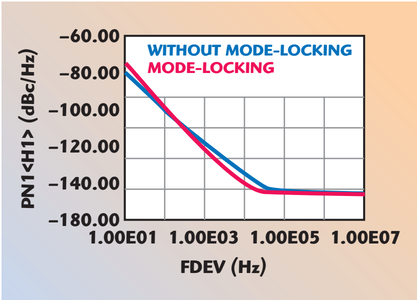
of DC and RF currents, the fundamental frequency and its harmonics. When increasing the drive level, the harmonic content rapidly increases. S_{12}, mostly defined by the feedback capacitance, now reflects harmonics back to the input. If these measurements are done in a 50 Ω system, which has no reactive components, then we have an ideal system for termination. In practical applications, however, the output is a tuned circuit or matching network, which is frequency selective. To measure large-signal S-parameters, the device was mounted to a test fixture that was calibrated to provide 50 Ω to the transistor leads. The test set-up consisted of a DC power supply and a network analyzer for combined S-parameter measurements. The R&S ZVR network analyzer was chosen because its output power can be swept from +10 to –60 dBm.

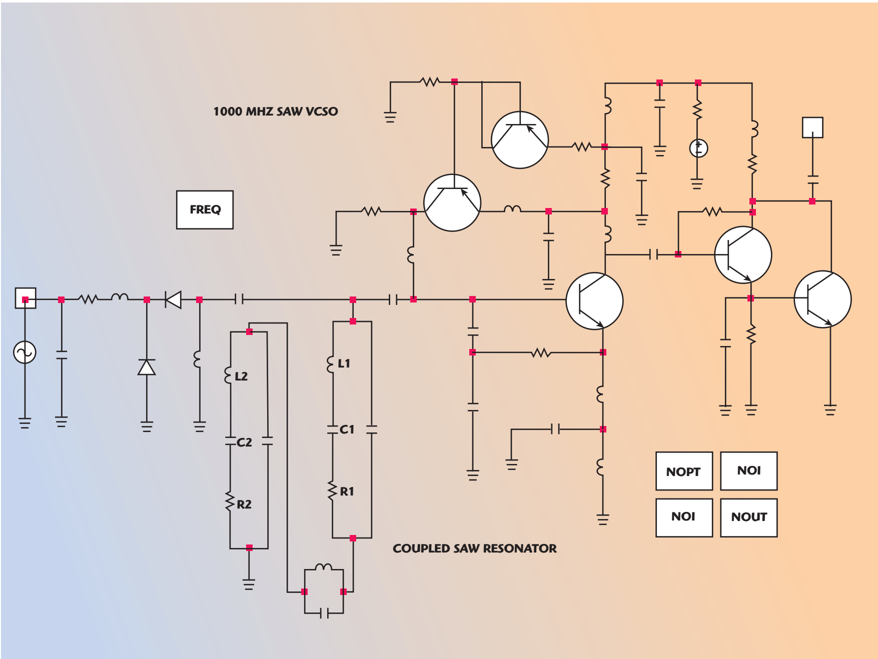
Figure 9 shows the plot of the measured S-parameters under large-signal drive condition for the characterization of oscillation condition and noise dynamics of the oscillator circuits. However this exercise is time-consuming and, therefore, not cost-effective. Fortunately, commercially available Agilent Technologies X-parameters could measure large-signal S-parameters that describe nonlinear behavior of the active device and can correlate the spectra found at a device's terminals for a given set of stimuli and termination impedances. Therefore, tweaking of prototype circuits is much less common, and today's designers have powerful CAD tools that can make meaningful sense of the nonlinear characteristics of the active circuitry.

Figure 10 shows the schematic of tunable 1 GHz SAW oscillator circuit, designed using large-signal S-parameters measured at different drive-levels. The CAD simulated phase noise confirms the improvement in performance at 1 kHz and higher offset frequency from the carrier and validated with experimental results shown in ***Figure 11***.

Figure 12 shows the schematic of hybrid mode tunable 1 GHz SAW oscillator. For comparative analysis



▲ *Fig. 11 Phase noise plot of mode-coupled tunable 1 GHz SAW resonator oscillator.*



▲ *Fig. 12 Schematic of typical tunable hybrid mode 1 GHz SAW resonator oscillator.*

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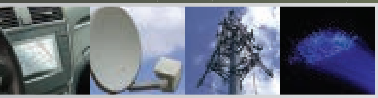

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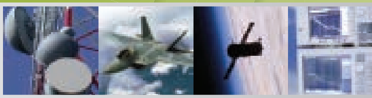

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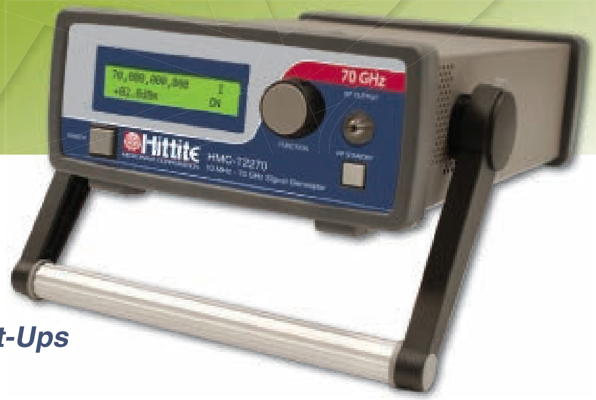

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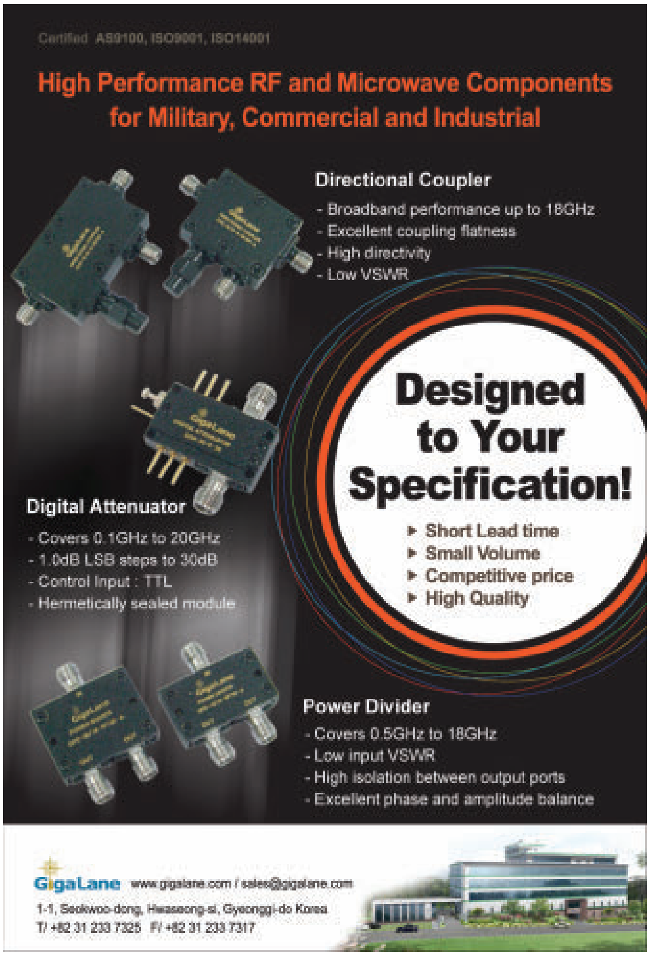
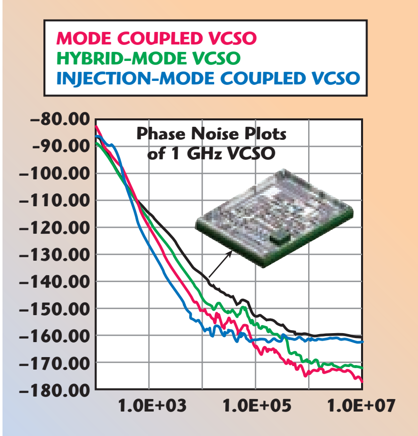


and brief insights about the various topologies, ***Figure 13*** shows the measured phase noise plots of tunable SAW oscillators. It can be seen from the figure, injection-mode coupled VCSOs offer promising phase noise with 1 MHz tuning to compensate the ageing and frequency drift. The drawback of this approach is vibration sensitive VCSO circuit. Care must be taken for the application where g-sensitive criteria is an important yard stick. By properly packaging and securing the SAW resonator in the cavity using double layer PCB for compensating the temperatrre charateristics, g-insensitive solutions can be produced.



▲ *Fig. 13 Measured phase noise plots of tunable SAW oscillators.*

CONCLUSION

The new ultra low phase noise VCSOs offer significant promise in terms of performance, price and product delivery to satisfy both the technical and business needs for low cost, low phase noise high frequency reference sources for synthesizer applications. ■

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A NEW GENERATION OF HIGH FREQUENCY SIGE HBTS

The addition of a small amount of C in the B-doped base layer of a npn SiGe heterojunction bipolar transistor (HBT) paved the way for exposing the high frequency (HF) performance potential of such devices more than 10 years ago.[1] Significantly, the suppression of thermal diffusion and point-defect assisted enhanced diffusion, due to the presence of C, helps to sustain steep base profiles through the fabrication process. As a consequence, the base transit time, the crucial delay time in previous HF bipolar transistor generations, could be reduced without degradation of the base sheet resistance, by realizing a highly-concentrated, narrow base doping in combination with a carefully tailored SiGe profile.

A further substantial decrease of the total transit time, τ_{EC}, or the transit frequency, $f_T = 1/(2\pi\tau_{EC})$, can be achieved only if the emitter and collector resistances, as well as the charging times of the base-emitter and base-collector space-charge regions, are reduced adequately. The introduction of a mono-crystalline emitter[2] and the vertical scaling of the emitter-base and base-collector junction contributed to the f_T progress.

However, specifying f_T alone is not sufficient to characterize the high speed performance. Another important figure of merit, in evaluating the HF behavior, is the maximum oscillation frequency, f_{max}. The base resistance, RB, the base-collector capacitance, CBC, and f_T are associated with f_{max} by the expression $f_{max} = \sqrt{(f_T/(8\pi R_B C_{BC}))}$. On one side, f_{max} can be increased by optimizing the vertical profile with respect to f_T and the internal components of R_B and CBC. On the other side, f_{max} can be improved if the parasitic effects that are particularly caused by the external contributions of RB and CBC are decreased. In reality, both situations have to be considered simultaneously, because device architecture, process flow, lateral dimensions and reliability constraints influence each key parameter.

These efforts to achieve optimization resulted in SiGe HBT performance improvements from a f_T/f_{max} level of approximately 50 to 100 GHz to values of 200 to 300 GHz during the course of 10 years, starting from the mid-1990s. The integration of best SiGe bipolar performance into CMOS technologies down to the 0.13 µm node[3-5] and the superior HF analog capabilities of the bipolar versus CMOS devices[6] enabled the penetration of SiGe HBTs into the communication market.[7] Upcoming new applications in the fields of THz imaging and sensing, or high speed/high bandwidth communications at even higher frequencies, raise the question as to what extent the SiGe HBT or BiCMOS technologies could occupy this area, especially since further scaled, pure CMOS technologies are hardly able to meet these needs.

Recently, the three-and-a-half-year European DOTFIVE[8] project addressed the task of pushing the HF performance limits of SiGe HBTs. From February 2008 to July 2011, a consortium of 15 partners from industry and academia focused on the demonstration of a half Terahertz f_{max} SiGe HBT or a ring-oscillator gate-delay of 2.5 ps. A detailed summary was produced.[9]

In the project, IHP took two different approaches. The first, not presented here, intends

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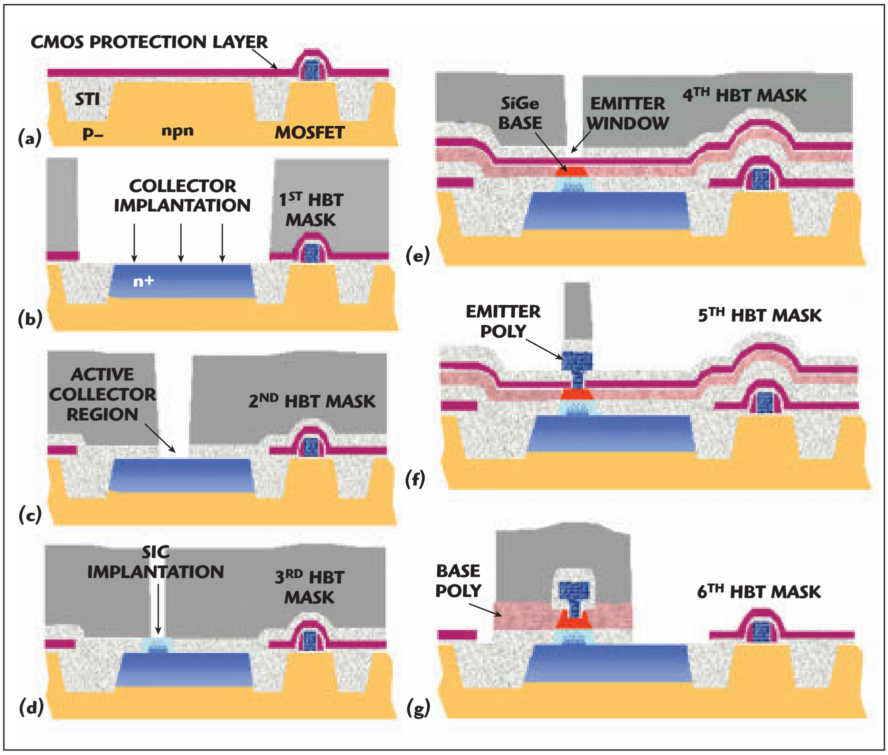


▲ *Fig. 1 Schematic cross sections at different steps of the device fabrication.*

to overcome scaling issues of the classical double-polysilicon (DP) technology that is widely used in industry.[4,10] This device architecture utilizes a selective epitaxial growth (SEG) of the base layer. The emitter window is self-aligned, not only to the external base region, but also to the internal collector region. It is clear that a selectively implanted collector (SIC) can also be formed, that is easily self-aligned to the emitter window. Promising results for a SEG DP technology with an unconventional way to form the external base were achieved.[11]

A second SiGe HBT approach, that is explained in this article, comprises the non-selective epitaxial growth (NSEG) of the SiGe base layer, completed by a self-aligned (SA) arrangement of the emitter window and the highly-doped, elevated external base region. The basic HBT process flow has been presented.[12] The HBT development of this work is performed in IHP's 0.25 µm SG25H1 BiCMOS technology.[13]

Progress in the performance of this established NSEG concept was realized during the course of the project,[14] step by step, by introducing a set of process modifications. Starting from the initial DOTFIVE generation D51, this article describes technological changes implemented in the final D53 version and their implications on the HF parameters. Based on this development, f_T/f_{max} values of 300 GHz/500 GHz and a CML ring-oscillator gate delay of 2.0 ps were reached.

HBT MODULE FABRICATION

The HBT module is fabricated in IHP's 0.25 µm SG25H1 BiCMOS technology environment. For this purpose, one poly-resistor, 5 Al metal layers and a 1 fF/µm^2 MIM capacitor are used. The process flow starts with the formation of the shallow-trench isolation (STI), the deep n well layer for the vertical isolation of nMOSFETs, the CMOS wells and gates, including gate spacer etching. Before HBT fabrication, the wafer is covered with a layer stack protecting the CMOS regions (***Figure 1a***). Then, the highly-doped collector well is formed. A resist mask is patterned to open the HBT regions (first lithography step M1), followed by the well implantation (***Figure 1b***) and anneal. The deep-trench (DT) free collector wells[15] are not deeper than the STI. Consequently, the active transistor and the collector contact region is not separated by STI to ensure a low collector resistance, R_C, and a low collector-substrate capacitance,

C_{CS}. An additional advantage of this collector design, dedicated to achieve the highest HBT speed, is the possibility of obtaining collector profiles on the base side, which are steeper than those of the conventional buried-layer process, due to a reduced thermal treatment. Moreover, the thermal resistance associated with the DT-free architecture is reduced.

After forming the highly-doped collector, the NSEG HBT module is subjected to the deposition and structuring of an oxide layer to define the active collector region (M2 in ***Figure 1c***). The resulting windows in the oxide layer then have to be filled with silicon. At this point, an essential process change was introduced in the course of the project. In the final process generation D53, after filling the gap in the oxide layer by selective epitaxy, the SIC is formed with the help of a patterned resist mask before non-selective base deposition (M3 in ***Figure 1d***).

Subsequently, the base layer is grown at a later stage. In previous generations, only one epitaxial step was carried out, while the SIC was arranged after base epitaxy, simultaneously with the emitter-window opening. Although this modification means greater effort and gives up the self-alignment of the SIC to the emitter window, it improves the possibility of tailoring the low-doped collector profile as the degradation of the base profile is avoided, together with an improvement in the HF performance.

At this point, a further modification has to be mentioned, which affects the design of the external base-collector region. The best HF results are achieved for a crystal orientation of the wafer substrate which is rotated by 45° compared to the standard configuration. The primary reason for this effect is attributed to the suppressed growth of facets along side-walls of dielectric layers during selective epitaxy.

Compared to the initial process generation D51, the B-doped SiGe base profile is optimized. The Ge content and the B dose are increased in such a way that the collector current density is not decreased while the base sheet resistance is lowered. Essential features of the emitter-base architecture applied correspond to the process flow.[12] These include deposition and patterning of an oxide/nitride/oxide layer stack to form the emitter window (M4 in ***Figure 1e***), fabrication of emitter-base inside spacers, emitter formation, including deposition of a dielectric layer stack, emitter-polysilicon structuring (M5 in ***Figure 1f***), elevating the external-base region by selective epitaxy, and finally patterning of the base polysilicon (M6 in ***Figure 1g***).

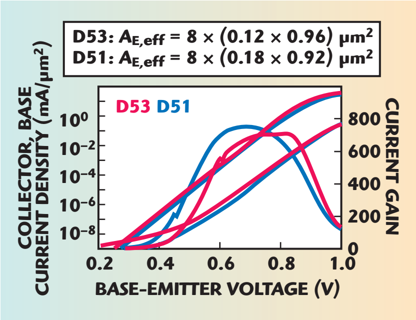
A substantial reduction of the emitter-base oxide spacer width from 45 to 30 nm could be achieved by fine-tuning the combination of wet and dry etching applied to form the emitter-window inside-spacers. The lateral scaling also impacts on the minimum emitter window size that is reduced from 180 to 120 nm. Furthermore, the dimensions of the collector window and the emitter contact region are reduced by approximately 30 percent. Other advantages of increasing the HF performance include higher emitter doping, a lower sheet resistance of the silicide layer and the reduced temperature of the final spike anneal.

DEVICE RESULTS

Let's compare the electrical results for the initial DOTFIVE HBT generation D51 and the final generation D53 with NSEG. Gummel and output characteristics are shown in ***Figures 2*** and ***3***. In these graphs, the current values are normalized to the effective emitter area, $A_{E,eff}$, to give a better overview of the impact of process modifications. The measurements are performed at V_{CB} =0 V and T = 300 K, on 8-emitter devices $A_{E,eff} = 8 \times (0.18 \times 0.92)\ \mu m^2$ for D51 and $A_{E,eff} = 8 \times (0.12 \times 0.96)\ \mu m^2$ for D53.

As indicated in the Gummel plot, the collector current density is slightly increased in the final generation (6 percent at V_{BE} = 0.7 V) despite a reduction of the pinched base sheet resistance, R_{SBi}, from 3.5 to 2.6 kΩ. This result is not only due to the effective increase of the Ge content, but it is also influenced by the decrease of the spike anneal temperature and by moving the SIC implantation from after the base epitaxy to before it.

A higher Ge content also tends to produce higher base currents, IB, due to an increased neutral base recombination, whereas the elimination of SIC implantation through the base lowers I_B. In addition, higher emitter



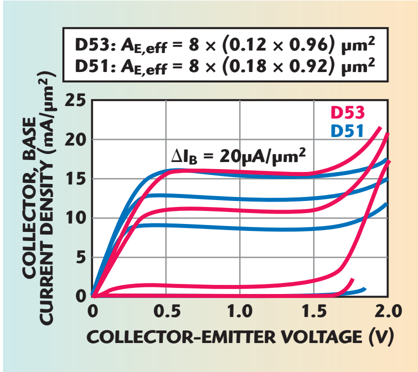
▲ *Fig. 2 Gummel plots of 8-emitter devices, normalized to the effective emitter area $A_{E,eff}$ for the HBT generations D51 and D53.*

doping increases I_B markedly, due to an enhanced Auger recombination. Altogether, the base current density is enhanced only by 16 percent for the D53 versus D51.

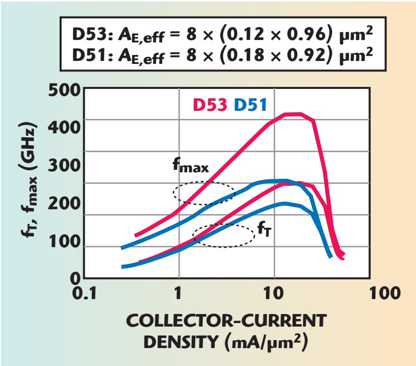
Consequently, the peak current gain is very similar for both generations with values of approximately 700. In the output characteristics, it can be seen that the collector-emitter breakdown-voltage, BV_{CEo}, is reduced from 1.7 to 1.6 V going from D51 to D53, which is attributed to the increased doping concentration of the SIC. Compared to a typical BV_{CEo} of the 200 to 300 GHz SiGe HBT version, there is no deterioration. However, the SIC doping is not sufficient to prevent the increased collector resistance of D53 caused by the smaller collector window size (shown in Figure 3).

In ***Figure 4***, the transit frequency, f_T, and maximum oscillation frequency, f_{max}, are plotted versus the collector current density, j_C, which is referred to as $A_{E,eff}$, with the same 8-emitter transistors being used for the DC measurements. To extract the f_T and f_{max}, S-parameters were measured on wafer up to 110 GHz (network analyzer 8510 XF). The f_T, f_{max} values are extrapolated at 40 GHz from the small-signal current gain h_{21} and the unilateral gain U respectively, with –20 dB per frequency decade, at V_{CE} = 1.5 V and T = 300 K.

The sum of the base and the emitter resistances (R_B+R_E) is determined from the circle fit of S_{11} for a device operating at peak f_T. In addition, the DC fly-back method is applied to specify R_E. Although there is still no well-established procedure for extracting these parameters, it is assumed that the values presented in this article enable evaluation of the trend quantitatively.



▲ *Fig. 3 Output characteristics of 8-emitter devices, normalized to the effective emitter area $A_{E,eff}$ for the HBT generations D51 and D53.*



▲ *Fig. 4 Transit frequency f_T and maximum oscillation frequency f_{max} vs. collector current density normalized to $A_{E,eff}$ for the HBT generations D51 and D53.*

Due to the variety of process modifications, a substantial improvement of f_T/f_{max} is demonstrated for the D53 HBT generation with peak values of 300 GHz/500 GHz. The device parameters, shown in ***Table 1***, indicate a 27 percent increase of f_T and a 16 percent decrease of the normalized C_{BC} for D53 compared to D51. However, the crucial contribution for improving f_{max} is originated by an approximate 50 percent reduction of RB for this HBT module in the DOTFIVE run time.

Comparing both HBT generations, the f_T and f_{max} decay and, therefore, the onset of the Kirk effect is shifted towards higher current densities in the final generation. Furthermore, j_C at peak f_T is increased from 13.5 mA/µm² for D51 to 18.5 mA/µm² for D53. The enhanced doping concentration of the SIC is responsible for this effect. The new base profile with higher Ge content and lower R_{SBi}, combined with a lower final spike anneal, affects R_B and f_T positively.

Besides the reduced spike-anneal temperature (D51: 1,100° C > D53:

TABLE I

DEVICE PARAMETERS OF HBT GENERATION D51 AND D53

Parameter	Measuring Conditions	D51	D53
$A_{E,\,eff}$ (μm^2)		8× (0.18×0.92)	8× (0.12×0.96)
f_T (GHz)	V_{CE} = 1.5 V	235	300
f_{max} (GHz)	V_{CE} = 1.5 V	300	500
τ(ps)	V_{EE} = -2.5 V, ΔV = 300 mV	3.1	2.0
BV_{CEO} (V)	I_B reversal, V_{BE} = 0.7 V	1.7	1.6
BV_{EBO} (V)	j_E=10 $\mu A/\mu m^2$	2.0	1.7
BV_{CES} (V)	j_C=0.5 $\mu A/\mu m^2$	5.1	5.2
$R_{EX}\, A_{E,eff}$ ($\Omega\ \mu m^2$)	flyback	2.38	2.12
$(R_B+R_E)\times A_{E,eff}$ ($\Omega\ \mu m^2$)	S_{11} circle fit, V_{BE} = 0.92 V	15.6	8.4
$C_{BC}/ A_{E,eff}$ ($fF/\mu m^2$)	S-parameter	18.0	15.1
$C_{BE}/ A_{E,eff}$ ($fF/\mu m^2$)	S-parameter	16.9	21.8
R_{SBi} (kΩ)		3.5	2.6

1,050°C), moving the SIC formation from after to before base deposition has contributed essentially to further improve R_B and f_T and consequently f_{max}. From the device parameters, it is estimated that the primary contribution of the improvement in f_{max} (approximately 70 percent) is due to structural process modifications, while the remaining 30 percent can be attributed to device scaling.[14]

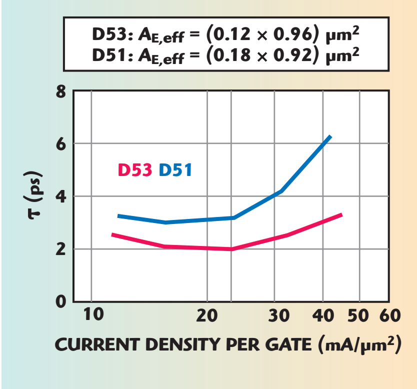
The CML ring oscillator (RO) has proven to be a powerful tool for evaluating the HF-performance progress of SiGe HBTs, because their gate delay shows a strong correlation to key parameters such as f_T and f_{max} and because it delivers fast and reliable measured values. Now the gate delays of ROs will be compared using a single-ended configuration. The minimum gate delay τ_{min} is decreased from 3.1 ps (D51) to 2.0 ps (D53) for a voltage swing ΔV of 300 mV at a supply voltage of V_{EE} = –2.5 V (***Figure 5***). The supply voltage can be lowered to 1.7 V without affecting τ_{min} if ΔV is reduced to 200 mV (***Figure 6***).

In the DOTFIVE project, not only CML ring oscillators were used to benchmark the performance of this NSEG HBT module – designers at the University of Wuppertal realized complex circuits in several DOTFIVE generations, representing new levels of high frequency circuit performance with respect to complexity.[16]

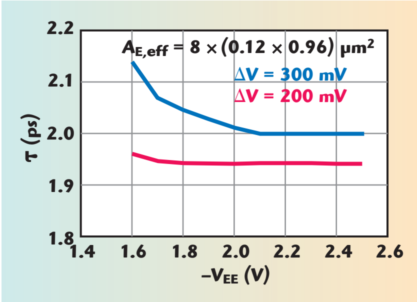
SUMMARY

Substantial progress with regard to the high speed performance of SiGe HBTs has been demonstrated, achieving the target of the European DOTFIVE project. The performance improvement of the HBT module, with non-selective base epitaxy and self-aligned emitter base architecture, is primarily based on modifications of the base profile, the wafer orientation, the annealing regime, the salicide sheet resistance, the emitter deposition and the selectively implanted collector. Approximately 30 percent of the f_{max} advance is due to lateral scaling of key HBT dimensions. Starting from the reference status, the process changes described in this article have led to peak f_{max} values of 500 GHz and minimum CML ring oscillator gate delays of 2.0 ps.

In collaboration with DOTFIVE partners, the new generation HBT has been tested successfully in complex circuits. This performance demonstrates the potential of SiGe HBTs for arising applications, such as sub-mm-wave imaging. Currently, work is being undertaken on the transfer of such performance levels into the 0.13 µm BiCMOS platform. This activity is facilitated by the fact that the fundamental HBT integration scheme of the standard 0.13 µm BiCMOS process is similar to the D53 module. ■



▲ *Fig. 5 CML ring oscillator gate delay τ vs. current per gate normalized to $A_{E,eff}$ for oscillators consisting of 53 stages with single emitter HBTs fabricated in generation D51 and D53.*



▲ *Fig. 6 Minimum CML ring oscillator gate delay τ vs. V_{EE}.*

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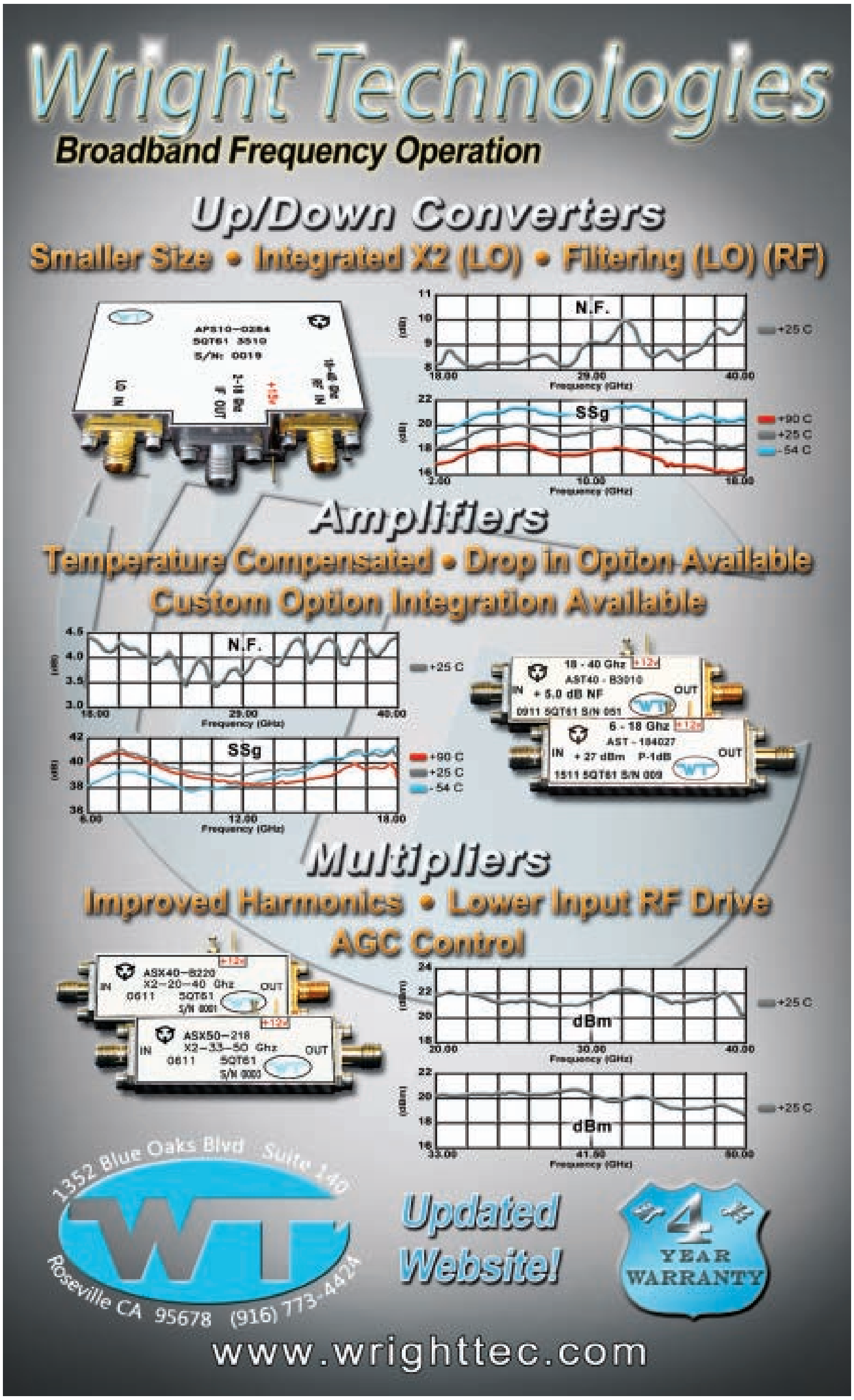

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NEW BANDSTOP FILTER USING SIMPLE DEFECTED MICROSTRIP STRUCTURE

A defected microstrip structure (DMS) has similar properties as a defected ground structure (DGS), but without any leakage through the ground plane. In this article, the stopband performance of a DMS is studied, and new single-band and dual-band bandstop filters with DMS are proposed. In order to verify the design, a single- and a dual-band bandstop filter are fabricated and the measured results are similar to the simulation. The new DMS bandstop filters have the advantages of better frequency selectivity, low loss and simple circuit topology, and simultaneously, have miniature circuit sizes.

Currently, the defected ground structure (DGS)[1-4] has been widely employed to improve filter performance and reduce filter size. DGSs show good stopband performance and excellent harmonic suppression in microwave circuits design and especially the periodic DGSs,[4] which extend the stopband greatly. DGS increases the effective capacitance and inductance of a microstrip line and, as a result, restrains the spurious responses by rejecting harmonics in microwave circuits. Consequently, the performance of filters or other microwave components is effectively improved. However, DGS introduces wave leakage through the ground plane.

Compared with a DGS circuit, the typical defected microstrip structure (DMS)[5-7] unit is made by etching two vertical narrow slots in the microstrip line, so the enclosure problems need not be considered because there is no leakage through the ground plane. DMS is more easily integrated with other microwave circuits and has an effectively reduced circuit size, compared with DGS. Simultaneously, DMS exhibits the properties of slow-wave, rejecting microwaves at certain frequencies and has an increasing electric length in certain circuits, which are similar to the well known DGS, but without affecting any of the ground plane.

Both DMS and spurline are made with slots on the strip; there is not much difference between the two structures. However, spurline[8] commonly refers to the structure shown in ***Figure 1***, and is commonly used to assist a bandpass or bandstop filter design for obtaining better performance. DMS has a more flexible topology, compared with spurline, which can be used in designing filters (including low pass, bandpass and bandstop), power dividers and amplifiers, etc. The defect in microstrip

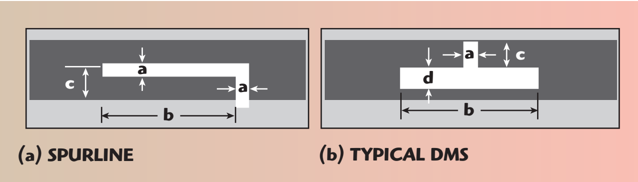

Fig. 1 Defected microstrip structures.

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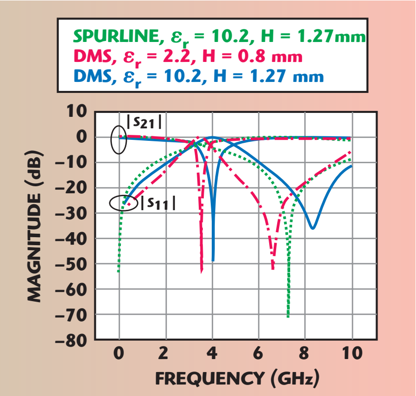


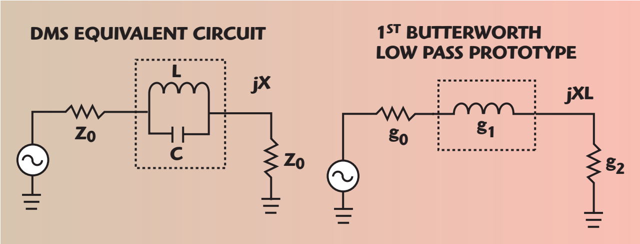
▲ *Fig. 2 Simulated S-parameters of a 50 Ω microstrip line with DMS and spurline.*

line creates resonance characteristics in the frequency response. Spurline may be regarded as one of the structures of DMS, for both have band rejection performance for certain slot dimensions.

In the present work, the defected microstrip structure is studied and novel bandstop filters, with single and dual band, are designed for the first time. Based on EM simulation and similar performance with a DGS, a simple circuit model of a DMS unit is established, and lumped elements are extracted. Two kinds of bandstop filters with a DMS are fabricated and measured, and the experiment confirms the new design.

MODELING OF DEFECTED MICROSTRIP STRUCTURE

A DMS consists of a horizontal rectangular slot and a vertical rectangular slot in the middle of conductor strip, as Figure 1 shows. Similar to a DGS, a DMS increases the electric length of microstrip line and disturbs its current distribution, and the effective capacitance and inductance of a microstrip line increase. Accordingly, the DMS has stopband and slow-wave characteristics,[1] as shown in ***Figure 2***, for the DMS with $\varepsilon_r = 2.2$, a = 0.2 mm, b = 13 mm, c = 0.8 mm, d = 1 mm; for the DMS with $\varepsilon_r = 10.2$, a = 0.2 mm, b = 14 mm, c = 0.3 mm, d = 0.3 mm; for a spurline with $\varepsilon_r = 10.2$, a = 0.3 mm, b = 8.5 mm, c = 0.6 mm. New microwave components, especially bandstop filters and low pass filters, can be designed by using these characteristics. In order to do a comparison, the simulated results are obtained by using a 50 Ω microstrip line with a substrate relative permittivity of 2.2 and 10.2, and a thickness of 0.8 mm and 1.27 mm, respectively. It can be seen that the spurline and DMS have obvious stopband performance and similar frequency responses, and a bandstop filter can be easily obtained using a substrate with higher permittivity. So, a spurline may be regarded as a kind of defected microstrip structure. In this study, it was observed that the DMS shown can be described by the horizontal slot length b and the vertical slot width a. It shows that the horizontal slot length affects the effective inductance, which increases with b increasing, and introduces a lower stopband. While the vertical slot width affects the effective capacitance, which decreases with a increasing, the lower capacitance induces a higher resonant frequency f_0.

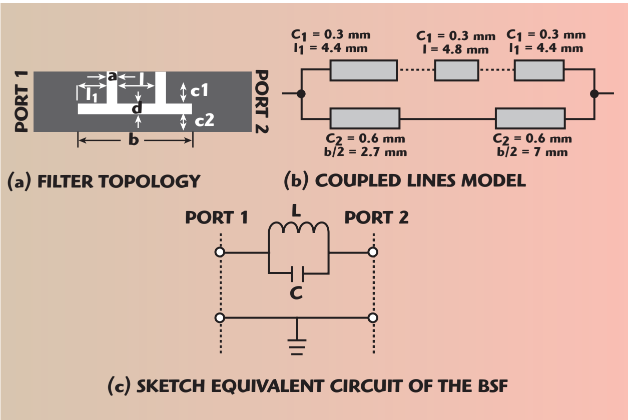


▲ *Fig. 3 Equivalent circuits of the DMS and Butterworth low pass prototype.*

TABLE I

EXTRACTED EQUIVALENT CIRCUIT OF A DMS USING A 50 Ω MICROSTRIP LINE

DMS Dimensions (mm)	a=0.2, c=0.8, d=1.0		
	b=5.9	b=9.2	b=13.9
f_0 (GHz)	10.58	8.92	6.49
f_c (GHz)	6.01	4.73	3.01
L (nH)	1.73	2.54	4.16
C (pF)	0.12	0.12	0.15



▲ *Fig. 4 Single band stop filter 1 with DMS.*

The electrical performance of a stopband with DGS is simulated by a parallel LC resonant circuit.[2,5,6] Because the stopband performance of the new DMS is similar to that of the DGS unit, the equivalent circuit model of DGS 2 can be used to extract the equivalent circuit parameters of DMS, as ***Figure 3*** shows, and the equivalent circuit of DMS matches the response of the 1st Butterworth low pass prototype. The reactance of DMS can be expressed as

$$X_{LC} = \left[\omega_0 C\left(\frac{\omega_0}{\omega}+\frac{\omega}{\omega_0}\right)\right]^{-1} \qquad (1)$$

Where, ω_0 denotes the resonant frequency of the parallel LC resonator. The series inductance of the 1st Butterworth low pass prototype shown can be written as

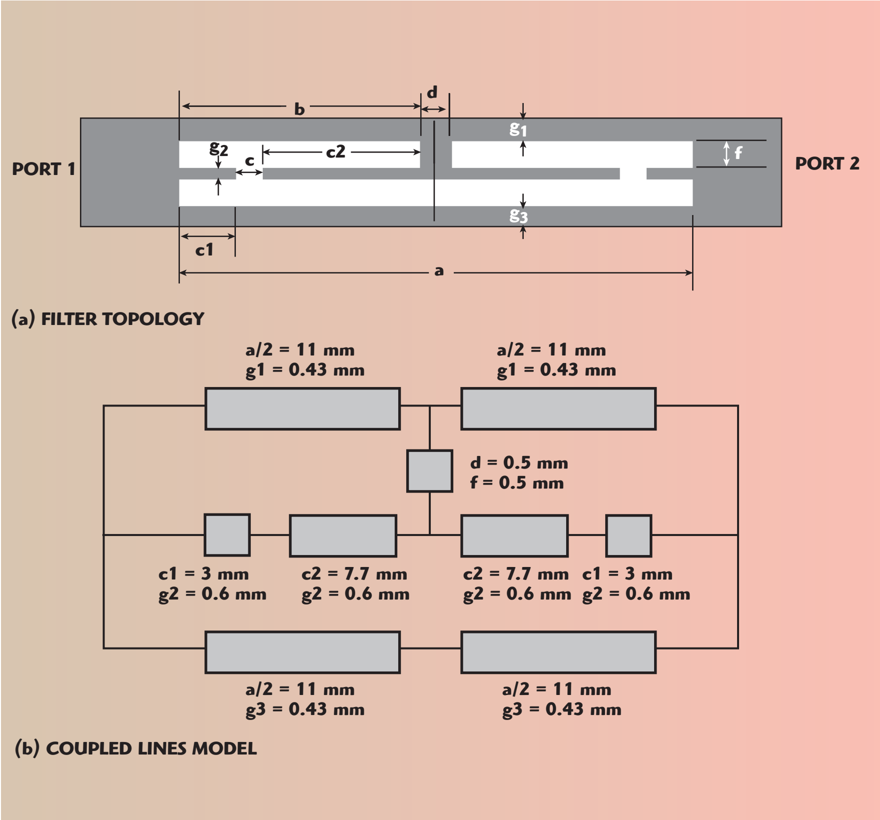
$$X_L = \omega' Z_0 g_1 \qquad (2)$$

Where, ω' is the normalized angular frequency, Z_0 is the characteristic impedance, and g_1 is the normalized parameter of the 1st Butterworth low pass prototype. According to circuit theory, the reactance values shown in the figure should be equal when $\omega = \omega_c$, and the expression is

$$X_{LC}\Big|_{\omega=\omega_c} = X_L\Big|_{\omega'=1} \qquad (3)$$

Here, ω_c denotes the cut-off frequency of the parallel LC resonator, and inductance L and capacitance C can be obtained from Equations 1 to 3 as:

$$C = \left(\frac{\omega_c}{Z_0 g_1}\right)\frac{1}{\omega_0^2-\omega_c^2}, \quad L = \frac{1}{4\pi^2 f_0^2 C} \qquad (4)$$

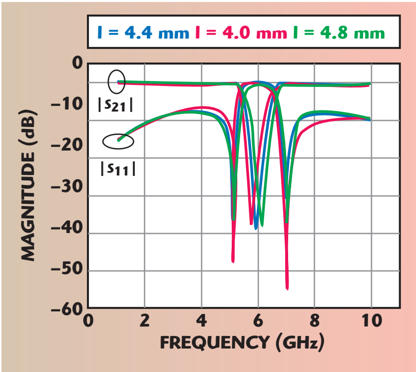


▲ *Fig. 5 Single band, band stop filter 2 with DMS.*

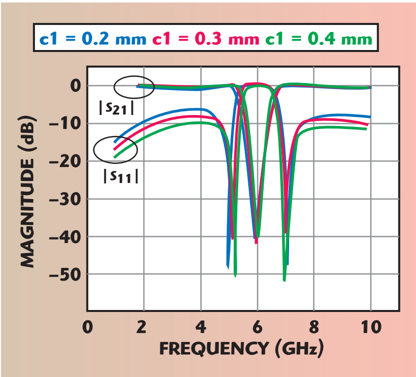
The equivalent circuit parameters of the DMS can be calculated from Equation 4, and the calculated values of the lumped-element parameters, using a 50 Ω microstrip line with $\varepsilon_r = 2.2$ and H = 0.8 mm, are shown in ***Table 1***.

BANDSTOP FILTER DESIGN AND EXPERIMENT

In order to demonstrate the stopband validity of DMS, two kinds of bandstop filters with a single band are designed, as shown in ***Figures 4*** and ***5***. The coupled lines models of the proposed filters are also shown. For single band bandstop filter 1, designed on a ceramic substrate with relative permittivity of 10.2, and a thickness of 1.27 mm, the simulated frequency responses comparison with topology parameters l, c1 and d are shown in ***Figures 6***, ***7*** and ***8***, with a = 0.3 mm, b = 14 mm, respectively. It can be seen that the parameters l, c1 and d have a small influence on filter performances, except for the bandwidth. Simulated filter frequency responses in function of parameter b are shown in ***Figure 9***, where a = 0.2 mm,



▲ *Fig. 6 Frequency response of the band stop filter 1 as a function of l with c1 = 0.3 m and d = 0.3 mm.*



▲ *Fig. 7 Frequency response of the band stop filter 1 as a function of c1 with d = 0.3 mm and l = 4.4 mm.*

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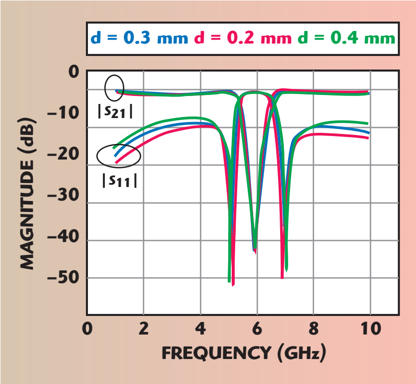
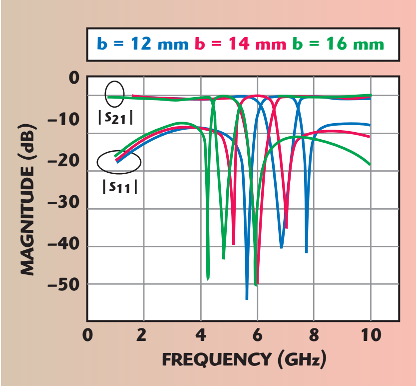


▲ *Fig. 8 Frequency response of the band stop filter 1 as a function of d with c1 = 0.3 mm and l = 4.4 mm.*

c1 = 0.3 mm, d = 0.3 mm, l = 4.4 mm. It shows the operating frequency increasing with the parameter b decreasing, and for b = 12 mm, the filter has a relative bandwidth of 19.3 percent with a low loss of less than 0.3 dB at the center frequency of 6.75 GHz, and a pair of transmission zeros with an attenuation of more than 39 dB.

For the single-band bandstop filter 2, which is designed on a duroid substrate with a relative permittivity of 2.2 and a thickness of 0.8 mm,

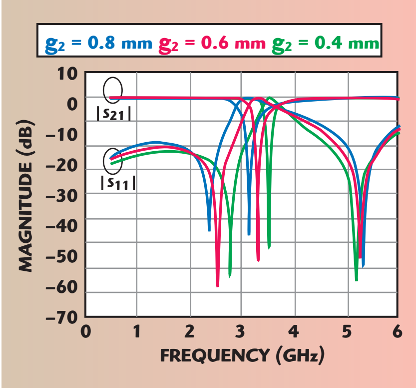


▲ *Fig. 9 Frequency response of the band stop filter 1 as a function of b.*

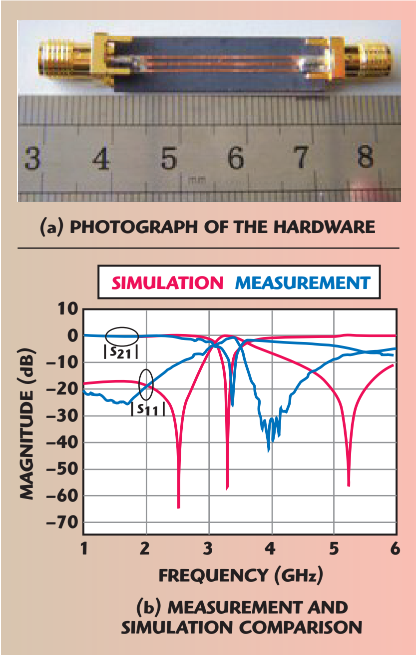
the simulated frequency responses as a function of g2 are shown in ***Figure 10***. It shows the filter center frequency increasing with the parameter g2 decreasing, and a smaller g2 introduces a narrower bandwidth. This kind of DMS also offers a low loss and a pair of transmission zeros.

In order to verify the design, bandstop filter 2 was fabricated and measured. The circuit size is smaller than 32 × 2.5 mm. The measured results, which are obtained with an Agilent E5071C vector network analyzer, are shown in ***Figure 11***, and are similar to the simulation.

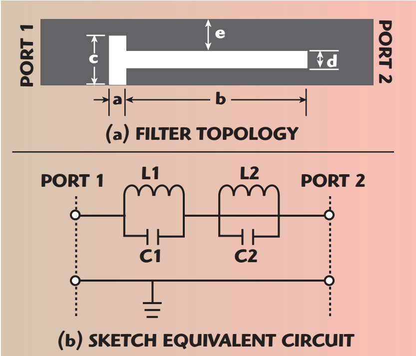
For dual-band bandstop filter implementation, a pair of vertical slots is introduced, as shown in ***Figure 12***. The horizontal slot affects the effective



▲ *Fig. 10 Simulated frequency response of the band stop filter 2 as a function of g2.*



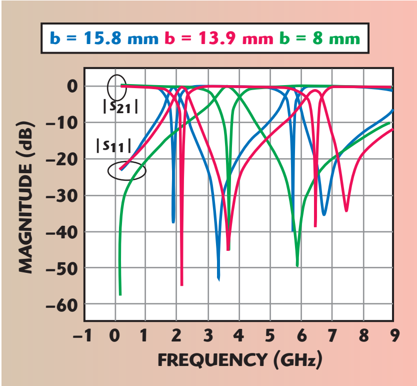
▲ *Fig. 11 Fabricated band stop filter 2.*



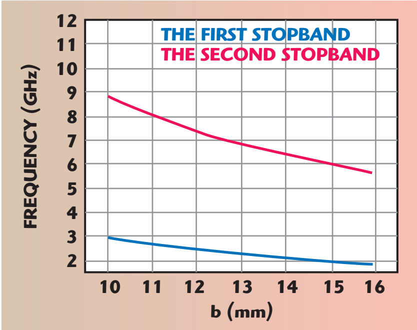
▲ *Fig. 12 Topology and equivalent circuit of the dual-band band stop filter with DMS.*

inductance, while the vertical slot affects the effective capacitance. The substrate relative permittivity and thickness of the filter are the same as for the bandstop filter 1. The simulated filter frequency responses as a function of the parameter b are shown in **Figure 13**, with a = 0.4 mm, c = 1 mm, d = 0.3 mm and e = 0.6 mm. The relationship of the operating frequency with the parameter b is shown in **Figure 14**. From the two figures, it can be seen that the operating frequencies of the dual-stopband decrease with the horizontal slot length b increasing, and for b = 15.8 mm, the dual-band operate at 1.89 and 5.69 GHz, respectively, and has low loss as well as transmission zeros. When b decreases to 8 mm, a single stopband is introduced. It also shows that the filter has a wide passband between the operating stopband, which is more than twice the filter's first operating frequency and an excellent band-gap performance of DMS is demonstrated.

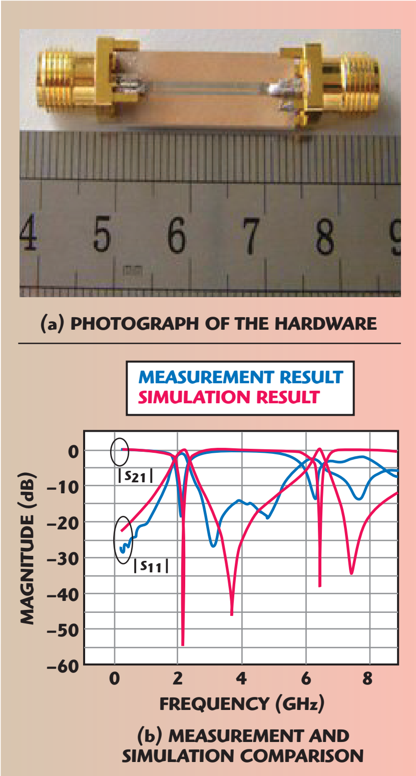
The dual-band bandstop filter was fabricated and measured, and the circuit size is less than 30 × 1.2 mm. The measured results shown in **Figure 15** are similar to the simulation. The



▲ *Fig. 13 Simulated frequency response of the dual-band band stop filter as a function of b.*



▲ *Fig. 14 Relationship of the operating frequency as a function of b.*



▲ *Fig. 15 Fabricated and measured dual-band band stop filter.*

discrepancies between measured and simulated results are mainly due to the simulation precision and fabrication uncertainty.

CONCLUSION

In this article, a defected microstrip structure is studied, and new bandstop filters with single band and dual band are developed. The measurements demonstrate the new design. Compared with the DGS, the DMS has no enclosure problem because there is no leakage from the ground plane. It shows that the DMS has a flexible design and a controllable operation for bandstop filter implementation, and the new DMS filters have advantages of simple topology, miniature size and better performance of transmission zeros with low loss. ■

ACKNOWLEDGMENT

This work is supported by Specialized Research Fund for the China Doctoral Program of Higher Education (200805611077), and the Open Research Fund of China State Key Laboratory of Millimeter Waves (K201107), and the Fundamental Research Funds for China Central Universities (2010B22714).

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LOADED ANNULAR RING SLOT MICROSTRIP ANTENNA FOR WIDEBAND AND MULTI-BAND OPERATION

Wideband and multi-band antennas have become part-and-parcel of modern telecommunication systems. In this article, an annular ring slot microstrip antenna loaded with two pie-shaped circular sectors is presented. With the use of pie-shaped circular sectors along the microstrip feed line, a multi-wider-band operation than for a conventional annular ring slot can be realized. By selecting proper dimensions of the circular sectors, the antenna typically provides three main operating bands and is capable of multi-frequency operations in various personal and wireless applications. From experimental results, with a VSWR ≤ 2, the antenna achieves three wide bandwidths of 190 MHz (0.88 to 1.07 GHz), 1.83 GHz (1.79 to 3.62 GHz) and 880 MHz (5.05 to 5.93 GHz), which are equivalent to impedance bandwidth of 19.5, 67.7 and 16.03 percent, respectively.

Tremendous developments in wireless communications have been observed during the last few decades. The evolution of personal communication devices has led to the convergence of image, speech and data communications at anytime and anywhere around the world with the help of one mobile data terminal, which includes computer data cards as well as mobile phones and other devices. The multifunctional mobile base stations and repeaters are thus required to comply with the various mobile communication protocols and standards. This indicates that the future communication terminal antennas must meet the requirements of multi-band or wideband to sufficiently cover the possible operating bands. However, when the number of operating frequency bands increases, antenna designing becomes more acute and critical.

There are many possible solutions for antennas with wideband radiation characteristics. Among them, probe fed with a W-shaped ground plane,[1] E-shaped patch antenna,[2] L-fed patch antenna structure,[3] are widely known as methods to enhance bandwidth. These techniques can improve broadband operation up to 30 percent. A recent paper[4] demonstrates that by using a meandering probe, the bandwidth can be improved to 37 percent, with high polarization purity. However, this model still does not exhibit multi-band operation of present personal communication systems.

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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
AML26P4011	2.0 - 6.0	40	40	41	12	28V, 1.0A	30%	EAR99
AML26P4012	2.0 - 6.0	45	43	44	25	28V, 2.5A	30%	EAR99
AML26P4013	2.0 - 6.0	45	46	47	50	28V, 6 A	30%	EAR99
AML59P4512	5.5 - 9.0	45	45	46	40	28V, 3.6A	35%	3A001.b.4.b
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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
AML811P5012	7.8 - 11.0	50	46	47	50	28V, 5.5A	30%	3A001.b.4.b
AML811P5013	7.8 - 11.0	50	49	50	100	28V, 11A	30%	3A001.b.4.b
AML618P4014	6.0 - 18.0	40	39	40	10	32V, 2.75A	12%	ITAR
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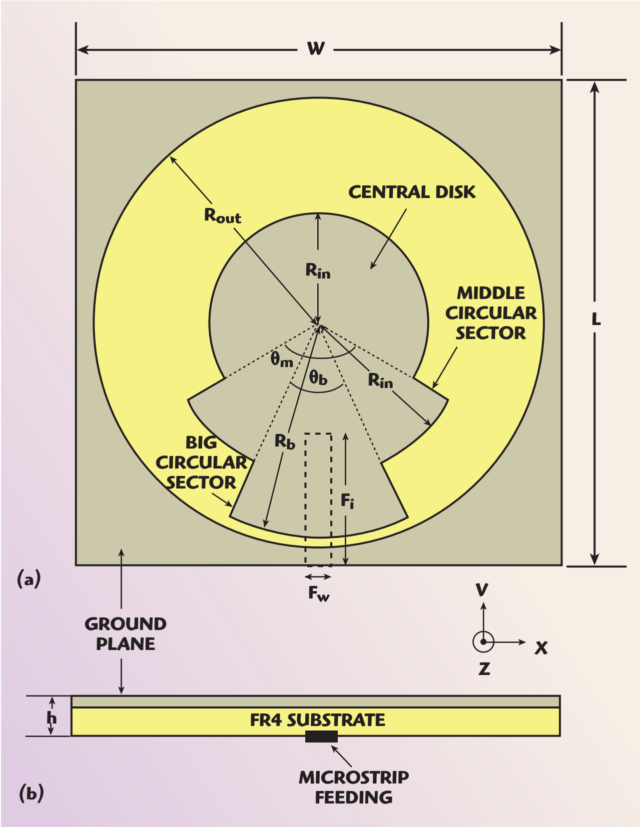
Characteristics of printed wide-slot antennas fed by a microstrip line with different tuning stubs have also been widely studied.[5-7] In the reported literature,[5,6] a printed slot antenna with a fork-like tuning stub and a cross shaped fed slot antenna have been shown to have a good bandwidth enhancement. However, it is not enough for the operating bandwidth to cover more wireless communication services. Another microstrip-line-fed printed wide-slot antenna with a fractal shaped slot has also been studied.[7] Although the antenna exhibits good impedance bandwidth, the fractal shapes makes the configuration of the slot antenna more complicated.

A single and double layer multi-band PIFA antenna is also reported in the literature.[8] But, as the structure profile is decreased by the use of a printed PIFA structure, the complexity rises and the gain decreases abruptly.

In this article, an annular slot antenna loaded with two pie-shaped circular sectors is introduced for multi-band wideband operation for an indoor repeater system used in various personal and wireless communications applications, as tabulated in *Table 1*. The intention of this invention is to employ the antennas to create a low cost system by requiring only one centralized multisystem repeater station for environments like rail stations, shopping malls or airports, where there may be a heavy localized traffic demand across a variety of user services. The antenna units would be wall or ceiling mounted and the connection to the base station would be made by optical fiber with an electro-absorption modulator (EAM), serving as both optical-to-electrical and electrical-to-optical transducer in the down and uplinks respectively.[9] The broadband nature of the optical link, from base station to antenna unit, makes it feasible to include all the major personal and wireless communications systems subject to creating a suf-

TABLE I
APPLICATIONS OF THE PROPOSED ANTENNA

System	*Frequency Bands (MHz)*
GSM 900	880 to 960
GSM 1900	1850 to 1990
DECT	1880 to 1900
UMTS/W to CDMA	1920 to 2170
Mobile WiMAX	2110 to 2200, 2300 to 2400, 2500 to 2690, 3400 to 3600
WLAN	2400 to 2485, 5150 to 5350, 5750 to 5850
Bluetooth	2400 to 2497
RFID	902 to 928, 2400 to 2483.5, 5725 to 5875

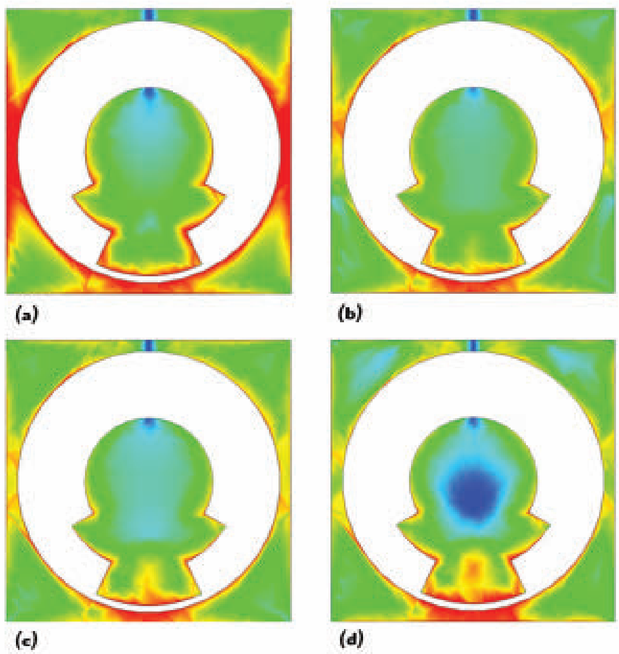


▲ *Fig. 1 Geometry of the proposed antenna (a) top view (b) side view.*

ficiently multi-band antenna.[8] The prototype of the proposed antenna has been constructed and tested, and details of both the predicted and measured antenna performance, such as input return loss, impedance bandwidths, surface current distributions, radiation patterns, and gains, are presented and discussed.

TABLE II
GEOMETRICAL PARAMETERS OF THE PROPOSED ANTENNA

Name	Parameters	Values
Microstrip Feed Line	$\{F_l, F_w\}$	{22, 4 mm}
Annular Slot	$\{R_{in}, R_{out}\}$	{18, 37 mm}
Middle Circular Sector	$\{R_m, \theta_m\}$	{25 mm, 120°}
Big Circular Sector	$\{R_b, \theta_b\}$	{35 mm, 60°}
Ground Plane	{L, W}	{80, 80 mm}



▲ *Fig. 2 Surface current distribution at resonant frequencies (a) 900 MHz, (b) 2.2 GHz, (c) 2.9 GHz and (d) 5.4 GHz.*

ANTENNA DESIGN AND NUMERICAL ANALYSIS

The general geometry of the proposed antenna is depicted in ***Figure 1*** and its parameters are listed in ***Table 2***. The proposed antenna is fabricated on an FR4 substrate with a relative permittivity $\varepsilon_r = 4.6$, a tangent loss $\tan\delta = 0.02$ and a thickness $h = 1.6$ mm. The radiating ground loaded with an annular slot is on the top layer of the substrate, whereas the feeding microstrip line is printed on the bottom layer.

The ground plane slot loading can be divided into three sections: an annular ring slot centered with a circular disk and two pie-shaped circular sectors of different sizes, named as middle and big circular sectors. The dominant TM_{n1} mode resonant frequency, f_n of the traditional annular slot antenna is determined by the following equation:

$$f_n \approx \frac{nc}{2\pi\sqrt{\varepsilon_{eff}}\left(R_m/2\right)} \qquad (1)$$

Where, R_m is the mean radius of the annular ring slot, n is the resonance mode number, ε_{eff} is the effective dielectric constant of the slot line and c is the speed of light in free space. Usually, the resonant frequencies are mainly determined by the mean radius of the annular slot. The mean radius can be defined as $R_m = (R_i + R_o)$, where R_i is the inner radius and R_o is the outer radius of the annular ring slot. The effective permittivity can be calculated from Equation 2, for $w/h \geq 1$.

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\frac{1}{\sqrt{1 + 12\, h/w}} \qquad (2)$$

The fundamental annular slot with inner radius of R_{in} and outer radius of R_{out} is loaded with two pie-shaped circular sectors having inner angle and radius of θ_m, R_m and θ_b, R_b. The angles and radiuses were optimized to the designed values to obtain multi-band performance and wide bandwidth. The circular sectors and fundamental circular disk are imposed symmetrically along the center line of the x-axis. The antenna is fed by a 50 Ω microstrip line, with a width Fw and


Channel surfing.
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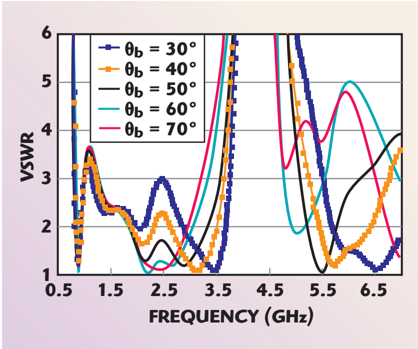
a length Fl. The antenna performance was studied using the commercially available full-wave, method-of-moment based, electromagnetic simulator Zeland IE3D version 12.0.

The excited scalar surface current distribution of the antenna, obtained from the IE3D simulator is pictured in ***Figure 2***. A strong current distribution at the outer circular edge of the antenna is observed at the lower frequency (900 MHz). The outer edge of the annular slot limits the lower frequency. At the second frequency band, at frequencies of 2.2 and 2.9 GHz, the currents are denser near the edges of the circular sectors. This gives proof of the dependence of the antenna resonance on the circular sectors at this frequency band. At middle and higher resonant modes, due to the feeding line effect, a substantial increase in current flow is noticed near the edge of middle and big circular sector of the slot loaded ground. Hence, the impedance matching at middle and higher frequencies is dominated by the feed line parameters.

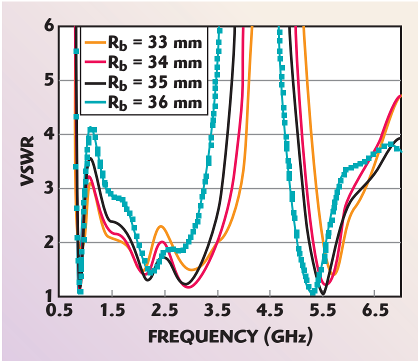
Figure 3 shows the VSWR plots for different values of the central angle, θ_b, of the big circular sector. As the angle decreases from 70° to 30°, the third resonant frequency also tends to decrease; consequently, the second operating bandwidth also decreases. However, the angular decrement reveals the decrease of the edge current path on the big pie, near the outer edge of annular slot. The fourth resonance depends vitally on the current path of the big circular sector, as seen from the current distribution, therefore the fourth resonant point increases monotonously with an increase in bandwidth of the third operating band. At the same time, the second resonance point is constant but with an increase in VSWR. This parameter can therefore be used to adjust the resonant frequency and bandwidth of the second and third band.

The radius of big pie-shaped circular sector, R_b, affects the second functional bandwidth significantly, which is plotted in ***Figure 4***. As the radius of the circular sector varies from the optimized value of 35 mm, the resonating modes separate and appear as two individual bands. However, like the previous parameter θ_b, the radius also does not have any effect on the first resonating band. Meanwhile, the decrease of the radius decreases the current path, and the fourth resonance frequency increases, although there is an increase in the VSWR observed.

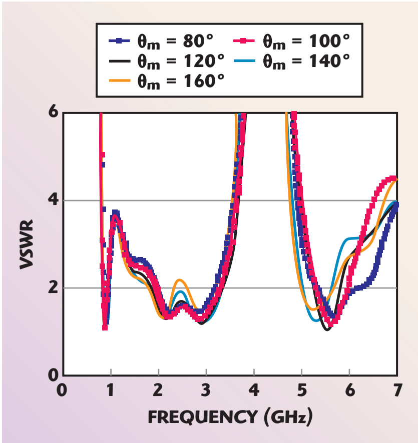
Figure 5 shows the relationship between the resonant frequency and the center angle, θ_m, of the middle circular sector. It is seen that the upper band resonant point and bandwidth is increased, although the second operational bandwidth is gradually reduced as the angle θ_m is decreased from the optimized value. On the other hand,



▲ *Fig. 3 VSWR of the proposed antenna as a function of* θ_b.



▲ *Fig. 4 VSWR of the proposed antenna as a function of* R_b.



▲ *Fig. 5 VSWR of the proposed antenna as a function of* θ_m.

when the angle is increased from the designed value, the upper resonant frequency decreases with a slight increase of VSWR. For the second band, the higher and lower edge frequencies decrease, maintaining almost the same difference between them, while the modes forming the second operating band tend to separate. This indicates the dominance of the angle θ_m over the impedance matching of the second and upper band. In this design, the angle, $\theta_m = 120°$ is taken as the optimized one. However, there is no change in the first resonating band for any of these variations.

The radius of the middle circular sector, R_m, is also an important parameter for determining the second operational band of the antenna. As depicted in ***Figure 6***, the second band is decreased with an increase of the radius. At the same time, the lower frequency edge of the upper band is slightly increased with this parametric change, keeping constant the resonant frequency. No change in the lower band is observed, which implies the independence of the lower band on the middle pie.

As R_{out} defines the outer edge of the annular slot, it has the most impact on the antenna impedance matching, which also was seen from the current distribution in the antenna, where, for all the resonant frequencies, the strong surface current at the outer edge of the annular slot excites the central conductor. From ***Figure 7***, it is evident that all the resonant frequencies have dropped-off with the decrease of the outer radius R_{out}. Therefore, this can be a way to design antennas at lower frequencies for wireless applications, if necessary.

The inner radius of the circular disk of annular slot, R_{in}, affected crucially the first resonant frequency and its impedance matching. As R_{in} is varied from 18 to 24 mm, the first resonance shifted from 900 to 850 MHz and the bandwidth becomes zero with VSWR 2. The impedance matching of the second band was also disturbed dramatically, which

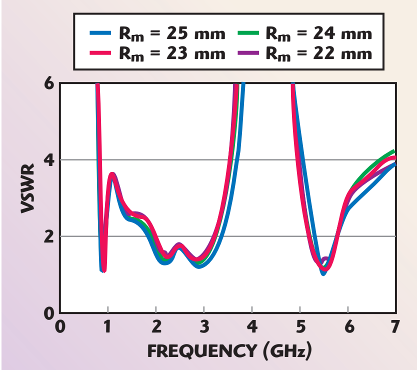


Fig. 6 VSWR of the proposed antenna as a function of R_m.

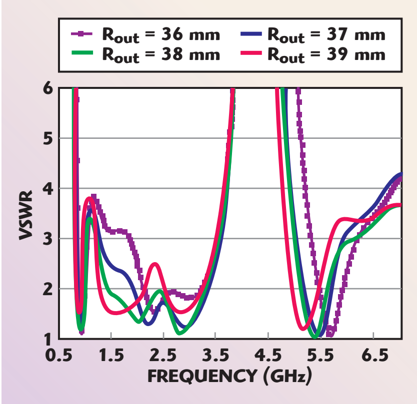


Fig. 7 VSWR of the proposed antenna as a function of R_m.

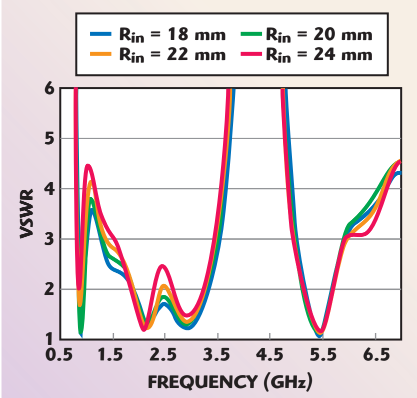


Fig. 8 VSWR of the proposed antenna as a function of R_{in}.

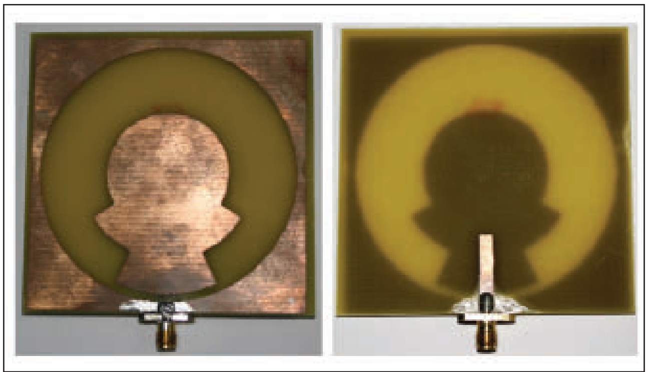
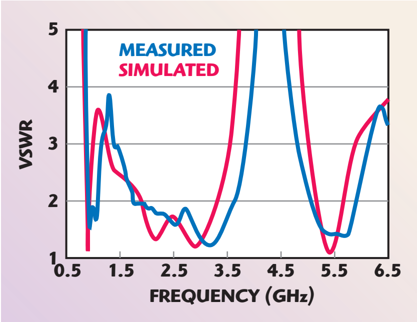
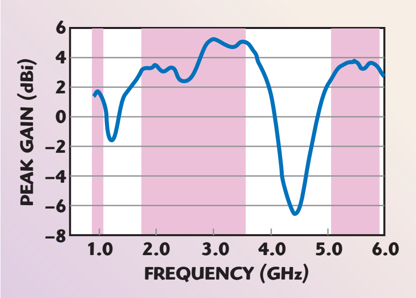


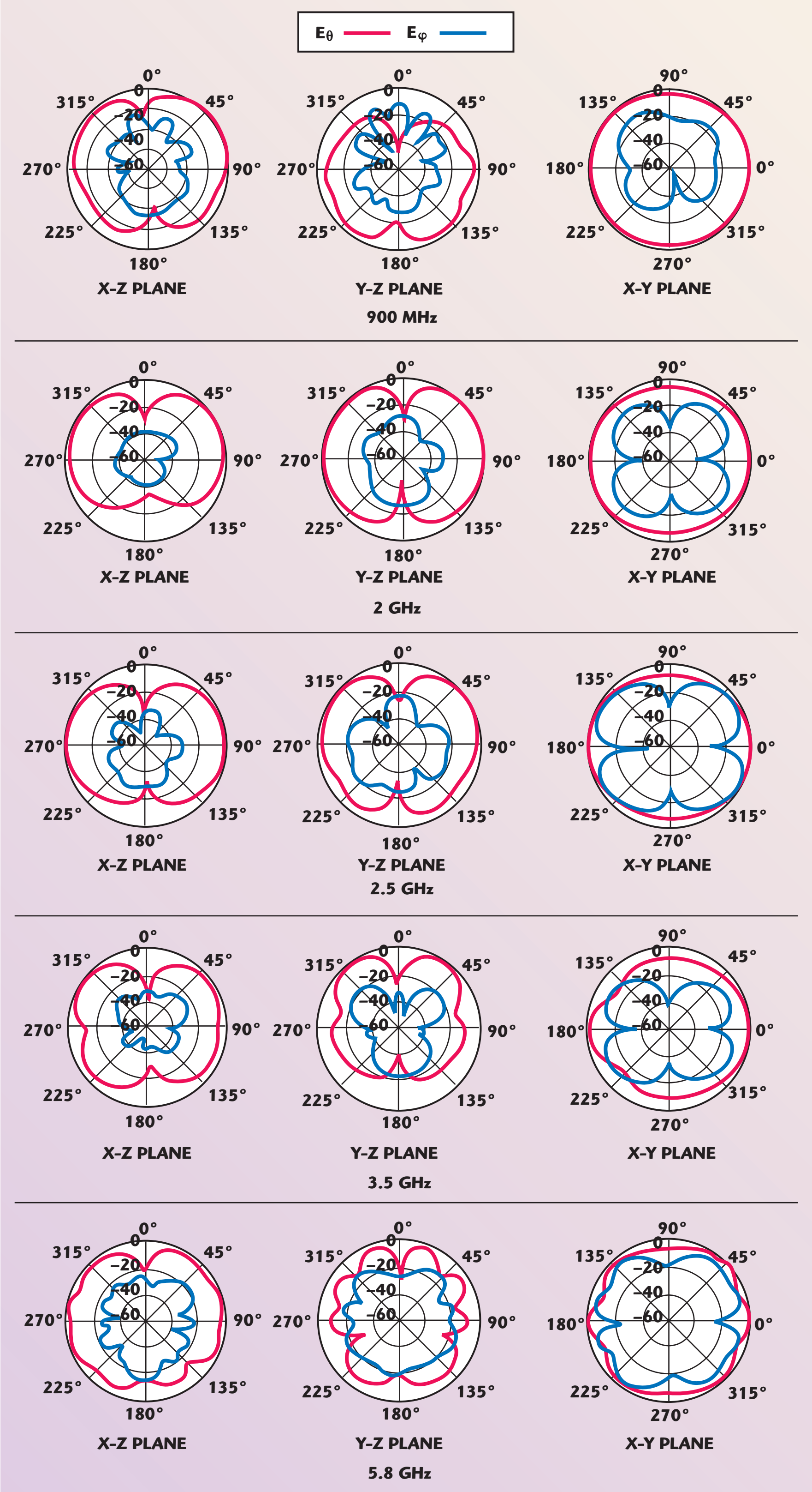
Fig. 9 Photograph of the prototype of the proposed antenna.



▲ *Fig. 10 Simulated and measured VSWR of the proposed antenna.*



▲ *Fig. 11 Measured peak gain of the proposed antenna.*



▲ *Fig. 12 Radiation patterns of the proposed antenna.*

also is verified by the VSWR with different values of R_{in}, providing the other shapes are unchanged. When the inner radius R_{in} is increased up to 22 mm, the two modes of the second functional band separate (VSWR ≥ 2). ***Figure 8*** shows that R_{in} has virtually no effect on the upper frequency band. This allows for the tuning of the first and second resonant impedance matching after the upper resonant frequency is tuned. When the inner radius is set to 18 mm, the impedance at all three resonant frequencies are matched and it is taken as the optimized value.

RESULTS AND DISCUSSIONS

Based on the simulated optimized parameters, a prototype of the wide multi-band antenna was fabricated, which is shown in ***Figure 9***. To verify the high performance of the proposed antenna, the prototype was measured in an anechoic chamber. A comparison of the measured and simulated VSWR of the proposed antenna is shown in ***Figure 10***. The VSWR of the antenna was measured with the Agilent 8510C vector network analyzer. The measured prototype achieves three wide bandwidths of 190 MHz (0.88 to 1.07 GHz), 1.83 GHz (1.79 to 3.62 GHz) and 880 MHz (5.05 to 5.93 GHz), which are equivalent to 19.5, 67.7 and 16.03 percent impedance bandwidth, respectively, with center frequencies of 0.98, 2.71 and 5.49 GHz. The simulated curve shows four dominant resonant modes at 900 MHz, 2.2, 2.9 and 5.4 GHz. However, the measured prototype shows the resonances at some higher frequencies. This difference in results can be attributed to the assumption of lossless 50 Ω

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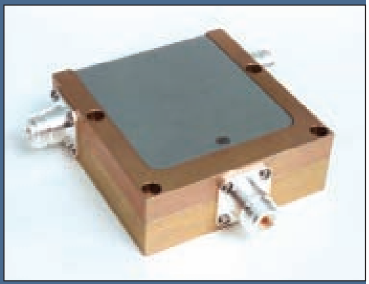

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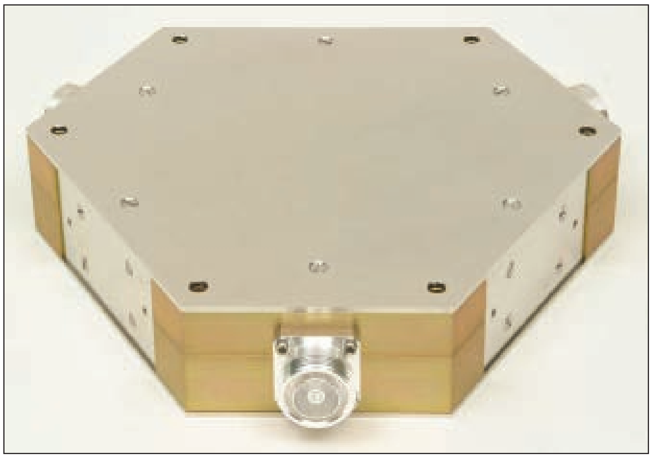

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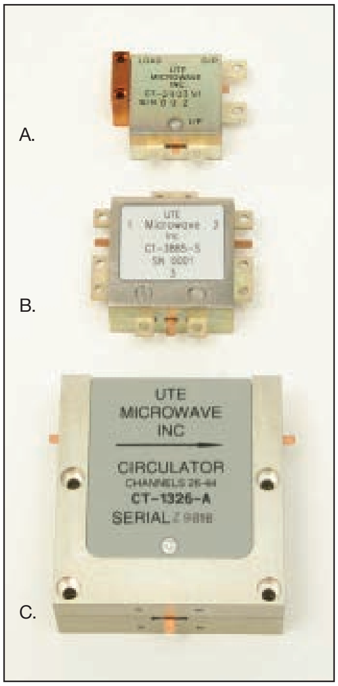

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SMA in the simulation of IE3D. The deviation can also be caused by the fabrication limitations, because of the uncertainty of the slight variation in the used substrate thickness and the permittivity constant of the substrate over the whole wide operating bandwidth. It can be seen that this antenna easily covers GSM 900/1900/UMTS, ISM/Bluetooth WLAN (2.4/5 GHz), UHF and microwave RFID and mobile WiMAX applications.

The measured peak gain of the prototyped antenna is shown in ***Figure 11***. The antenna exhibits a peak gain of 1.8 dBi in the lower frequency band. The gain degradation at this frequency can be attributed to the relatively smaller size of the antenna at this band. At the second band, the antenna shows the highest gain of 5.3 dBi with a fluctuation of 3 dBi over the whole band. The gain varies from 2.3 to 3.8 dBi in the upper band. These results show that the antenna is fully operational, providing the requirements of the above mentioned services.

Figure 12 shows the measured radiation patterns of the co-polarized field (E_θ) and cross-polarized field (E_φ) in the azimuth (x-y) plane and the elevation (x-z and y-z) planes, for the antenna operating at frequencies of 900 MHz, 2, 2.5, 3.5 and 5.8 GHz. Almost similar and stable patterns have been found at all these frequencies. Good bi-directional and omni-directional radiation patterns are observed in the elevation (x-z and y-z) planes and azimuth (x-y) plane, respectively, which are analogous to those of a standard dipole antenna. There are some nulls observed at the higher frequencies, which is attributed to the higher harmonics of the resonating antenna. It was found that the cross-polarization radiation increases with increasing operating frequencies. However, the cross-polarization level is below 20 dB for almost all the radiating planes of the proposed antenna.

CONCLUSION

A wide, multi-band, loaded annular ring slot antenna for a mobile centralized multifunctional repeater station is proposed and a prototype is fabricated. The prototype has a small profile of 80 × 80 × 1.6 mm and exhibits three wide bandwidths of 190 MHz (0.88 to 1.07 GHz), 1.83 GHz (1.79 to 3.62 GHz) and 880 MHz (5.05 to 5.93 GHz), which are equivalent to 19.5, 67.7 and 16.03 percent impedance bandwidth, respectively, at the center frequencies of 0.98, 2.71 and 5.49 GHz. Also, the antenna presents stable bidirectional radiation patterns and the maximum gain varies from 1.5 to 5.3 dBi over the whole operating bands. Due to its very wide bandwidth, the antenna provides potentials to satisfy the frequency requirement of existing and future emerging wireless services and applications. ■

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Determination of Transmission Zeros of Self-Equalized Cross-Coupled Resonator Bandpass Filters

A method to determine the filter order and the locations of transmission zeros of self-equalized bandpass filters is presented, according to given filter specifications by optimization. The objective error function for the optimization is computed from the given filter amplitude and group delay specifications. The least filter order and the optimum locations of transmission zeros can be obtained to meet the required specifications by minimizing the error function using a genetic algorithm (GA). Application examples illustrate the excellent performance and the validity of this method.

In many RF/microwave communications systems, a bandpass filter with a flat group delay is demanded, in addition to its selectivity. One way to obtain this is by designing a self-equalized filter, in which the group delay equalizer is realized within the filter itself. In general, for a self-equalized filter, real and complex transmission zeros (TZ) are used to achieve both high selectivity and good linear phase performance; it has smaller structures, requires no cascading devices, but is relatively complex and difficult to design.[1]

In the cross-coupled filter synthesis, most of the publications focus on the coupling matrix synthesis. For example, Cameron proposed general coupling matrix synthesis methods for general Chebyshev filtering functions, based on an analytical technique.[2,3] Numerical optimization was used in synthesizing coupling matrix of resonator filters.[4-6] The analytical and numerical methods mentioned above can also be used to synthesize coupling matrix of self-equalized filters. However, the precondition of these methods is that the filter order and TZs must be prescribed. These methods did not discuss how to determine the filter order and TZs to meet the given filter specifications, although this is the foundation of the cross-coupled filter design. A self-equalized, pseudo-elliptical, filter based on the substrate integrated waveguide (SIW) technology was proposed,[7] but how to determine the filter order and TZs was not discussed.

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There are still few papers dealing with how to extract the filter order and TZs. The common solution for determining them is according to experiences and repeated tests. Although Ylldirim et al. used the circuit transformations to realize complex transmission zeros extraction and the cross-coupled filter synthesis with linear phase,[8] the method involves complicated circuit transformations and is difficult to implement in some cases. H.T. Hsu et al. presented a design procedure for coupled-resonators cavity group-delay equalizers, whose TZs are obtained by optimization.[1] However, the error function proposed for the optimization only contains the given filter group delay specifications, thus it cannot guarantee that the locations of TZs are optimum.

This article presents a simple and effective method to obtain the least filter order and optimum TZs to meet the given filter specifications, by minimizing an error function using GA. The proposed error function contains the given filter amplitude and group delay specifications. The proposed method eliminates the need for circuit model and only depends on the given filter specifications. The article solves the first problem of coupling matrix synthesis of resonator filters. Once the filter order and the locations of TZs are determined, the coupling matrix of self-equalized filters can be obtained by analytical methods[2,3] or numerical optimization methods.[4-6] The next step requires the choice of proper resonator types, for example SIW[7] or stepped-impedance resonators,[9] to realize the self-equalized filter design.

THEORY

For any two-port lossless filter network, the transfer and reflection functions may be expressed as a ratio of two polynomials.[3]

$$S_{21}(\Omega) = \frac{P(\Omega)/\varepsilon}{E(\Omega)}$$

$$S_{11}(\Omega) = \frac{F(\Omega)/\varepsilon_R}{E(\Omega)} \qquad (1)$$

Where Ω is the real normalized angular frequency variable, the roots of P and F correspond to the filter's TZs and reflection zeros, respectively,

$$\varepsilon = \left(1/\sqrt{10^{RL/10}-1}\right)\left(P(\Omega)/F(\Omega)\right)_{\Omega=1}$$

RL is the prescribed return loss in decibels, and ε_R is unity if m<N, where m is the number of finite TZs and N is the filter order or the number of resonators. ε_R will have a value slightly greater than unity if m = N.[3]

According to the group delay in the Ω domain,[4] the actual value of the group delay in the physical frequency f domain is derived as

$$\tau = -\mathrm{Im}\left(\frac{1}{S_{21}}\frac{\partial S_{21}}{\partial \Omega}\frac{\partial \Omega}{2\pi \partial f}\right) \qquad (2)$$

The frequency transformation from Ω to f can be expressed as follows,

$$\Omega = \frac{1}{FBW}\left(\frac{f}{f_0}-\frac{f_0}{f}\right) \qquad (3)$$

where FBW is the fractional bandwidth, f_0 is the center frequency of the bandpass filter. Equation 2 may now be expressed using Equations 1 and 3 as follows,

$$\tau = -\mathrm{Im}\left[\frac{\partial P(\Omega)}{\partial(\Omega)}\frac{1}{P(\Omega)} - \frac{\partial E(\Omega)}{\partial(\Omega)}\frac{1}{E(\Omega)}\right]\cdot \frac{1}{2\pi FBW}\left(\frac{1}{f_0}+\frac{f_0}{f^2}\right) \qquad (4)$$

Once the filter order and the finite TZs are determined in the Ω domain, E(Ω), F(Ω) and P(Ω) are determined, based on Cameron's recursive technique.[2] Both the amplitude $S_{21}(f)$ and group delay τ(f) response of the filter, which has a center frequency f_0 and a fractional bandwidth FBW, are determined in the f domain, since Ω in Equations 1 and 4 is calculated by Equation 3. So, determining the filter order and TZs is the key problem of filter synthesis.

Usually, self-equalized filter specifications are listed as follows:

Center frequency: f_0
Fractional bandwidth: FBW
Passband return loss: RL (dB)
Group delay variation: <Δτ (ns), when $f_{p1} \le f \le f_{p2}$
Stopband rejection: Las ≥ L_s (dB), when $f > f_{s1}$ or/and $f < f_{s2}$

So, two functions are constructed as:

$$\varphi_1 = \max\left(\left|S_{21}(f)\right|^2\right),$$

$$f > f_{s1} \text{ or/and } f < f_{s2} \qquad (5)$$

$$\varphi_2 = \max(\tau) - \min(\tau), f_{p1} \le f \le f_{p2} \qquad (6)$$

The function φ1 denotes that the filter has the highest stopband rejection, when φ1 reaches its minimum. The function φ2 denotes that the filter has the flattest group delay response, when φ2 reaches its minimum. The proposed error function for GA is as follows:

$$\varphi = C(\varphi_2 - \Delta\tau) + (\varphi_1 - 10^{-Ls/10}) \quad (7)$$

where C is the weighted constant determined by $C = 10^{-Ls/10}/\Delta\tau$. Note that C is the key parameter that determines a correct solution. In order to meet the given filter specifications, φ must satisfy $\varphi \leq 0$. An error function similar to Equation 7, for more than two requirements in given filter specifications, can be constructed.

For self-equalized bandpass filters, TZs (Ω_n) on Ω-axis are used to increase selectivity, and complex pairs of TZs ($T_i = \Omega_{ai} \pm j\sigma_{ai}$), which are called equalization zeros, are used to equalize in-band group delay. In general, the better the group delay equalization, the worse the selectivity performance for a filter. Hence, the group delay and the selectivity can be balanced in the filter designs. Ω_n, Ω_{ai} and σ_{ai} making up finite TZs will be used as optimized variables in GA. In this article, the GA toolbox for MATLAB, provided by the University of Sheffield, is chosen to solve the global minimum of the error function. The range of parameters to be optimized can be set in this toolbox. The toolbox is easy to download from the Internet.[10] The search for TZs to minimize Equation 7 is done by increasing the filter order and the number of the TZs gradually, using GA, until $\varphi < 0$, and then the least filter order and the optimum TZs can be obtained to meet filter specifications. This method is easy to determine the TZs and filter order of a self-equalized filter with symmetric or asymmetric response.

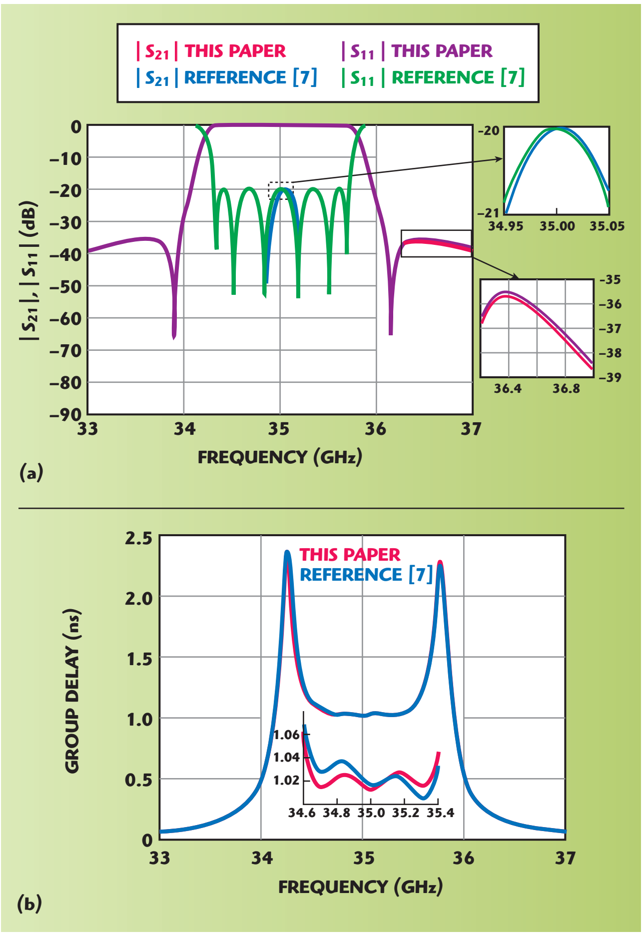
EXAMPLES

Filter 1

A self-equalized filter (filter 1) is required to meet the following specifications:

- –Center frequency: 35 GHz
- –Bandwidth: 1.4 GHz (fractional bandwidth = 4 percent)
- –Passband return loss: 20 dB
- –Group delay variation: < 0.025 ns, when $34.65 \leq f \leq 35.35$ GHz (within 50 percent bandwidth)
- –Stopband rejection Las > 35 dB, when f > 36.08 GHz and f < 33.92 GHz

These specifications were taken from Chen and Wu's article[7] to provide a direct comparison. In the example, the real TZs (Ω_n) is symmetric with respect to zero on Ω-axis, since



▲ *Fig. 1 Comparison of the filter responses computed from this article and reference 7 (a) amplitude and (b) group delay.*

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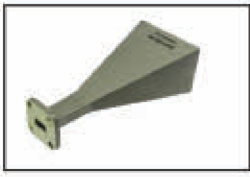

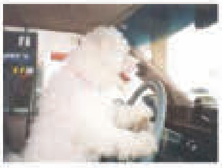

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the required amplitude specification is symmetric with respect to the center frequency. The least filter order N=6 and four TZs $\Omega_{1,2} = \pm 1.6044$ and $T_{1,2} = 0.0317 \pm 1.0441j$ are obtained according to the proposed method, and the value of the error function is -1.96×10^{-4}. In Chen and Wu's article, the filter order N = 6, four TZs $\Omega_{1,2} = \pm 1.6060$ and $T_{1,2} = \pm 1.0356j$ are given, and the value of error function is equal to -1.47×10^{-6}, calculated by substituting TZs and filter order obtained from Chen's into Equation 7. The amplitude and group delay responses of filter 1 are computed according to TZs and filter order given in this article and in Chen's paper, using Equation 1, and are shown in ***Figure 1***. A comparison of the values of the error function and the filter responses shows that the locations of TZs given in this article are much better, which validate the proposed method. The detailed comparison of the group delay in the passband is zoomed in, demonstrating the equal-ripple group delay of the filter synthesized by the proposed method.

Filter 2

The specifications for filter 2 are as follows:

- Center frequency: 1960 MHz
- Bandwidth: 60 MHz (fractional bandwidth = 3.06 percent)
- Passband return loss: 20 dB
- Group delay variation: < 0.5 ns, when 1945 ≤ f ≤ 1975 MHz (within 50 percent bandwidth)
- Stopband rejection: Las > 25 dB, when f < 1920 MHz.

The least filter order N = 5 and three TZs $\Omega_1 = -1.4569$ and $T_{1,2} = 0.2569 \pm 1.1420j$ can be obtained, according to the proposed method, to meet the specifications of filter 2, and the value of the error function is -4.73×10^{-4}. The realizable coupling coefficient matrix and external quality factor obtained by Cameron's method 2 are given in Equation 8, since the filter order and TZs have been determined by the proposed method.

$$K = \begin{bmatrix} 0.0013 & -0.0268 & 0 & 0 & 0.0040 \\ -0.0268 & 0.0015 & -0.0181 & 0.0057 & -0.0027 \\ 0 & -0.0181 & -0.0127 & -0.0164 & 0 \\ 0 & 0.0057 & -0.0164 & 0.0003 & -0.0266 \\ 0.0040 & -0.0027 & 0 & -0.0266 & 0.0013 \end{bmatrix} \quad (8)$$

$$Q_{ei} = Q_{eo} = 31.3975$$

The amplitude and group delay response are shown in ***Figure 2***, which are obtained from the coupling coefficient matrix in Equation 8 and the transfer and reflection functions in Equation 1, respectively. The difference between the two results is not visible, which confirms the validity of the proposed method.

Filter 3

The specifications for filter 3 are as follows:

- Center frequency: 1800 MHz
- Bandwidth: 60 MHz
- Passband return loss: 20 dB

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DCO6080-3	600 - 800	0 - 3	+3 @ 15 mA	-105	0.3 x 0.3 x 0.1
DCO7075-3	700 - 750	0.5 - 3	+3 @ 12 mA	-108	0.3 x 0.3 x 0.1
DCO80100-5	800 - 1000	0.5 - 8	+5 @ 26 mA	-111	0.3 x 0.3 x 0.1
DCO8190-5	810 - 900	0.5 - 16	+5 @ 34 mA	-118	0.3 x 0.3 x 0.1
DCO100200-5	1000 - 2000	0.5 - 24	+5 @ 36 mA	-95	0.3 x 0.3 x 0.1
DCO1198-8	1195 - 1205	0.5 - 8	+8 @ 30 mA	-115	0.3 x 0.3 x 0.1
DCO170340-5	1700 - 3400	0.5 - 24	+5 @ 29 mA	-90	0.3 x 0.3 x 0.1
DCO200400-5 DCO200400-3	2000 - 4000	0.5 - 18	+5 @ 46 mA +3 @ 46 mA	-90 -89	0.3 x 0.3 x 0.1
DCO300600-5 DCO300600-3	3000 - 6000	0.5 - 18	+5 @ 35 mA +3 @ 35 mA	-80 -78	0.3 x 0.3 x 0.1
DCO400800-5 DCO400800-3	4000 - 8000	0.5 - 18	+5 @ 20 mA +3 @ 20 mA	-78 -76	0.3 x 0.3 x 0.1
DCO432493-5 DCO432493-3	4325 - 4950	0.5 - 11	+5 @ 22 mA +3 @ 22 mA	-88 -86	0.3 x 0.3 x 0.1
DCO473542-5 DCO473542-3	4730 - 5420	0.5 - 22	+5 @ 20 mA +3 @ 20 mA	-88 -86	0.3 x 0.3 x 0.1
DCO490517-5 DCO490517-3	4900 - 5175	0.5 - 5	+5 @ 22 mA +3 @ 22 mA	-88 -86	0.3 x 0.3 x 0.1
DCO495550-5 DCO495550-3	4950 - 5500	0.5 - 12	+5 @ 22 mA +3 @ 22 mA	-83 -85	0.3 x 0.3 x 0.1
DCO579582-5	5780 - 5880	0.5 - 10	+5 @ 20 mA	-90	0.3 x 0.3 x 0.1
DCO608634-5 DCO608634-3	6080 - 6340	0.5 - 5	+5 @ 20 mA +3 @ 26 mA	-85 -86	0.3 x 0.3 x 0.1
DCO615712-5 DCO615712-3	6150 - 7120	0.5 - 18	+5 @ 22 mA +3 @ 22 mA	-85 -83	0.3 x 0.3 x 0.1

Model	Frequency Range (GHz)	Tuning Voltage (VDC)	DC Bias VDC @ I [Typ.]	Phase Noise @ 10 kHz (dBc/Hz) [Typ.]	Size (Inch)
DXO Series					
DXO810900-5 DXO810900-3	8.1 - 8.925	0.5 - 15	+5 @ 32 mA +3 @ 32 mA	-82 -80	0.3 x 0.3 x 0.1
DXO900965-5 DXO900965-3	9.0 - 9.65	0.5 - 12	+5 @ 27 mA +3 @ 27 mA	-80 -78	0.3 x 0.3 x 0.1
DXO10701095-5	10.70 - 10.95	0.5 - 15	+5 @ 25 mA	-82	0.3 x 0.3 x 0.1
DXO11441200-5	11.44 - 12.0	0.5 - 15	+5 @ 30 mA	-82	0.3 x 0.3 x 0.1
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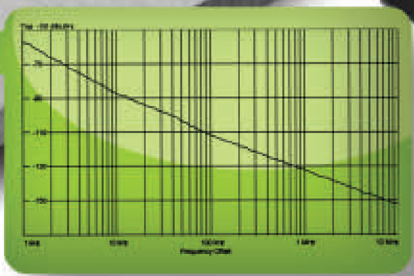

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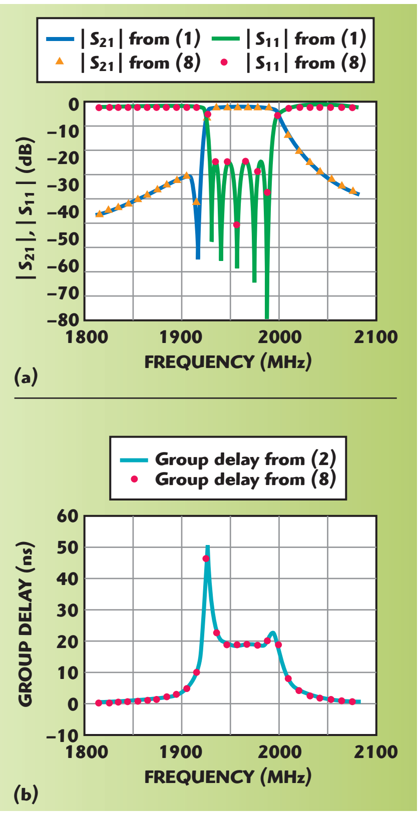
– Rejection at $f_0 \pm 64$ MHz: > 15 dB

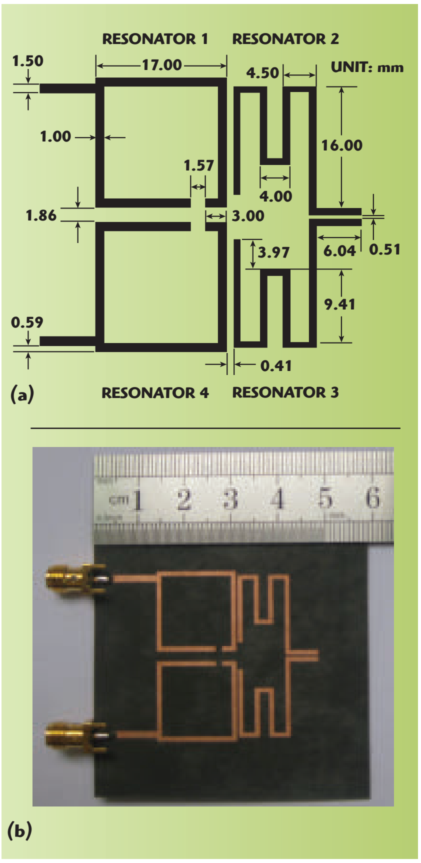
The least filter order N = 4 and T1,2 = ± 1.6575j are obtained according to the proposed method to meet the specifications of filter 3, and the value of the error function is –0.036. The coupling coefficients and external quality factor obtained by Amari's method[4] are:

$$K_{12} = K_{34} = 0.312$$
$$K_{23} = 0.0209, K_{14} = 0.0058$$
$$Q_{ei} = Q_{eo} = 27.233 \qquad (9)$$

After the coupling coefficients are determined, the next step requires the choice of proper resonator types to complete the filter design. In this design, a half-wavelength resonator was chosen.



▲ *Fig. 2 Synthesized responses of filter 2 from equations 1 and 8 (a) amplitude and (b) group delay.*



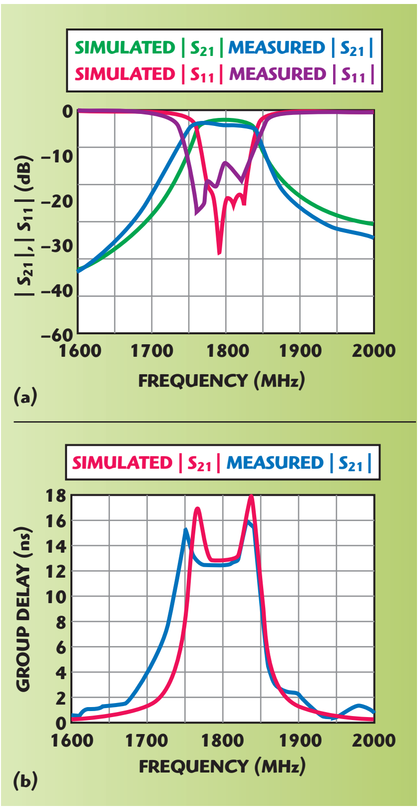
▲ *Fig. 3 Physical dimensions (a) and photograph (b) of filter 3.*

A full-wave simulator IE3D has been used to extract the parameters in Equation 9. In general, the coupling coefficient K_{ij} between two resonators i and j, and the external quality factor are evaluated as[11]

$$K_{ij} = \frac{f_2^2 - f_1^2}{f_2^2 + f_1^2}$$

$$Q_{ei} = Q_{eo} = \frac{f_0}{\Delta f_{3-dB}} \qquad (10)$$

Where f_1 and f_2 are the lower and upper resonant peaks in the transmission response, respectively, and f_0 and Δf_{3-dB} represent the resonant frequency and the 3 dB bandwidth of the input and output resonators, when externally excited. The filter is designed to be fabricated on a Rogers RT/duroid 5880 substrate, with a relative dielectric constant of 2.2, a thickness of 0.508 mm, and a loss tangent of 0.0009. A photograph and the physical dimensions of filter 3 are shown in **Figure 3**. By using open-loop and meandering half-wavelength resonators configurations, unwanted couplings can be reduced effectively.



▲ *Fig. 4 Measured and simulated frequency responses of filter 3 (a) amplitude and (b) group delay.*

The measured and simulated results of the filter are shown in ***Figure 4***. The measured results are a bit worse than the simulated results because of fabrication errors and the influence of the transition between sub-miniature version A (SMA) connectors and microstrip. This example illustrates the general design procedure for self-equalized cross-coupled resonator bandpass filters whose TZs are obtained by the proposed method.

CONCLUSION

This article has presented a simple and efficient method to determine the least filter order and optimum TZs of self-equalized filters, to meet the given amplitude and group delay specifications using GA optimization method. To prove the validity of the proposed method, the filter order and TZs of three self-equalized filters have been determined. A fourth-order self-equalized filter has been designed and fabricated, which illustrates the gener-

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BTE	L - Ku	1 kHz	2.2	-73	-80	-96	-96	-97	-123	12.72 GHz	13
MFS	L - K	1 kHz	2	-60	-75	-90	-95	-95	-120	5.3 GHz	13
CFS	L - K	1 Hz	2	-62	-75	-85	-89	-97	-110	14.84 GHz	13
Ku3LS	X - Ku	1 kHz	2.2	-62	-70	-75	-85	-97	-115	12.50 GHz	13
C3LS	C	1 kHz	1.1	-63	-88	-90	-100	-100	-115	5.50 GHz	13
UWB	S - K	1 kHz	Multioctave	-60	-71	-80	-90	-96	-105	12 GHz	13
MOS	VHF - K	1 kHz	Multioctave	-55	-65	-75	-85	-90	-100	20 GHz	13
SLS	L - Ku	125 kHz	1	-70	-80	-86	-88	-105	-115	3.3 GHz	13
SLFS	VHF - Ku	100 kHz	2	-70	-75	-80	-90	-115	-125	5 GHz	13
LFTS	VHF - Ku	100 Hz	1	-78	-88	-98	-98	-110	-130	350 MHz	13
VFS	L - Ku	>25 MHz	1.5	-60	-80	-110	-115	-115	-130	12.5 GHz	13

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al design procedure for self-equalized cross-coupled resonator bandpass filters. The proposed method has solved the first problem of coupling matrix synthesis of self-equalized filters. ■

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A Repetitive Sampling Receiver for Pulsed Time Domain Load-Pull

The capability of a Nonlinear Vector Network Analyzer (NVNA) repetitive sampling receiver, which is designed to perform pulsed RF S-parameter and load-pull measurements, is presented. Due to its unique sampler-based architecture, unlike a mixer based VNA, the dynamic range of the NVNA is independent of the duty cycle. This results in a good dynamic range even for tiny duty cycles. This NVNA is presented in combination with an open-loop active harmonic load-pull setup, thus enabling fast waveform engineering in pulsed mode.

Nowadays it is a big challenge for engineers dealing with high power RF/microwave transistors to perform an accurate and complete characterization of their devices and to build and validate a transistor model. The modeling process usually starts by extracting a simple linear model from S-parameter measurements. An initial nonlinear model is obtained using pulsed IV and pulsed S-parameter measurement systems. These methods are the ones typically used by the transistor modeling community. A second method, based on load-pull measurements, is used to check the validity of the model for large signal behavior.

Load-pull measurements are typically used by amplifier designers to find the optimum operating conditions of the transistor in order to meet specific amplifier requirements, but also to fully understand the operating behavior of their transistors, particularly when they are used in the nonlinear region. The RF designer can today simulate time domain slopes in RF software, and particularly load lines, to preview the behavior of devices. Therefore, it is imperative to validate simulations against measurements, which can be achieved by associating the NVNA measurement system with an active harmonic load-pull setup. This gives engineers the capability to perform time domain load-pull and S-parameters measurements in CW and pulsed mode.

BACKGROUND

The better way to understand nonlinear phenomena in microwave transistors is to work close to the saturation region with significant power compression. Moreover, most RF power amplifiers operate close to the saturation region, because the power added efficiency (PAE) can be maximized in this area. In the saturation region, nonlinear phenomena and parasitic effects have been observed and have direct consequences on the electrical performance of the components.

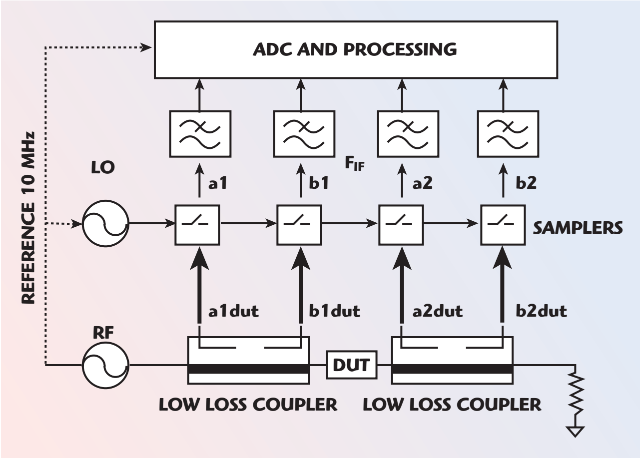
Jad Faraj
Verspecht-Teyssier-DeGroote SAS, France
Simon Mathias
Mesuro Ltd., UK
Jean-Pierre Teyssier
XLIM, University of Limoges, France
Johannes Benedikt and
Michael Casbon
Cardiff University, UK

▲ *Fig. 1 SWAP X402 sample-based NVNA.*

More high power devices are used in pulsed mode and in applications where high peak-to-average ratios are common. Consequently, the memory effects taking place in active devices (thermal effects and trapping effects) will be excited more, so they have to be accurately considered, in particular, a shift in the device characteristics. The RF designers can benefit from the transient envelope simulator tools, but, once again, such simulations need to be checked with measurements.

SAMPLER-BASED NVNA

The SWAP X402 (see ***Figure 1***) is a sampler-based NVNA product from Verspecht-Teyssier-DeGroote (VTD).



▲ *Fig. 2 Sampler-based NVNA architecture.*

It contains four independent and synchronized RF sampler-based receivers, whose role is the conversion of the RF signals into intermediate signals (see ***Figure 2***). The sampling clock, which is driving the four samplers, is generated by a precise and stable local oscillator (LO). This LO is phase-locked to a stable reference that is shared with the RF source and the analog to digital converter (ADC) clock.

As shown the Figure 2, the RF incident and reflected waves a1, b1, a2, b2 at the ports of the DUT, which are separated by low loss couplers (wave-probe or directional coupler), are down-converted by the RF samplers using the high precision local frequency $F_{LO}=F_{RF}-KF_{IF}$ (K is an integer number) and then filtered by a 50 MHz low-pass filter, and acquired by four ADCs. This simple architecture is very efficient for high power measurements.

With this receiver configuration the full wave information is obtained at the calibration planes, as the wave data at the fundamental and harmonics frequencies are acquired simultaneously and coherently by using one-shot measurements. Using robust calibration algorithms, the time domain current and voltage slopes versus time or the load line cycles can be drawn at the reference planes. Moreover, all the information of the performance data, such as the output power, input power, gain, power added efficiency, can also be obtained easily.

By using one-shot measurements to get all the RF (fundamental and harmonic frequencies) information, this NVNA can measure 25 dynamic load lines per second, significantly faster than a mixer-based NVNA. It is also simple to integrate it into any load-pull environment, whether active or passive load-pull is being used.

Next is an example of classical time domain load-pull measurements. These measurements were performed on a power amplifier with a fundamental frequency of 2 GHz and whereby two harmonic frequencies are measured up to 6 GHz. The electrical performance is shown in ***Figure 3*** and the time domain drain current and drain voltage waveforms in ***Figure 4***. Figure 3 shows the output power and the gain versus the input power for a given set of impedances. An output power of 25 dBm has been reached at 10 dB of gain compression (circle point). At

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NEW LZY-22+	0.1-200	43	+42.0	+45.0	8.9	+52	24	6.0	1495	1470
LZY-1+	20-512	43	+45.7	+47.0	8.6	+54	26	7.3	1995	1895
LZY-2+	500-1000	46	+45.0	+45.8	8.0	+54	28	8.0	1995	1895
ZHL-5W-1	5-500	44	+39.5	+40.5	4.0	+49	25	3.3	995	970
ZHL-5W-2G+	800-2000	45	+37.0	+38.0	8.0	+44	24	2.0	995	945
ZHL-10W-2G	800-2000	43	+40.0	+41.0	7.0	+50	24	5.0	1295	1220
ZHL-16W-43+	1800-4000	45	+41.0	+42.0	6.0	+47	28	4.3	1595	1545
• ZHL-20W-13+	20-1000	50	+41.0	+43.0	3.5	+50	24	2.8	1395	1320
ZHL-30W-252+	700-2500	50	+44.0	+46.0	5.5	+52	28	6.3	2995	2920
ZHL-30W-262+	2300-2550	50	+43.0	+45.0	7.0	+50	28	4.3	1995	1920
• ZHL-50W-52	50-500	50	+46.0	+48.0	6.0	+55	24	9.3	1395	1320
• ZHL-100W-52	50-500	50	+47.0	+48.5	6.5	+57	24	10.5	1995	1920
• ZHL-100W-GAN+	20-500	42	+49.0	+50.0	7.0	+60	30	9.5	2395	2320
ZVE-3W-183+	5900-18000	35	+34.0	+35.0	5.5	+44	15	2.2	1295	1220
ZVE-3W-83+	2000-8000	36	+33.0	+35.0	5.8	+42	15	1.5	1295	1220

• ***Protected under U.S. Patent 7,348,854***

*For models without heat sink, add **X suffix** to model No.(Example: LZY-1+, LZY-1X+)*

ZHL-16W-43X+
ZHL-30W-252X+
ZHL-30W-262X+

ZHL-5W-1X
ZHL-5W-2GX+

LZY-1X+
LZY-2X+
LZY-22X+
ZHL-10W-2GX
ZHL-50W-52X
ZHL-100W-52X
ZHL-100W-GANX+

ZHL-20W-13X+

ZVE-3W-83X+
ZVE-3W-183X+

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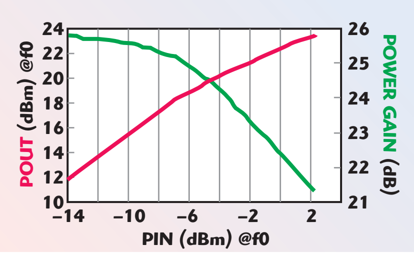
IF/RF MICROWAVE COMPONENTS



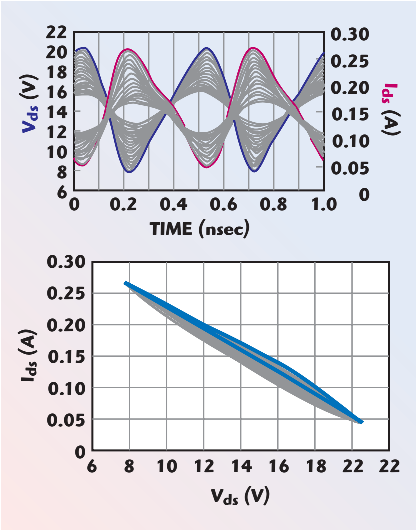
▲ *Fig. 3 Output power and gain vs. input power at 2 GHz.*

10 dB of gain compression, we observe the time domain waveform in Figure 4. These figures convey the nonlinear phenomena and the distortion of the signal at the output of device due to the large compression of the gain.

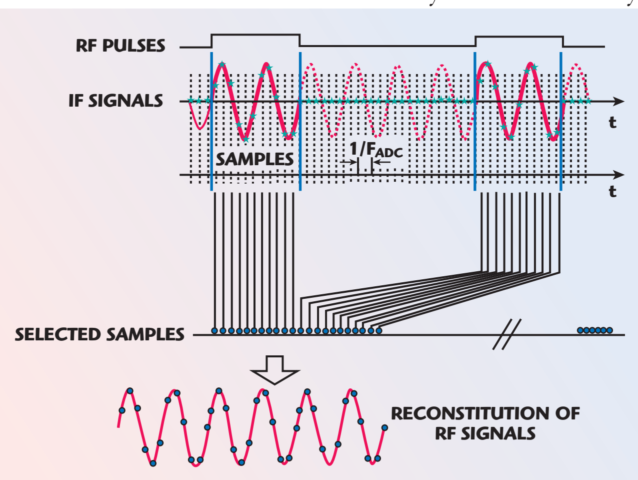
With the presence of a large signal in CW mode, we risk the destruction of the device. Alternatively, the excitation of the high power device with pulse signals allows the characterization of the components with signals that have large amplitudes sometimes up to the avalanche point while reducing the risk of damaging the device. It also highlights some nonlinear phenomena like the thermal effects and the trap effect in newer high power devices. So there is a real need for power amplifier designers to perform transistor characterization under pulsed operating conditions.

This sampling process of CW large signals can be explained in the time domain as a stroboscope. It allows the instrument, in a one-shot measurement, to acquire both the fundamental and harmonic frequencies data for all the incident and reflected waves. The PIV and pulsed RF measurement techniques have already proven their efficiency for the characterization of high power devices. The authors have developed a new approach for the pulsed measurements, one that operates like a second-level stroboscope. This is the so-called Time Domain Approach (TDA) for RF pulse measurements. It is based on a progressive acquisition of all the required data points before sending them to the Fast Fourier Transform (FFT) of the NVNA. Inside every pulse, a defined number of samples is stored, and put together in phase with the preceding ones. This principle, shown in ***Figure 5***, is a stroboscope approach because the RF sampler shots are slightly shifted compared to the observed RF frequency. The exact computation of all the related frequencies of the system – RF signals, RF samplers, ADC acquisition – is a mandatory point, to be sure of the phase coherence between the samples to be put together before the FFT.

This method affects the total acquisition time which depends directly on the measurement duty cycle, but does not have any effect on the dy-



▲ *Fig. 4 Time domain wave form and load line for different input power at 2 GHz.*



▲ *Fig. 5 Synchronized samples in the IF band frequency.*

TABLE I

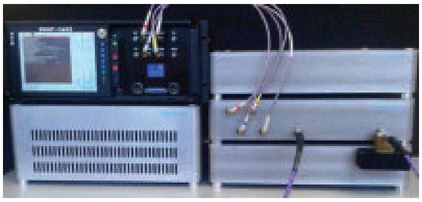
ACQUISITION MEASUREMENTS TIME FOR DIFFERENT DUTY CYCLES

Duty Cycle (%)	(1/10)100	(1/100)100	(1/1000)100
Acquisition Measurement Time	10 µs	100 µs	1000 µs

namic range because there are no relative long-term jitter. The amount of detected energy with this approach is the same as that in CW, although the measurement time is extended. This approach was validated with a duty cycle as small as 1/10000 without any dynamic loss. To ensure good performance, the TDA needs a common reference for the triggers of the ADCs and for the RF receiver; all the frequencies must be very accurately synthesized in order to ensure exact ratios and phase shifts. ***Table 1*** shows the acquisition measurement time for different duty cycles.

ACTIVE LOAD-PULL SETUP WITH NVNA

The VTD NVNA measurement system lends itself well to use within pulsed load-pull measurements and as such, the development team at Mesuro has implemented it as the receiver in its current open-loop Active Harmonic Load-Pull solution. The instrument's ability to define the number of samples taken from each pulse and to adjust the time from the pulse trigger signal to the start of the sampling window proves very useful when measuring devices that are intended to be operated within pulsed environments. In simple terms, this means that one is able to gather as much data from each pulse as required while being able to avoid the transition areas.

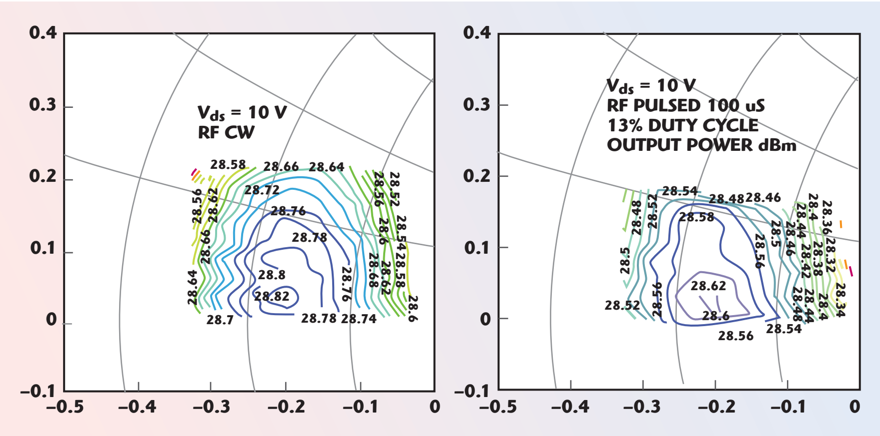


▲ *Fig. 6 Setup for pulse time domain load-pull measurements.*

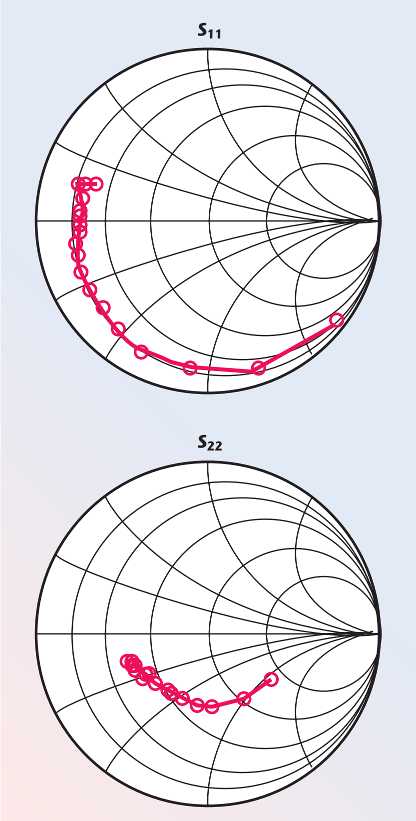
Good correlation has been established so far between CW performance and pulsed measurements on the same device.

Figure 6 shows the Mesuro/VTD setup for the pulse time domain open-loop Active Harmonic Load-Pull measurement. ***Figure 7*** shows contour plots of a device under test, both under CW and pulsed conditions, establishing the optimum output power performance in each case. Work has also been undertaken to confirm correlation of the waveforms at the output current generator reference plane, where both output voltage waveforms and dynamic load lines have been validated.

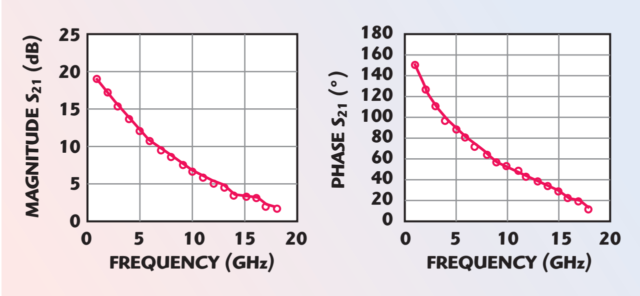
The greatly reduced thermal loading on the device under test, by operating in a pulsed signal environment, enables the designer to undertake measurements far beyond the safe CW operating region and under more realistic operating conditions. This significantly extends the capabilities of the Active Harmonic Load-Pull setups, allowing for a practical methodology for data gathering for use within measure-



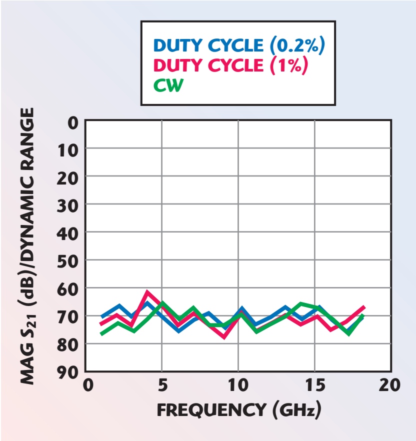
▲ *Fig. 7 Output power contour plots, CW vs. pulsed.*



▲ *Fig. 8 S_{11} and S_{22} plots of the transistor from 1 to 18 GHz.*



▲ *Fig. 9 The magnitude and phase of S_{21} from 1 to 18 GHz.*



▲ *Fig. 10 Dynamic range vs. frequency up to 18 GHz for different duty cycles.*

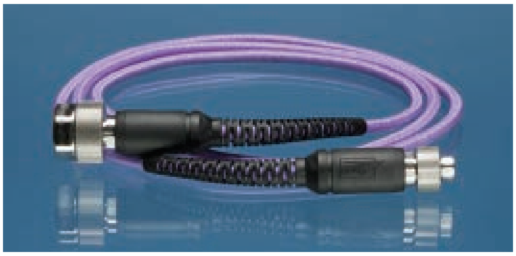
ment-based models. It also allows for waveform engineering to be undertaken on devices viewed as thermally vulnerable in order to achieve the high efficiency modes of operation.

The NVNA can also perform scattering parameter measurements in both mode CW and pulsed mode. Here, we present some results of S-parameters measurements in the pulsed mode. These measurements were performed on a GaN device and on-wafer configuration. The pulse configuration was fixed for a pulse width of 200 ns with 0.2 percent duty cycle and without any dynamic loss. The frequency range for these measurements is 1 to 18 GHz. The quiescent point was fixed on the gate and the drain with V_{gs} = –4.5 V; V_{ds} = 20 V and I_{ds} = 100 mA. ***Figure 8*** shows the data for S_{11} and S_{22} of the transistor.

The magnitude (dB) and phase (degrees) of the S_{21} are shown on ***Figure 9***. These measurements are very accurate. It is observed that the transistor model is able to accurately represent the S-parameter variations versus the bias points values. The measurements in ***Figure 10*** show the dynamic range up to 18 GHz for two different duty cycles 0.2 and 1 percent. This is the S_{21} for an open circuit between port 1 and port 2 in CW and pulse mode with a duty cycles up of 0.2 percent. The dedicated stroboscopic approach allows the NVNA to conserve a dynamic range of up to 65 dB.

CONCLUSION

Pulse measurements allow engineers to study nonlinear behavior and thermal effects in devices that might otherwise be damaged under high power CW conditions. Harmonic Active Load-Pull solutions with the capability to handle very high power devices allow designers to perform waveform engineering. A cost-effective sampler-based NVNA with extended pulse capabilities that is compatible in terms of hardware and software with an active load-pull system has resulted in a very versatile and fast Time Domain Load-Pull setup running with the same level of performances in CW or pulsed mode. ■



RUGGED 18 GHZ CABLE ASSEMBLY FOR HIGH-THROUGHPUT PRODUCTION TESTING

For test applications that require precise, repeatable measurements, GORE® PHASEFLEX® Microwave/RF Test Assemblies have been designed to provide optimal phase and amplitude stability with flexure. The expanded polytetrafluoroethylene (ePTFE) material used in their construction enables them to be rugged yet lightweight and deliver reliable performance with longer service life and reduced equipment downtime. This results in lower costs for testing in laboratory, production and field test environments (see ***Figure 1***).

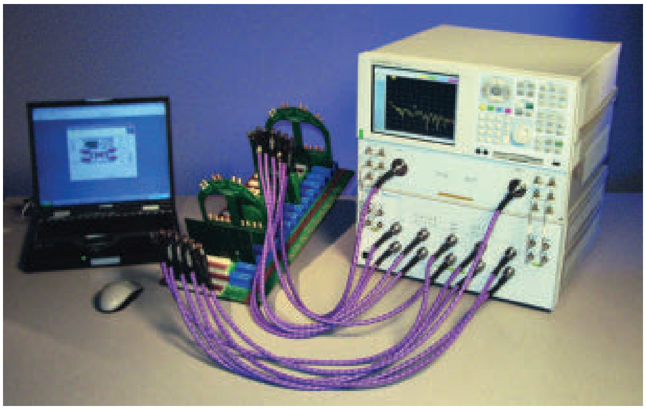


Fig. 1 GORE® PHASEFLEX® Microwave/RF Test Assemblies are designed for test applications that require precise, repeatable measurements (photo courtesy, Agilent Technologies Inc.).

Cable assemblies have a significant impact on the total cost of testing in production environments. Frequent troubleshooting, time-consuming recalibration and re-testing all have a direct impact on throughput in a manufacturing process which, in turn, significantly increases costs. Also, having to use a torque wrench to connect and disconnect each product from the test equipment slows the testing process.

In response to customer concerns about these issues, Gore has engineered a new Mi-

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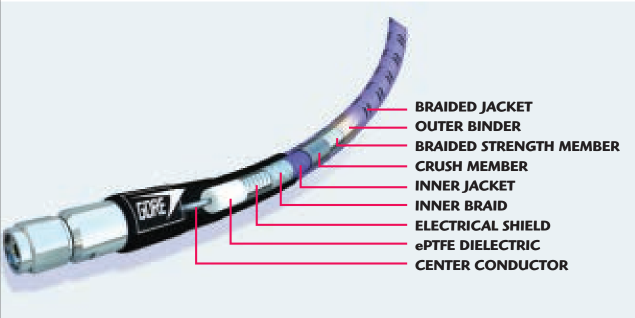
crowave/RF cable assembly that is smaller, more durable, lighter in weight and easier to use. ***Figure 2*** shows the construction of the new GORE® PHASEFLEX® Microwave/RF Test Assemblies (18 GHz, 0G cable type) that are specifically engineered for high-throughput production test applications in the wireless infrastructure market. Although the assemblies' performance has been optimized for frequencies through 6 GHz (the "sweet spot" common to these types of high-throughput production test applications), they will perform well through 18 GHz, a well established performance category in the industry.

The new GORE® PHASEFLEX® Microwave/RF Test Assemblies incorporate a unique connector design



▲ *Fig. 2 Construction of GORE® PHASEFLEX® Microwave/RF Test Assemblies.*

TABLE I

HIGH THROUGHPUT PRODUCTION TEST ASSEMBLY SPECIFICATIONS[1]

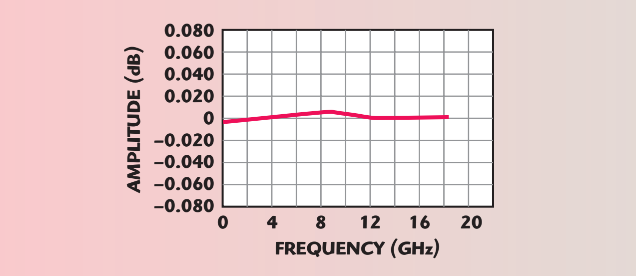
	Gore Cable Type	0G[1]	
Electrical Properties	Maximum Frequency (GHz)	6	18
	Typical VSWR	1.08:1	1.27:1
	Typical Insertion Loss (dB)	1.20	2.19
	Impedance (Nominal) (Ohms)	50	
	Typical Phase Stability (degree)[2]	±0.5	±2.0
	Typical Amplitude Stability (dB)[2]	< ±0.05	
	Dielectric Constant (Nominal)	1.4	
	Velocity of Propagation (Nominal) (%)	85	
	Shielding Effectiveness (dB through 18 GHz)[3]	> 100	
	Time Delay (Nominal) ns/cm (ns/in)	0.04 (0.103)	
Mech./Env. Properties	Center Conductor	Solid	
	Overall Diameter mm (in)	5.3 (0.210)	
	Nominal Weight g/m (oz/ft)	65.0 (0.70)	
	Minimum Bend Radius mm (in)	25.4 (1.00)	
	Typical Flex Cycles[4]	100,000	
	Temperature Range (°C)	-55 to 125	
	Crush Resistance kgf/cm (lbf/in)	33.5 (187)	
	Connector Retention N (lbf)	> 445 (> 100)	

[1]*The electrical specifications in this table are based on a 1 m (39.4 in) assembly length at 6 and 18 GHz.*

[2]*When cable is wrapped 360° around a 57 mm (2.25 in) radius mandrel.*

[3]*Per MIL-STD-1344, method 3008.*

[4]*When bent ± 90° at a radius that is twice the minimum bend radius, test assembly performs reliably through the stated flex cycles.*



▲ *Fig. 3 Typical amplitude stability with flexure and shake for 1 m (39.4 in) cable assembly.*

that includes a larger knurled area to facilitate hand-tightening as well as free-spinning, precision-coupling nuts that enable the connector to spin faster, returning to the home position in 1-1/2 turns while providing the necessary amount of engagement for a robust connection. The new cable assemblies maintain accurate measurement repeatability while withstanding demanding conditions such as continuous flexing, temperature cycling, broad temperature ranges and frequent connecting and disconnecting to the instrument or device under test (see ***Figure 3***).

What the new 18 GHz 0G type cable assemblies bring to the party is maximum strain relief at the point where the cable and connector meet and an internally ruggedized construction that is more durable, delivering crush resistance of 187 pounds per linear inch (85 kg/cm). These assemblies can withstand 100,000 flexures at a minimum bend radius of one inch. They are resistant to chemical exposure and can even be submerged in water. Available in 1.0 and 1.5 meter lengths with both SMA and N-type male connectors, they are also designed to be easy to use for operators in the wireless telecom market who may be inexperienced in handling cable assemblies. They are smaller and more lightweight, and can be connected and disconnected manually – the ergonomic design includes an enlarged knurled area that makes hand tightening easy and eliminates the need to use a torque wrench to accurately connect and disconnect, increasing throughput on the manufacturing line. ***Table 1*** summarizes the specifications of the new 18 GHz 0G type cable assemblies.

The new 18 GHz cable assemblies reduce overall testing costs because they last longer, decreasing the frequency of cable assembly replacements. One reason is that Gore manufactures every component used in them, from the dielectric and the helically wrapped outer conductor to the ePTFE jacketing. This enhanced performance stability ensures ultra-precise measurements and accurate repeatability, reducing the risk of testing errors and the need for time-consuming troubleshooting and system calibration.

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HIGH SPEED MILLING PLOTTER FOR RF MATERIALS

When prototyping RF circuits, it is essential to work in micrometer precision. Even small deviations can lead to undesirable results. Basically, PCBs are manufactured in a negative process: nonconductive regions are removed from a full surface-coated substrate and the conductor structures remain intact.

This conductive layer can be removed by chemical processes such as etching, usually by service providers or in series production. However, when it comes to geometrical precision, rapid prototyping or protecting sensitive data layout, chemical-free methods have significant advantages. This is because the geometry of the generated circuit boards is very similar to the idealized standards of layout and simulation programs. In particular, the higher the transmitted frequencies, the more apparent the impact of variations on the signal quality.

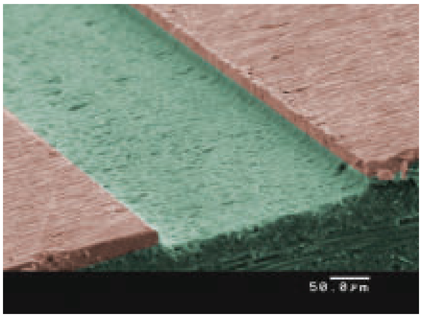
LPKF has been delivering systems for milling PCB prototypes since 1976. The company has upgraded its milling plotters, the ProtoMat family, with additional options that include features that make the plotters particularly suitable for RF applications. They are supplied with a modern soundproof enclosure and, recently developed, easy-to-use software is also included.

All ProtoMats are suitable for structuring classical circuit boards, drilling, depanelling or front panel engraving. The mechanical repeatability is 0.5 microns, with a maximum head speed of 150 mm/s (6 in/s). The work surface accommodates substrates up to 9 × 12 inch (229 × 305 mm).

PROTOMAT S103

The S3 series plotter can be gradually upgraded one step at a time: From the entry-level S43 to the top of the range LPKF ProtoMat S103, which is the most suitable for RF applications. With a spindle speed of 100,000 rpm, the ProtoMat S103 is able to structure both very hard and sensitive materials and the result is steep edges (see ***Figure 1***), which minimize signal losses. The sectional view (colored) shows the straight walls and low penetration depth.

LPKF LASER & ELECTRONICS AG
Garbsen, Germany



▲ *Fig. 1 FR4 material processed with a specialized RF tool (End Mill RF).*

▲ *Fig. 2 Standard configuration of the ProtoMat S103.*

As has been mentioned, the milling plotters incorporate new, user-friendly LPKF CircuitPro software. With this software, occasional users are guided by wizards through the individual process steps, while more experienced users have individual access to each program option. CircuitPro adopts data from the layout program and prepares it to control the circuit board plotter. A material library with an extensive collection of parameters is included and is used to optimize the structuring results on a material-specific basis. Individual parameters can also be added.

Even in standard configuration the ProtoMat S103 comes with fiducial camera, vacuum table, dispenser and a high performance milling head, as shown in ***Figure 2***. Also, the structuring process of the new plotter is considerably more automated than its predecessor, with the facility to change the necessary tools from a 15-piece tool bank. Any use of the tools is logged, enabling conclusions to be made on the degree of wear.

Another innovation is that the ProtoMat automatically selects the penetration of the tool. This ensures precise milling depth while structuring and results in minimal effects on the substrate during milling. For instance, on 18/18 FR4 material, isolation channels and signal-track width can be implemented safely at 100 microns.

MILLING DEPTH CONTROL

In addition to the automatic milling depth, the ProtoMat S103 has an integrated pneumatic milling depth control that contactlessly monitors the penetration depth while structuring. The pneumatic depth gauge runs on an air cushion, so the milling head does not touch the surface of the substrate. Only the tool is in direct contact.

The required depth of penetration into the material is well defined in the software and continuously maintained by the Z-axis. This feature ensures secure control of the signal loss and as

▲ *Fig. 3 RF antenna structure made using the ProtoMat S103.*

a result enables the ProtoMat S103 to process substrates with sensitive coatings, such as Rogers 5880. Its precision is shown in ***Figure 3***.

The controlled Z-axis has a stroke of 0.9 inch (22 mm) and extends the plotter's capabilities: it permits the processing of aluminum enclosures. In addition, it can create pockets in rigid printed circuit boards, which prevents the cross-talking of neighboring processors.

VACUUM TABLE AND CAMERA

Other benefits for RF designers are provided by the vacuum table and the fiducial camera. The vacuum table fixes thin and flexible substrates securely in place while processing, which allows a much higher repeatability than the pass-hole system registry pins. With the vacuum table, prepregs for multilayer production or even PUPI-stencils for solder paste printing can be cut out.

The camera opens up even greater possibilities. For instance, it recognizes fiducials on substrates and calibrates the working result at this location. This allows intermediate processes, so after patterning, the substrate is removed from the ProtoMat, measured and can be connected again for accurate reworking. This is ensured by the vision system with an accuracy of approximately 20 microns for reproccessing and front-to-back alignment. For example, vias or electronic measurements between two patterning steps can be done. Significantly, the reprocessing enables an iterative approach to the prototyping of complex circuitry layouts.

Another innovation becomes relevant when the board is completely structured. For the first time, a ProtoMat model is equipped with a solder paste dispenser. This dispenser uses the integrated camera and locates the solder pads quickly and accurately. In many cases this eliminates a complete step, the printing of solder paste. Ideally, the printed circuit board can be structured and then immediately soldered in the reflow oven.

The ProtoMat S103 is a powerful system for mechanical structuring of RF circuit boards. It is the result of more than 30 years of development and utilizes the capabilities of mechanical processing to the limit. For even higher standards of accuracy and speed, LPKF has also developed the ProtoLaser S, which is a laser system that can structure laminated and ceramic substrates with the help of an IR laser.

LPKF Laser & Electronics AG,
Garbsen, Germany
+49 5131 7095-0,
www.lpkf.com.

HIGHLY INTEGRATED GPS/GLONASS RX FRONT-END MODULES

In the development of high-end electronic devices, a steep rise is being observed in the demand for module solutions for RF components. The reason is to be able to compete in a market that desires new features everyday in the smallest form factor, at lowest current consumption and with best performance. To meet the requirement on the fastest time to market with the right device, the ideal solution for a system designer is to opt for a drop-in module integrating several devices in a single package, without having to go through a long PCB level design cycle and verification. RF front-end design for navigational applications is no exception in this regard.

With the evolution of Global Navigation Satellite System (GNSS) from GPS only into a more complex system, also including Russian GLONASS, European Galileo and Chinese COMPASS, the product development for navigation applications gets challenging. In addition, today's GNSS systems find their application in multi-mode hand-held devices with many other wireless applications co-existing, which can cause interference and jamming. Also, other navigation devices like personal

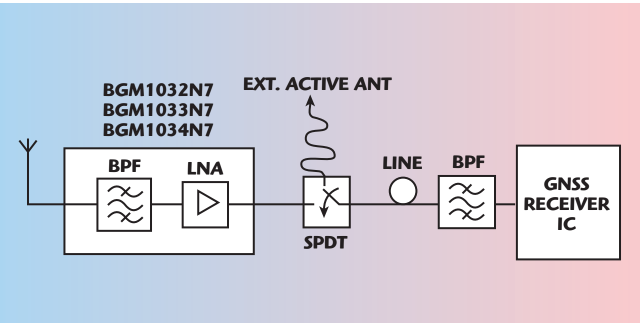


Fig. 1 GNSS application diagram.

INFINEON TECHNOLOGIES AG
Neubiberg, Germany

DEVICE	Vdd (V)	Idd (mA)	GAIN (dB)	NF (dB)	INBAND IP1dB (dBm)	INBAND IIP3 (dBm)	OUT-of-BAND IP1dB (dBm)		REJECTION (dBc)			
FREQUENCY (MHZ)				GPS/ GLONASS	1575–1605	1757–1605	900	1710	787	900	1710	2400
BGM1032N7	2.7	4.0	14.8	1.65/2.0	–6	–6	30	30	74	53	43	54
BGM1033N7	2.7	4.0	14.8	1.65/2.0	–6	–6	30	30	-	53	43	54
BGM1034N7	2.7	3.1	17.0	1.7	–15	–10	22	26	-	55	43	56

▲ *Fig. 2 Performance comparison of BGM103xN7 series.*

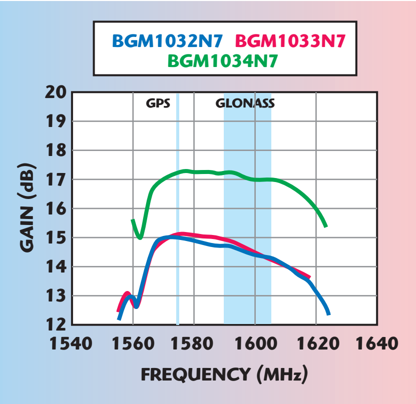
navigation devices (PND), watches, cameras are susceptible to the coupling of high power GSM/UMTS/LTE/WLAN signals, which may interrupt the regular functioning of the device.

First, to achieve state-of-the-art receiver sensitivity levels due to the extremely low signal strengths of GNSS signals, the need for an external low noise amplifier (LNA) is proven to be essential. Due to the ever-growing high power interfering signals, appropriate filters are needed in front of the LNA to suppress these jammers. A pre-filter at the input of the LNA has a dual role in that it prevents the LNA to be driven into saturation by the high power jammer signals and, at the same time, helps achieve a high selectivity for the frequency of interest to enable reception also in worst-case conditions. However, it also adds to the losses of the receiver chain with its insertion loss. So the selection of filter is to be based on an optimum trade-off between insertion loss and rejection levels of out-of-band signals. A post-filter might also be necessary to suppress interfering signals coupling to the system after LNA.

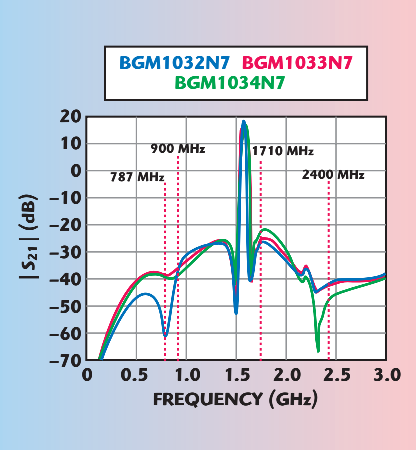
Infineon, with its expertise in RF technology and design has taken up all the above-stated challenges and successfully designed drop-in front-end solutions for system requirements. Infineon offers three different GNSS RF front-end modules with an integrated pre-filter and LNA. They are optimum for cases where the post-filter is placed close to the GNSS receiver and where the designer has flexibility to choose a post filter of choice (with suitable NF, attenuation, single-ended/balanced). The advantage of using a separate post filter is that the module with pre-filter LNA can be placed close to the antenna to achieve better sensitivity and also enables the use of an additional external active antenna connected directly to the post-filter. All modules feature very low insertion loss/high out-of-band rejection pre-filter, followed by a high performance GNSS LNA (see ***Figure 1***). They are offered in a tiny TSNP-7-10 leadless package (2.3 × 1.7 × 0.73 mm), which makes them the smallest available solutions in the market.

The three product offerings are:

- BGM1033N7: mid-gain version;



▲ *Fig. 3 In-band gain and out-of-band suppression of BGM103xN7 series.*



▲ *Fig. 4 In-band gain of BGM103xN7 series.*

standard solution to meet high performance GNSS specification.

- BGM1032N7: in addition to BGM1033N7 features, specially designed to suppress LTE Band 13 signals. This LTE band is very critical as the upper frequency of Band 13 is 787 MHz, and the second harmonic of this frequency, that is 1574 MHz, falls exactly into the GPS band.
- BGM1034N7: high gain version; for systems with high losses in the receiver chain. However, the higher gain affects linearity but is still acceptable for applications like PNDs and DSCs, where jamming due to high power cellular signals is less critical.

The performance of these three modules is shown in ***Figure 2***. ***Figure 3*** shows the in-band gain and out-of-band suppression of the BMG103xN7 series modules, while ***Figure 4*** shows their in-band gain only.

Applications: Smart Phones, Tablet PCs, Personal Navigation Devices (PND), Digital Still Cameras (DSC), Watches, etc.

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- Tiny TSNP-7-10 leadless package: 2.3 × 1.7 × 0.73 mm
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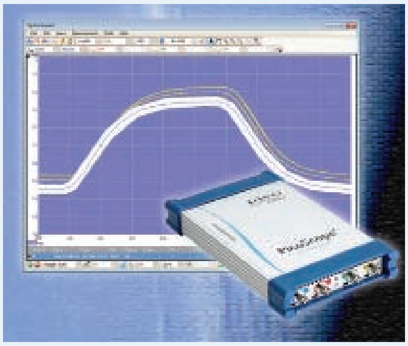

FAST FOUR-CHANNEL PICOSCOPE 6404 PC OSCILLOSCOPE

The new four-channel PicoScope 6404 PC Oscilloscope has an analog bandwidth of 500 MHz. This is matched by a real-time sampling rate of 5 GS/s, which guarantees accurate representation of signals up to the full bandwidth. The oscilloscope also has an ultra-deep 1-gigasample buffer memory that allows capture and analysis of complex waveforms, even when sampling at full speed.

Building on the company's 20 years of experience in PC oscilloscope design, this instrument packs high performance and added features into a space-saving USB oscilloscope enclosure. As well as the headline specifications, the scope offers a built-in function generator, arbitrary waveform generator, mask limit testing, switchable bandwidth limiting on each channel, and switchable 1-megohm and 50 Ω inputs. This is in addition to the spectrum analysis, advanced triggering and serial decoding that are standard features of the company's PC oscilloscopes.

The scope connects to any Windows XP, Vista or Windows 7 computer with a USB 2.0 port. It can be used with a PC to save space on a workbench, or it can be connected to a laptop to create a portable instrument that is ideal for field servicing and on-site demonstrations.

The high sampling rate and bandwidth makes the PC oscilloscope suitable for analog and digital circuit designers, test engineers and installers. And for those users who want to write their own application to control the scope or use it as a digitizer, Pico Technology provides a software development kit, including example code, free of charge. The PicoScope 6404 also includes valuable features, such as segmented memory, serial decoding and advanced digital triggers, at no extra cost.

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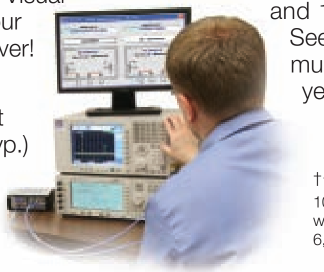

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The HMC-T2270 Synthesized Signal Generator was developed to provide the R&D engineer and the production test engineer with the highest level of performance and functionality, while maintaining reasonable cost. The result is a high powered Synthesized Signal Generator, which is priced at $34,998.

The HMC-T2270 is a 10 MHz to 70 GHz signal generator that delivers up to +29 dBm of CW output power in 0.1 dB steps over a 60 dB dynamic range. Harmonic rejection is better than –40 dBc at 30 GHz output, while spurious products are better than –65 dBc at all integer frequencies. Phase noise is –113 dBc/Hz at 10 kHz offset from 1 GHz, and –79 dBc/Hz at 100 kHz offset from 67 GHz, with insignificant deviation over the temperature range of 0 to +35°C.

The HMC-T2270 exhibits frequency resolution of 1 Hz and fast switching speed of only 500 µs, making it ideal for frequency hopping and threat simulation applications. Furthermore, the broad frequency coverage of the HMC-T2270 will be attractive to OEMs involved in the development of new and emerging automotive sensors, millimeterwave communications and medical equipment, as well as those taking advantage of the unlicensed communication spectrum between 57 and 66 GHz.

The HMC-T2270 is a versatile signal generator that is compatible with many different control interfaces (USB, GPIB and Ethernet) ensuring carefree integration in any test environment. An installation disk that accompanies each unit includes all of the drivers required to remotely control the instrument, as well as a user friendly LabWindows™ based GUI interface compatible with Windows XP®, Windows Vista® and Windows 7® operating systems.

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AMTI has a new website for its filter division, AMTI Microwave Circuits, at www.diplexers.com. The website features a new advanced search function, which allows customers to get detailed information on a specific filter. Customers can achieve the desired specifications of a product by accessing the new online product listings. Another feature allows users to log in and access specialized content.

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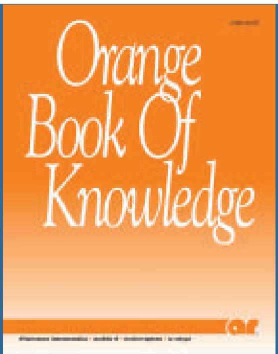

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Components and Equipment

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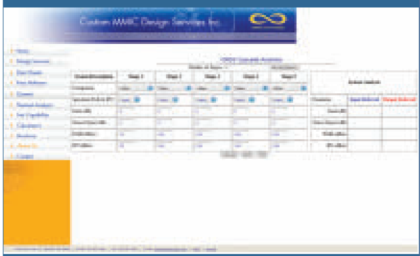


MMIC Development

Custom MMIC Design has a new Cascade Analysis tool on its website. The unique quality of the tool is that the user can enter either the input or output specifications of the component into the web page. CMDS knows of no other tool that allows users to enter parameters in this fashion. This tool solves the P1dB dilemma so microwave system designers can go straight from data sheet to analysis without hesitation.

Custom MMIC Design,
1 Park Drive (Unit 12),
Westford, MA 01886

www.custommmic.com

Market Research and Forecasting

Engalco is constantly researching the market and the company provides tech-sector industrial market research in the form of custom consultancy and off-the-shelf reports. Engalco has a comprehensive collection of detailed reports and provides in-depth company analyses and market forecasts for commercial, industrial and military sectors. The company tends to specialise in aerospace and defense. The formatting is in chart and tabular styles.

Engalco,
3 Georgian Mews, Bridlington,
East Yorkshire, UK

www.engalco-research.com

RF/IF and Microwave Components

VENDORVIEW

Mini-Circuits has updated its website to make it quicker and easier to navigate. Yoni2, an advanced search engine, provides three ways for customers to find models – scroll through the product lines, enter a model number or enter performance requirements. Among the clickable details for each model in the catalog are data sheets, S-parameters, environmental specifications, material declarations, export information, technical notes, PCN history, engineering tools, PCB layouts and companion products.

Mini-Circuits,
PO Box 350166, Brooklyn, NY 11235

www.minicircuits.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 homepage table to immediately download brochures and data sheets 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

Test and Measurement Product Selector

The new RF Test and Measurement Product Selector provides four interactive matrices that give easy-click access to the latest products. Customers can use the product selector to find the best parts for their test lab or factory testing environment, including test cable assemblies (0 to 110 GHz), adapters, connectors, DC Blocks, amplifiers, attenuators, couplers, coaxial switches, dividers/combiners, heat sinks, terminations, and a variety of RF component test lab kits. Visit www.rell.com/test.

Richardson RFPD Inc., 40W267
Keslinger Road, La Fox, IL 60147

www.richardsonrfpd.com

Connectors

Sabritec announces the implementation of Stockcheck, a Hearst Business Media inventory locator tool. This new feature will benefit customers by providing an option to easily view and place orders for Sabritec connectors in real time. Customers can find this feature on the Sabritec website homepage. The customer enters the part number into Stockcheck, it will then pull a list of distributors who stock the part and the level of inventory they currently have, with links to their websites. The customer can then link to the distributors websites and request quotes.

Sabritec,
17550 Gillette Ave., Irvine, CA 92614

www.sabritec.com

PCB Prototyping

T-Tech proudly introduces the new www.t-tech.com website. Easily navigated and visually refreshing, browse the new site for up-to-date product information, company news, and a direct portal to the company's industry-leading customer service department. Visit www.t-tech.com for all of your printed circuit board (PCB) prototyping needs and allow T-Tech to help make you more successful.

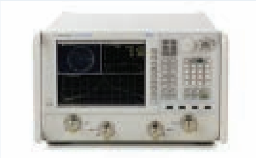
T-Tech Inc.,
510 Guthridge Court,
Norcross, GA 30092

www.t-tech.com

The following booth numbers are complete as of August 9, 2011.

PNA N522XA Network Analyzer

VENDORVIEW

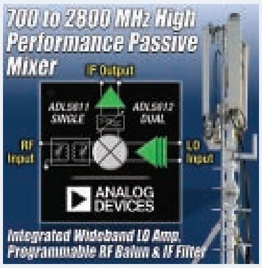


The new PNA Series is based on Agilent's PNA-X architecture and is described as a high performance microwave network analyzer, setting a new price/performance standard in the industry. The Agilent PNA is used to test passive and active devices, such as filters, duplexers, amplifiers and frequency converters. The high performance characteristics of the PNA make it an ideal solution for these types of component characterizations as well as millimeter-wave, signal integrity and materials measurements.

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

Booth 301

Integrated Circuits



Analog Devices will showcase its broad portfolio of high performance RFICs, covering the entire signal chain from antenna to bits. Among the highlights are the ADL5811 and ADL5812 passive mixers and the ADF4351 PLL synthesizer. Using a unique combination of design skills, system understanding and process technologies, Analog Devices offers the broadest portfolio of RFICs covering the entire RF signal chain from industry-leading high performance RF function blocks to highly integrated single chip transceiver solutions. The RF function blocks include PLL, PLL/VCO and DDS synthesizers; power detectors; amplifiers; mixers, modulator and demodulators; ADC drivers; clocks and data converters.

Analog Devices,
Norwood, MA (781) 329-4700,
www.analog.com/rf.

Booth 319

Vector Network Analyzer

VENDORVIEW

Anritsu claims to redefine the broadband VNA market with the introduction of ME7838A broadband vector network analyzer system that provides single-sweep coverage from 70 kHz to 110 GHz with operation from 40 kHz to 125 GHz. The ME7838A conducts highly accurate and efficient broadband device characterization of active and passive microwave/mmWave devices, including those designed into emerging 60 GHz wireless personal area networks (WPAN), 40 Gbps and higher optical networks, 77 and 94 GHz automotive radar, digital radio links, 94 GHz imaging mmWave radar, and Ka-band satellite communications.

Anritsu Co.,
Morgan Hill, CA (800) 267-4878,
www.anritsu.com.

Booth 101

1 to 2.5 GHz Solid-State Amplifiers

VENDORVIEW

AR's new family of solid-state amplifiers provides up to 500 W of power from 1 to 2.5 GHz. These amplifiers are extremely linear and have low spurious signals making them ideal as driver amplifiers in testing wireless and components and subsystems. They are also suitable for EMC test applications where low distortion modulation envelopes are desired and are an excellent replacement for present TWTA designs offering increased reliability and superior specifications.

AR RF/Microwave Instrumentation,
Souderton, PA (215) 723-8181,
www.arworld.us

Booth 417

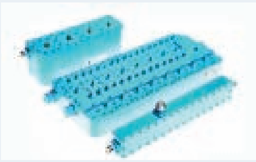
Components, Modules and Subsystems

The CMP family comprises eight well established operating companies: BSC Filters, Dilabs, Dow-Key Microwave, K&L Microwave, Novacap, Pole Zero, Syfer and Voltronics. CMP makes application specific passive components, modules and subsystems for high voltage, high temperature, high reliability and high frequency uses in the military, medical, telecom, oil, industrial and automotive markets. Products include ceramic capacitors, EMI suppression filters, capacitor and planar arrays, precision trimmer capacitors, filters, switches and resonators.

Ceramic Microwave Products,
East Cazenovia, NY (315) 655-8710,
www.dilabs.com.

Booth 235

Filter Portfolio



Creowave provides RF and microwave electronic products and solutions for challenging conditions. The radio-testing business unit offers a variety of subsystems and filters, including suitable products for spurious emissions, multiband testing and passive intermodulation measurements. The filter portfolio consists of diplexers, duplexers, band pass filters, band stop filters and high pass filters. Along with standard models, tailored solutions are offered.

Creowave,
Oulunsalo, Finland
358 50 5628 789,
www.creowave.com.

Booth 222

Customized Components

DLI is your global partner for application specific microwave and millimeter-wave components, serving customers in fiber optic, wireless, medical, transportation, semiconductor, avionics and military markets. You can rely on DLI for all your high frequency single layer and multilayer capacitors, build-to-print thin film circuits and custom thin film applications, specific ceramic components, such as filters, gain equalizers and resonators. DLI products can be found wherever customization, tight tolerance, unique technologies and exceptional customer service is required.

Dielectric Laboratories Inc.,
East Cazenovia, NY (315) 655-8710,
www.dilabs.com.

Booth 235

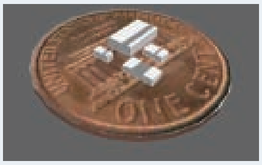
Low PIM Switches

As low PIM requirements on passive devices are getting increasingly significant in test and communication industries, Dow-Key Microwave, part of Ceramic Microwave Products, presents to the RF and microwave industry coaxial switches reducing nonlinear PIM responses. To avoid high intermodulation levels, most Dow-Key coaxial switches from SPDT up to SP12T are available with the low PIM option. These switches are specifically designed and guaranteed to meet third order PIM requirements below -160 dBc at 1870 MHz with carrier levels at 1930 MHz and 1990 MHz, at approximately +43 dBm.

Dow-Key Microwave,
Ventura, CA (800) 266-3695,
www.dowkey.com.

Booth 235

New Thermal Jumpers



These ceramic chips are designed to help in thermal management by transferring the heat from components in the PCB to an area where it can be safely dissipated. The thermal jumpers are electrically isolated and can be used in both, RF and DC applications. The extra metallization provides added heat transfer by increasing the effective area in the thermal path. These thermal jumpers are RoHS compliant and are offered in BeO and AlN with different sizes and thickness.

Electro Technik Ind.,
Largo, FL (813) 421-2129,
www.electrotechnik.com.

Booth 224

Microwave Generator

The new MSYS245 is the compact, lightweight and portable solution developed specifically for the field of medical microwave ablation. Fully 60601 compliant, the MSYS245 microwave generator is ready for rapid integration into your system design. The MSYS245 uses

TINY

TOP HAT™

Wideband Transformers

0.15-6200 MHz as low as 99¢ each (qty. 1000) RoHS compliant.

Rugged, repeatable performance.
At Mini-Circuits, we're passionate about transformers. We even make own transmission line wire under tight manufacturing control, and utilize all-welded connections to maximize performance, reliability, and repeatability. And for signals up to 6 GHz, our rugged LTCC ceramic models feature wrap-around terminations for your visual solder inspection, and they are even offered in packages as small as 0805!

Continued innovation: Top Hat.
A Mini-Circuits exclusive, this new feature is now available on every open-core transformer we sell. Top Hat speeds customer pick-and-place throughput in four distinct ways: (1) faster set-up times, (2) fewer missed components, (3) better placement accuracy and consistency, and (4) high-visibility markings for quicker visual identification and inspection.

More models, to meet more needs
Mini-Circuits has a variety of over 200 SMT models in stock. So for RF or microwave baluns and transformers, with or without center taps or DC isolation, you can probably find what you need at minicircuits.com. Enter your requirements, and Yoni2, our patented search engine, can identify a match in seconds. And new custom designs are just a phone call away, with surprisingly quick turnaround times gained from over 40 years of manufacturing experience!

See minicircuits.com for technical specifications, performance data, pricing, and real-time, in-stock availability!
Mini-Circuits...we're redefining what Value is all about!

Mini-Circuits®
ISO 9001 ISO 14001 AS 9100

P.O. Box 350166, Brooklyn, New York 11235-0003 (718) 934-4500 Fax (718) 332-4661

Yoni2® **The Design Engineers Search Engine** finds the model you need, Instantly • For detailed performance specs & shopping online see minicircuits.com

U.S. Patents 7739260, 7761442

IF/RF MICROWAVE COMPONENTS

377 rev X

NEW WAVES

state-of-the-art technology to produce a highly efficient system capable of generating variable power in excess of 100 W at 2.45 GHz, with superior reflection measurement capability and temperature stability. For industrial and scientific applications, inquire about the ISYS245.

Emblation Ltd.,
Inglewood, Alloa, UK
+44 (1259) 236132,
www.emblationmicrowave.com.

Booth 133

Smart Detector

VENDORVIEW

EMC Technology's Smart Detector is a passive, internally temperature compensated, true RMS RF power sensor. Designed to be used for power monitoring over a frequency range of DC to 6 GHz, it can also be used as a high power VSWR detector with an appropriate directional coupler. The Smart Detector combines an RF termination and a signal detector into one completely passive device, reducing power monitoring circuit complexity. It effectively replaces active diode detectors and other semiconductor devices and dramatically improves circuit reliability.

EMC Technology,
Stuart, FL (800) 544-5594,
www.emc-rflabs.com.

Booth 435

Injection-moulded Absorbers

VENDORVIEW

Eccosorb® MF-PP represents a family of injection-moulded absorbers based on a thermoplastic material with high magnetic loss. It is the ideal absorber for medium to high volume applications. Eccosorb MF-PP products are used as attenuator and termination in waveguides, coaxial or stripline applications. Other applications include phase shifters in phased array antennas and structural absorbers for board-level and above board EMI suppression.

Emerson & Cuming Microwave Products,
Geel, Belgium +32 14 56 25 00,
www.eccosorb.eu.

Booth 423

EMC, Antenna and Wireless Testing

ETS-Lindgren is a leader and innovator in EMC, antenna and wireless testing. A fully integrated company of more than 750 employees supply complete test solutions and individual components, such as antennas, powerline filters, absorber and probes. The company's solutions cover the frequency range of DC to 110 GHz.

ETS-Lindgren Europe,
Eura, Finland +358 2 8383 300,
www.ets-lindgren.com.

Booth 401F

Measurement and Testing

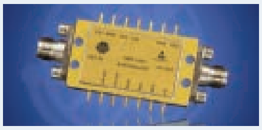
Evans Analytical Group (EAG) provides materials characterization, surface analysis and electronic testing services for the defense and microelectronics industries. EAG offers expertise across a full range of materials measurements and electronic testing, including: SIMS, XPS, XRF, GDMS, TEM, burn-in/reliability and ESD testing. This extensive range of materials characterization and electronic testing services, combined with highly skilled scientists provide unmatched capacity that enables fast turnaround time, superior data quality and excellent results.

Evans Analytical Group, Shinfield,
Reading, UK +44 (0) 11 89 87 54 00,
www.eaglabs.com.

Booth 227

Connectorized Modules

VENDORVIEW



Hittite offers 12 connectorized module product lines that are ideal for high performance laboratory, industrial and military subsystem applications. Standard module functions include amplification, control, logic, frequency conversion and frequency generation with operation to 38 GHz. The HMC-C083 MicroSynth® is a fully integrated broadband synthesizer that sweeps from 2 to 6 GHz in 0.6 Hz steps, delivers +17 dBm output power with excellent SSB phase noise of -93 dBc/Hz at 100 kHz offset. This powerful new synthesizer module is available from stock and can be customized for specific applications.

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

Booth 512

Flexible Microwave Cable

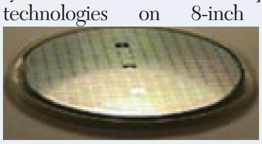
HUBER+SUHNER radio frequency assemblies comply with the highest demands, and the interconnection components that they rely on meet the highest standards as well. The SUCOFLEX®400 family gives you the opportunity to design with the highest performance flexible microwave cable in its class. The HUBER+SUHNER SUCOFLEX®400 microwave cable family has been specifically developed for defence, medical, test and measurement applications, and anywhere the best insertion loss and outstanding phase stability versus temperature are of the utmost importance.

HUBER+SUHNER,
Herisau, Switzerland +41 (0) 71 353 41 11,
www.hubersuhner.com.

Booth 343

Wafer and Foundry Service

IHP provides its Multi Project Wafer and Foundry Service with 0.13 and 0.25 µm SiGe BiCMOS technologies on 8-inch silicon wafers. Latest devices are integrated SiGe heterobipolar transistors with 500 GHz fmax and integrated RF MEMS for frequencies up to 100 GHz. Displayed in the exhibition are high performance analog and mixed signal circuits, such as 60 GHz transceivers, analog circuits up to 200 GHz and DAC components > 20 GSps.

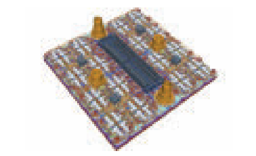


IHP – Innovations for High Performance
Microelectronics, Frankfurt (Oder),
Germany +49-335 5625 647,
www.ihp-microelectronics.com/12.0.html.

Booth 336

3D EM Field Solver

The new version of EMPIRE XCcel 5.51 is even further optimised to solve huge simulation domains, hundreds of wavelength in size. It is one of the leading 3D EM field solvers for RF and



microwave antennas, components and systems. New speed records: cluster solver 5560 MCells/s, 12 Intel Core i7-920 computers, single PC solver 2650 Mcells/s on Intel Dual Xeon X5680 and single PC solver, 2120 MCells/s on Intel Core i7-2600. For further information, visit www.empire.de.

IMST GmbH,
Kamp-Lintfort, Germany +49 (0) 2842-981-0, www.imst.com.

Booth 622

Surface-mount Switch

JFW's latest innovation in high powered RF switching is the 50S-1887 SMT. It is a surface-mount switch that can handle up to 100 W (average RF input power) and it is capable of hot-switching 20 W. The 50S-1887 SMT is designed to operate from 225 to 400 MHz, but other frequency ranges may be available upon request.

JFW Industries Inc.,
Indianapolis, IN (317) 887-1340, www.jfwindustries.com.

Booth 225

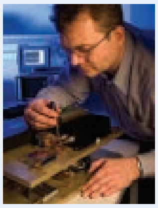
Signal Integrity Network Analyzer

The LeCroy SPARQ is a new class of instrument: the Signal Integrity Network Analyzer. SPARQ, which stands for "S-parameters Quick," is a TDR/TDT-based analyzer that measures 40 GHz, up to 12 port S-parameters with a single button press, and at a fraction of a cost of a VNA. Fully automatically calibrated measurements can be made in minutes, and without any need to connect or disconnect cables to calibration kit standards or electronic calibration modules (models from 2 to 12 ports).

LeCroy Ltd.,
Slough, Berkshire, UK +44 (0) 1753 725377, www.lecroy.com/europe.

Booth 318

Subsystem Designer/Manufacturer



Link Microtek will highlight its capability to design and manufacture RF and microwave subsystems for customers' specific requirements. The company offers a comprehensive subsystem service, encompassing design, fabrication, assembly and test. Working from customers' concepts, Link can design the subsystem in its entirety or make recommendations for improvements to the original design. The company then sources any standard components, produces the necessary customised hardware in its in-house machine shop and assembles the subsystem. Finished units can be tested at up to 40 GHz in Link's own test and environmental laboratories.

Link Microtek Ltd.,
Basingstoke, Hampshire, UK +44 (0)1256 355771, www.linkmicrotek.com.

Booth 124

Surface-mount Limiter

Linwave is pleased to announce the release of the first in a range of high performance system building blocks for the radar and EW markets. The QFN packaged limiter offers industry leading insertion loss and flat leakage performance in a small 5 × 5 mm package, along with 50 Ω internal matching for ease of system integration. The LW48-700117 is a 5 W CW wideband two-stage limiter operating over a 2 to 20 GHz frequency range and is also available with integrated LNAs.

Linwave Electronic Manufacturing Services,
Lincoln, UK +44 (0) 1522 681811, www.linwave.co.uk.

Booth 332

Digital Phase Shifters

VENDORVIEW

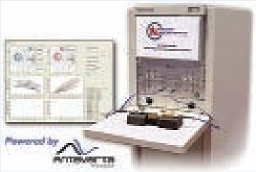
These phase shifters facilitate easy implementation in communication antennas, phased array radars, commercial weather radars and electronic warfare receivers. The GaAs PHEMT 4-Bit and 6-Bit digital phase shifters meet the high performance requirements of system manufacturers by

optimizing for fast switching speed, low phase error and serial or parallel control capability. The phase shifters are available in 4 mm 24-Lead PQFN packages and feature a built-in CMOS driver, that allows for serial or parallel control. Operating from 1.4 to 2.4 GHz, the phase shifters maintain low phase error and low attenuation variation over the 360° range.

M/A-COM Technology Solutions,
Lowell, MA (978) 656-2500, www.macomtech.com.

Booth 422

Mixed-Signal Active Load Pull Systems



Maury Microwave, partnering with Anteverta-mw, has released the turnkey MT2000-series of Mixed-Signal Active Load Pull systems. The MT2000 is unique in its ability to measure up to 1000 impedance/power states per minute and operate under CW, pulsed-CW, multi-tone and modulated-signal conditions. The MT2000 is the only load pull system with the capability of controlling up to 120 MHz of instantaneous impedance response, making it the only suitable solution for amplifiers operating under realistic wideband modulated conditions, such as WCDMA. The MT2000 is available in both fundamental and harmonic load pull configurations.

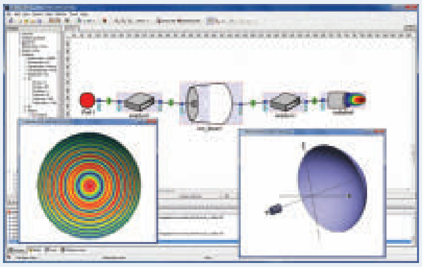
Maury Microwave Corp.,
Ontario, CA (909) 987-4715, www.maurymw.com.

Booth 401A

µWave Wizard™

µWave Wizard™'s radiation module now includes a reflector antenna analysis and optimization tool. The incident EM-field on the reflector is calculated by using the spherical wave expansion of the radiated horn antenna field. The calculation of the farfield of basic reflectors such as parabol, hyperbol and ellipsoid is being perfomed by physical optics approximation. The radiated reflector field is also available as spherical-wave-expansion. The definition of the reflector geometry is completed by just a few parameters and includes an automatic mesh generation. Any optimization of the

New Waves



antenna performance parameters, including the reflector, is supported.
Mician GmbH,
Bremen, Germany +49 421 168 993 51,
www.mician.com.
Booth 322

Precision Fixed Attenuator

VENDORVIEW

BW-S20-2W263+ is a coaxial precision fixed attenuator. Features of this 2 W, 20 dB attenuator include DC to 26 GHz, precise attenuation, excellent VSWR (1.07 typical) and stainless steel SMA male and female connections. Applications include matching, instrumentation and test set-ups.

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

Vector Signal Analyzer

The NI PXIe-5665 is one of the highest performance vector signal analyzers (VSA) in the market with a frequency range of 20 Hz to 14 GHz, a phase noise of -129 dBc/Hz at a 10 kHz offset and an average noise floor of -165 dBm/Hz. This instrument is 20 times faster than traditional boxed instruments for automated tests, can support multiple wireless and data standards, such as WCDMA and LTE, and can be synchronized to less than 1° for phase coherent and MIMO applications.
National Instruments,
Austin, TX (800) 258-7022, www.ni.com.
Booth 517

PXI RF Switches

Pickering Interfaces is expanding its range of PXI RF switches with the introduction of the 40 to 755 multiplexer, which supports up to 10 off SP4T RF switches in a single module and is available in two different versions based on a common switch design. The high density version occupies just one slot of a 3U PXI chassis and uses a multi-way connector that is suitable for switching frequencies to 500 MHz. The higher frequency two-slot version uses SMB connectors and is suited for switching signals to 1.8 GHz.
Pickering Interfaces,
Clacton-on-Sea, Essex, UK
+44 (0) 1255 687900,
www.pickeringtest.com.
Booth 533

Oscilloscope Series

The PicoScope 9000A Sampling Oscilloscope Series are multi-function, all-in-one instruments for characterising electrical or optical signals, pre-compliance testing of data communication/telecom signals and TDR/TDT testing. Unlike traditional, bulky bench-top instruments that contain a PC and a display, the PicoScope 9000A Series takes very little space on your workbench. The analyser connects to any Windows computer with a USB port. There are no extra software modules to buy – all the software you need is included in the initial cost.
Pico Technology,
St Neots, UK +44 1480 396 395,
www.picotech.com.
Booth 114

Extended Range Filters

Pole/Zero, designer and supplier of agile RF filters for communications, cosite, EW, SIGINT and other high dynamic range applications introduces two of the smallest 30 to 512 MHz agile Extended Range Filters (ERF) on the market. The MINI-ERF and MICRO-ERF SMT devices integrate high performance 30 to 512 MHz filter technology with 1 W and 1 mW power handling, respectively. Both filters provide selectable Parallel or Serial Peripheral (SPI) control interfaces and both SMT packages have been qualified to 25 G vibe and 40 G shock profiles.
Pole/Zero,
West Chester, OH (513) 870-9060,
www.polezero.com.
Booth 235

Printed Circuit Boards

P.W. Circuits Ltd. manufactures a diverse product range – flexi, flexi rigid, copper/invar/copper, controlled impedance, high layer count multilayers, heatsink, bonding, micro vias, buried and blind vias and double/single sided printed circuit boards. A wide range of materials – FR4, polyimide film, ED/RA, Rogers, Arlon, phonolic, aluminum backed copper, PTFE, ceramic, high TC FR4 and various copper weights and finishes – are available.
P.W. Circuits Ltd.,
South Wigston, Leicester, UK
+44 (0)116 278 5241,
www.pwcircuits.co.uk.
Booth 537

Omni Directional Antenna

An ultra-wideband omni directional antenna covering the frequency range 1 to 40 GHz, it is appealing to a wide variety of organisations involved in monitoring and managing the RF spectrum. The antenna is a versatile, small sized, unobtrusive substitute for multiple

antennas currently deployed in the electronic warfare and surveillance communities. Features include a VSWR of typically < 2.3:1, elevation 2 dB beamwidth of 102° to 21.4°, gain of -2 to 5.5 dBi (1.5 dBi at 2 GHz) and a K type connector. The power rating is 20 W CW, the weight is 1.5 kg and its size is 100 × 90 mm.

Q-par Angus Ltd.,
Barons Cross Laboratories,
Herefordshire, UK
+44 (0) 1568, 612138, www.q-par.com.

Booth 243

BMR-Spring Connectors

Radiall BMR-Spring connectors can handle a minimum board-to-board or rack and panel distance tolerance of at least 0.078" (2 mm) with custom misalignment of 3 mm or more. It also features a 6 degree tilt radial travel. It has an operating frequency range of DC to 8 GHz, a 1.1 max VSWR guaranteed up to 3 GHz, and it can handle up to 350 W at 2.7 GHz. The Radiall BMR-Spring adapter features a unique non-slotted spherical interface for improved electrical performance, high vibration and shock resistance, and an 80 dB of shielding up to 3 GHz. A self-alignment mechanism makes the BMR-Spring particularly ruggedized for blind-mate applications. The spring-loaded adapters are symmetrical to avoid any assembly issues. Custom configurations are also available.

Radiall Inc.,
Paris, France 0033 149 353535,
www.radiall.com.

Booth 435

Vector Network Analyzer

VENDORVIEW

The new R&S ZNB from Rohde & Schwarz features a dynamic range up to 140 dB, a sweep time of 4 ms with 401 points and excellent stability. Designed for demanding applications in the production and development of RF components, the R&S ZNB covers the frequency ranges from 9 kHz to 4.5 GHz or 8.5 GHz. Its large touchscreen allows users to access all instrument functions with no more than three operating steps and offers plenty of space to display the measurement results.

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

Booth 201

Laminate Materials

VENDORVIEW

Rogers Corp.'s Advanced Circuit Materials Division is a global technology leader providing high performance laminates and components

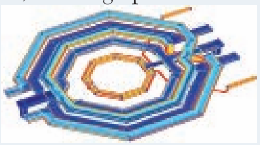
for use in high frequency and/or high reliability applications. Rogers will be showcasing its wide range of products including RO4000® LoPro™, RT/duroid® 6035HTC and RT/duroid 5880LZ high frequency laminate materials.

Rogers Corp.,
Chandler, AZ (480) 961-1382,
www.rogerscorp.com.

Booth 118

3D Planar EM software

Sonnet Software introduces the latest in its 3D planar EM software, the Sonnet Suites Release 13, featuring up to 3× faster analysis for large



circuits, efficient micro-via array meshing, enhanced integration to its high frequency EDA design framework partners and introducing diagonal ports and components. In Release 13, Sonnet's entry-level EM software suites have been revamped to double the allowed memory from previous releases and offer more features than ever before.

Sonnet Software,
North Syracuse, NY (877) 776-6638,
www.sonnetsoftware.com.

Booth 429

End Launch Connectors

Southwest Microwave's End Launch connector

series is being expanded to 1.85 mm, DC to 65 GHz, version in a high and low silhouette mounting block. These high performance connectors are designed to provide the industry's lowest VSWR for single-layer or multilayer circuit boards with the microwave layer on top. They are ideally suited for high frequency chip set evaluation, demo boards, test fixtures and board characterization. The connector requires no soldering, and they are reusable and repairable.

Southwest Microwave Inc.,
Tempe, AZ
(480) 783-0201,
www.southwestmicrowave.com.

Booth 432

Hybrid Rotary Joint Assemblies

Spinner is a supplier of hybrid systems for highly integrated rotary joint assemblies. The whole range of applications, such as RF rotary joints, slip rings, fibre-optic rotary joints, fast Ethernet transmission, media joints and encoders, are offered in a compact and highly reliable design.

SPINNER GmbH,
München, Germany
+49 (0)89 12601-0,
www.spinner-group.com.

Booth 123

New Waves

Laser Ablatable Substrate

Taconic will feature Taclamplus, which is a non-reinforced, laser ablatable substrate for mm-wave applications, metal based for superior heat dissipation and performance, fastrise27, a non-reinforced bondply for multilayer, as well as TRF-45, low loss base material with a Dk equivalent to FR4. Taconic ADD is a global supplier of RoHS-compliant low-loss materials for RF, microwave and high speed digital applications. Its product range of high performance materials, with Dk values from 2.17 to 10, makes Taconic a market leader and a partner of the RF and PCB industry.
Taconic Advanced Dielectric Division, Westmeath, Ireland +353/44/9396500, www.taconic-add.com.

Booth 442

Thick-Film SOI

The TowerJazz thick-film SOI process combines a 4/6 metal layer 0.18 µm CMOS process with a 1000 Ω-cm high resistivity thick-film SOI substrate and dual gate 1.8 and 3.3 V or 5 V regular and "native" Vt MOSFETs and a 5 V RF LDMOS and Ft of 19 GHz and BVDSS of 20 V. The 3.3 and 5 V FETs facilitate the integration of HVCMOS blocks, the 1.8 V FETs are suitable for the design of logic functions. The LDMOS device provides for reliable, high performance RF power devices.
TowerJazz,
Newport Beach, CA (949) 435-8181,
www.towerjazz.com.

Booth 515

Digital Variable Gain Amplifier

VENDORVIEW

TriQuint's innovative TQM8M9077 is the first of three new integrated digital variable gain amplifier solutions the company will release that offer high linearity over the entire control range (50 to 4000 MHz), low noise and digital variable gain with 31.5 dB range in 0.5 dB steps through a 6-bit serial mode control interface. The product includes matching circuits – no external matching is required, which can reduce the BOM. The TQM8M9077 comes in a 5 × 5 mm standard surface-mount leadless package and is ideal for 3G/4G base station transceiver and repeater applications.
TriQuint Semiconductor,
Hillsboro, OR (503) 615-9000,
www.triquint.com.

Booth 323

Precision Trimmer Capacitors

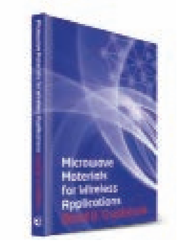
Voltronics Corp. designs and manufactures precision trimmer capacitors. The company's engineering team works with customers to develop technologies to solve all tuning needs. Voltronics trimmers include air, glass, sapphire and PTFE dielectrics that can be used from 1 MHz to more than 2 GHz and at voltages up to 15 KV. Voltronics also offers a line of non-magnetic components for the NMR and MRI industries.
Voltronics Corp.,
Denville, NJ (973) 586-8585,
www.voltronicscorp.com.

Booth 235

Foundry Services

WIN Semiconductors Corp., established in 1999, has become the world's largest 6" GaAs pure-play wafer foundry. Its current capacity from 2 fabs is 14,000 wafers per month. In addition to 1 µm, 2 µm and high voltage HBT processes, 0.5 µm E-D, 0.15 µm low noise and power, HFET, BiFET(H2W), and Ka/Ku-band 0.25 µm PHEMT processes, WIN is now offering 8 V, 0.25 µm and 0.1 µm power PHEMT processes. WIN has an experienced technical team, mature manufacturing capability and a pure-play business model.
WIN Semiconductors Corp.,
Tao Yuan Shien, Taiwan +886-3-397-5999,
www.winfoundry.com.

Booth 223



Microwave Materials for Wireless Applications

David Cruickshank, TransTech Inc.

The history of magnetic materials began with spinel ferrites, but the discovery of ferromagnetic garnets began a period of intense activity through to the late 1970s. With more of these devices being produced to more stringent requirements for today's cellular phones, the body of information generated in the 1970s is being reinvestigated and expanded to explain and improve today's materials and devices. This book hopes to fill the consequent generation gap in experience.

Dielectric materials, by contrast, did not become a topic of major interest for microwave engineers until the cellular revolution, and there is a much more continuous thread of development of plastic composites, laminates and ceramic materials from then until now. It seems likely the continuous pressure to reduce size in wireless infrastructure will continue to fund the search for the ultimate material: a high dielectric constant, high Q material that is temperature-stable, cheap and readily available.

This book tries to bridge the gap between the engineers, scientists and students of RF and microwave engineering involved in passive devices, and the corresponding group who design and manufacture materials for them. This includes managers directly or indirectly involved in the manufacture and use of these materials. The intention is to give a more systematic understanding of the chemistry and physics of the materials for RF and microwave engineers and to provide some insight into the microwave world for materials engineers. The treatment is intended to be nonmathematical wherever possible, but some knowledge of chemistry and microwave engineering is assumed.

The book is aimed mostly at engineers designing components like ferrite isolators and circulators, dielectric based filters, and antennas and radomes where there are significant specialist materials requirements. Because of the emergence of tunable device applications, a section on the potential tuning attributes of ferrimagnetic, dielectric and paraelectric materials is presented. This book is a good introductory piece on the subject and it is written by an industry expert so it presents a practical approach for engineers and managers.

To order this book, contact:
Artech House, 685 Canton St.,
Norwood, MA 02062
(800) 225-9977;
or
16 Sussex St., London, SW1V 4RW, UK
+44 (0)20 7596 8750

Pages: 250, $199, £66
ISBN: 978-1-60807-092-3

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MATH, SCIENCE AND LOGIC PUZZLES FOR THE 'ENGINERD' IN ALL OF US

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ANSWERS AVAILABLE ONLINE AT WWW.MWJOURNAL.COM

ADDRESS UNKNOWN

Mr. House would like to visit his old friend Mr. Street, who is living in the main street of a small village. The main street has 50 houses divided into two blocks and numbered from 1 to 20 and 21 to 50. Mr. House has forgotten the number, so he asks a passer-by, who replies "just try to guess it." Mr. House likes playing games and asks three questions:

1. In which block is it?
2. Is the number even?
3. Is it a square?

After Mr. House has received the answers, he says: "I'm still in doubt, but if you'll tell me whether the digit 4 is in the number, I will know the answer!" Then Mr. House runs to the building in which he thinks his friend is living. He rings, a man opens the door and it turns out that he's wrong. The man starts laughing and tells Mr. House: "Your advisor is the biggest liar of the whole village. He never speaks the truth!" Mr. House thinks for a moment and says "Thanks, now I know the real address of Mr. Street."

What is the address of Mr. Street?

INFECTED?

Suppose that 1 out of 1000 people of a specific country are infected with the deadly X-virus. An inhabitant of that country goes to the hospital and gives some blood for a survey. Her blood is checked on the X-virus by a test that gives a correct outcome in 99 percent of the cases. The test points out that the woman is infected. After the investigation, a doctor tells the woman that he is 99 percent sure that she is infected with the X-virus. Can the doctor be right by making this worrying statement?

WORKAHOLIC ENGINEER

On a particular evening, an engineer decides to work some hours at his office in London because his wife goes out with her friends. After some hard work, he opens the curtains of his office and looks outside (see the picture). Immediately he starts to panic. Why?