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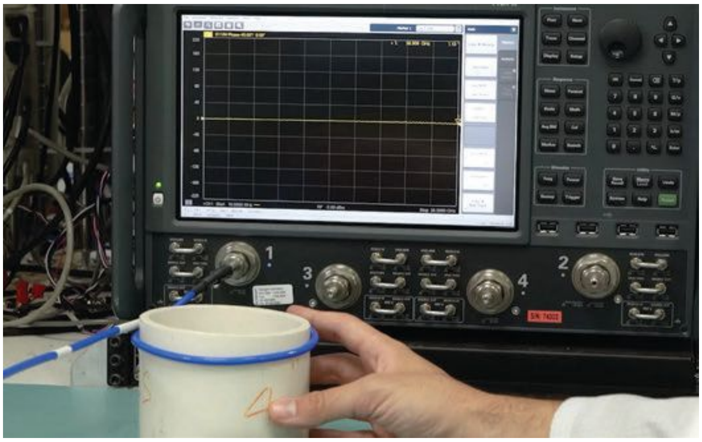

Figure 1: 1-port phase stability test with 360° bend around a 4-inch mandrel.

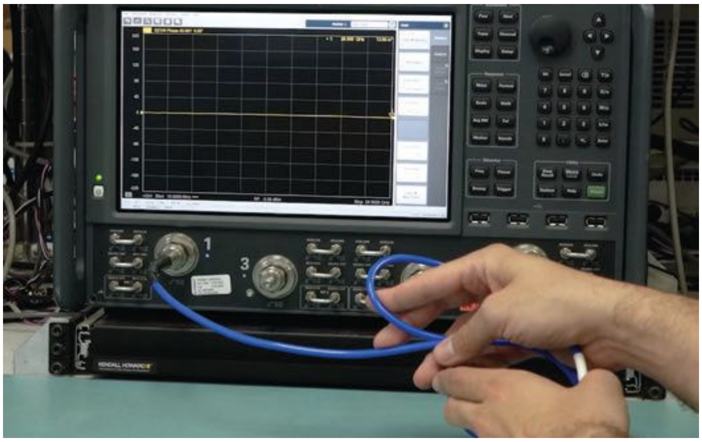

Figure 2: 2-port phase stability test with arbitrary flexure at multiple angles.

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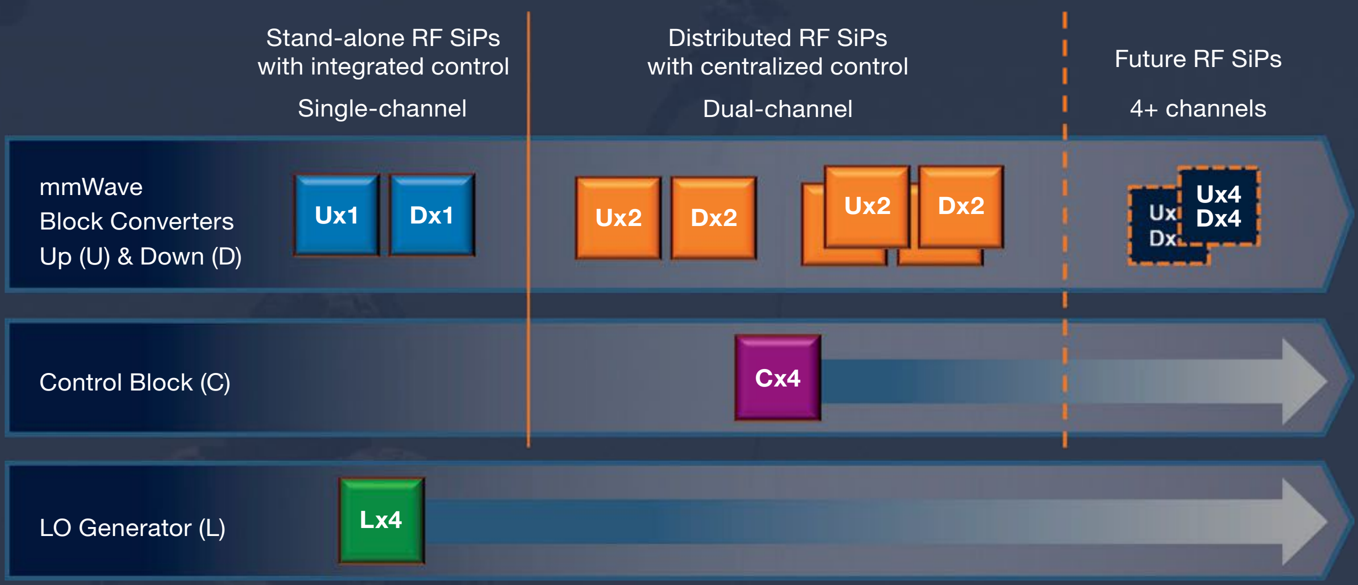

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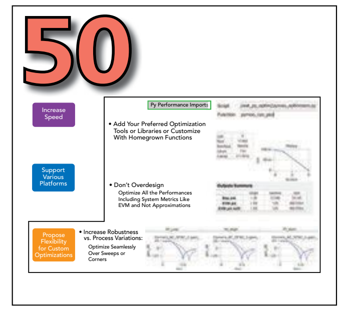

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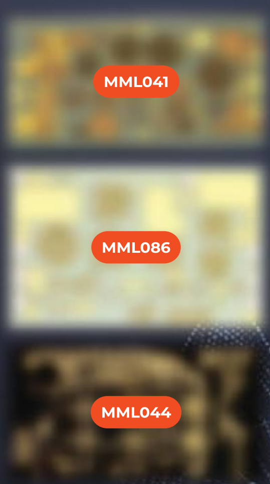

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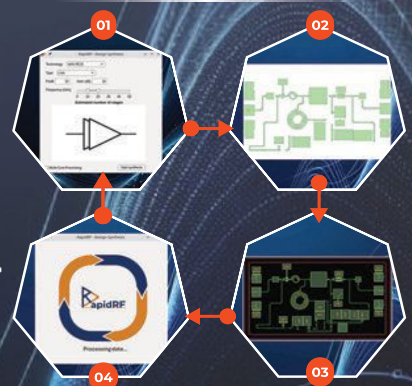

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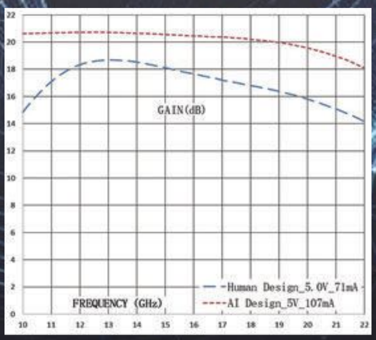

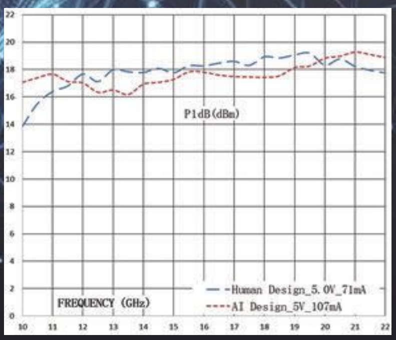

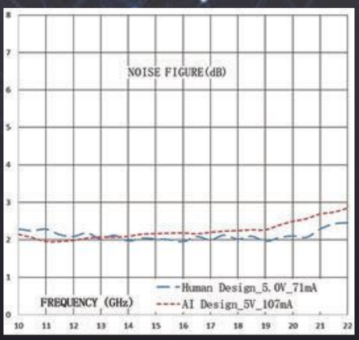

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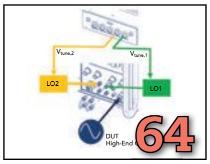

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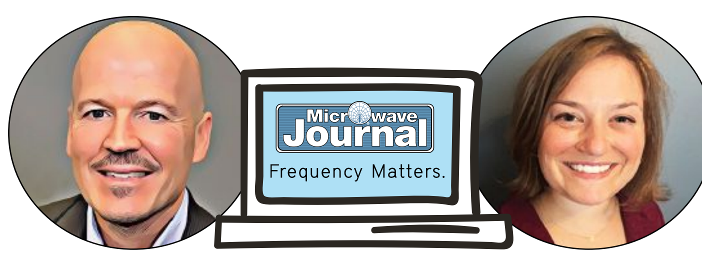

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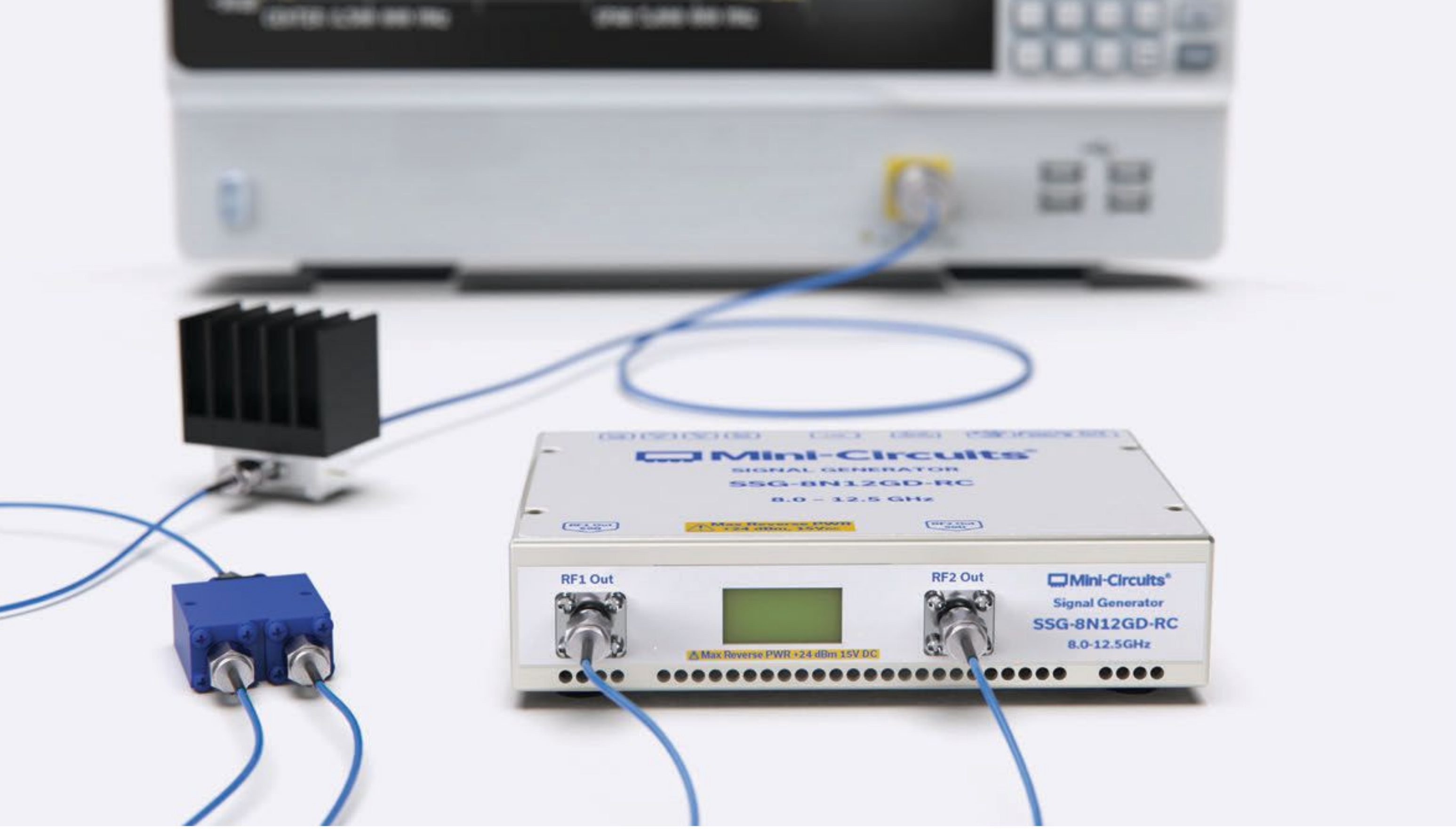

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High Volume OTA Testing of mmWave AiP Modules Using ATE Test Cells

Jose Moreira
Advantest Corp., Munich, Germany

The development of antenna in package (AiP) modules for consumer applications, like 5G new radio (5G NR), has created several new challenges for the test and measurement industry, including high volume manufacturing (HVM) testing.

In the generic view of an AiP module shown in ***Figure 1***, the 1 × 5 array of patch-like dual polarized radiators creates a beam in a direction perpendicular to the module antenna array plane. The AiP module may include a ball grid array or a board to flexible printed circuit connector on the backside for further assembly.

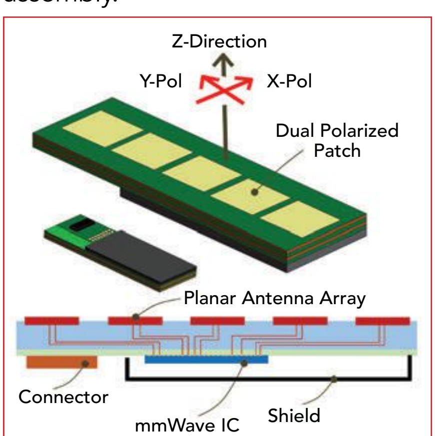

Fig. 1 **High-level diagram of an AiP module.**

Testing a device under test (DUT) such as an AiP module in HVM requires over-the-air (OTA) measurements to test the antenna radiators and their feed structure, including the front-end parts of the transceiver electronic chips. This means that a measurement antenna must be integrated into the automated test equipment (ATE) test cell, which is a new requirement for commercial ATE test cells.[1,2]

Figure 2 shows an example of an ATE test cell comprising an Advantest V93000 ATE system able to test digital, power, RF and mmWave signals to a maximum frequency of 70 GHz, as well as an Advantest M4841 handler that automatically feeds packaged parts for testing.

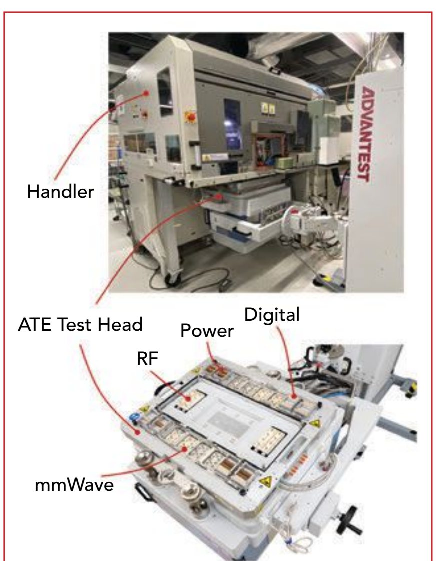

Fig. 2 **Example of a standard ATE test cell.**

Such test cells are the workhorse of the backend side of the semiconductor industry, where either finished silicon wafers or packaged devices need to be tested with high failure coverage and low cost-of-test (CoT). For example, they are used for conductive testing of mmWave devices at the wafer level.[3] However, when the dies are integrated into an AiP module, mmWave conductive testing is no longer an option, and only OTA testing with a measurement antenna is possible.

In the high-level diagram of the manufacturing test flow for an AiP module (see ***Figure 3***), a wafer containing the mmWave die that will be part of the AiP module is tested at the beginning of the flow. The testing can vary, for example, only DC parametric tests, mmWave loopback tests or even full parametric mmWave tests. The next step of the process is assembling the mmWave die into the AiP module. At this step of the process, techniques such as X-ray visualization can be used to check for failures in the assembly. Following the mmWave die integration, the AiP

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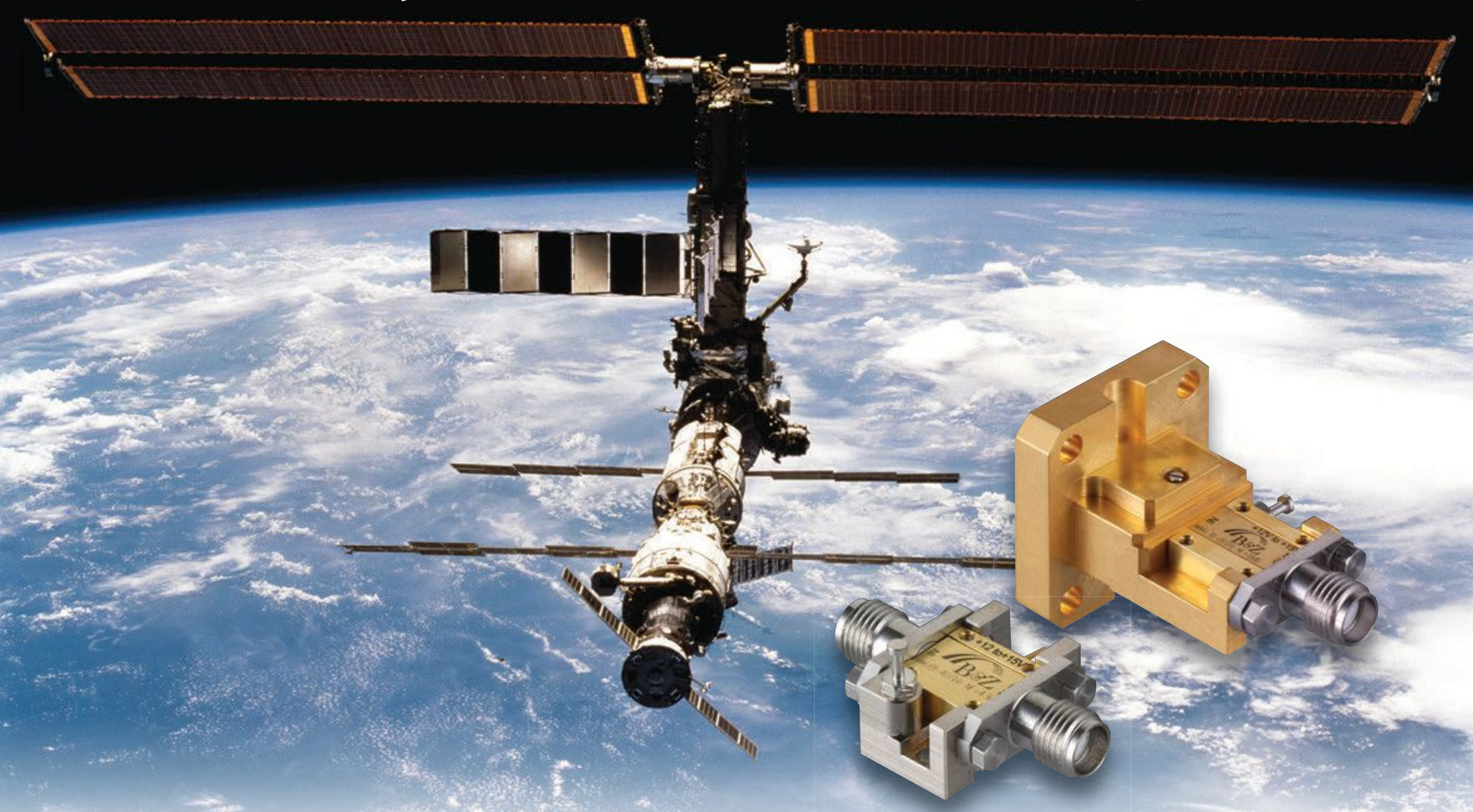

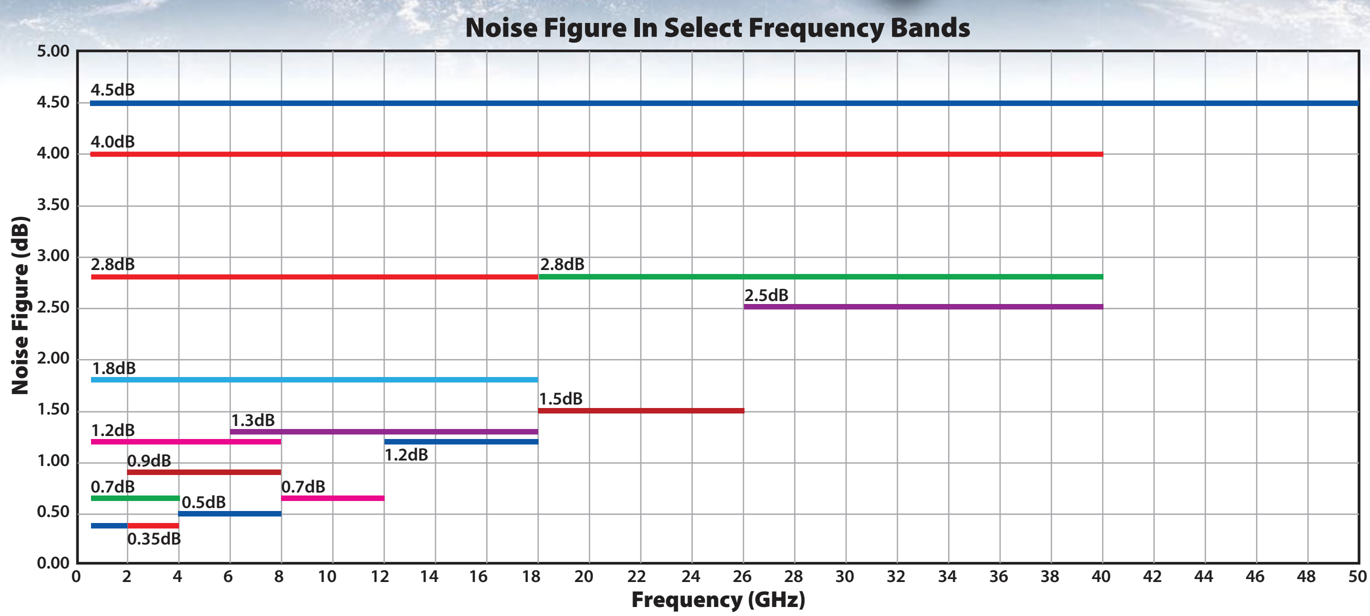

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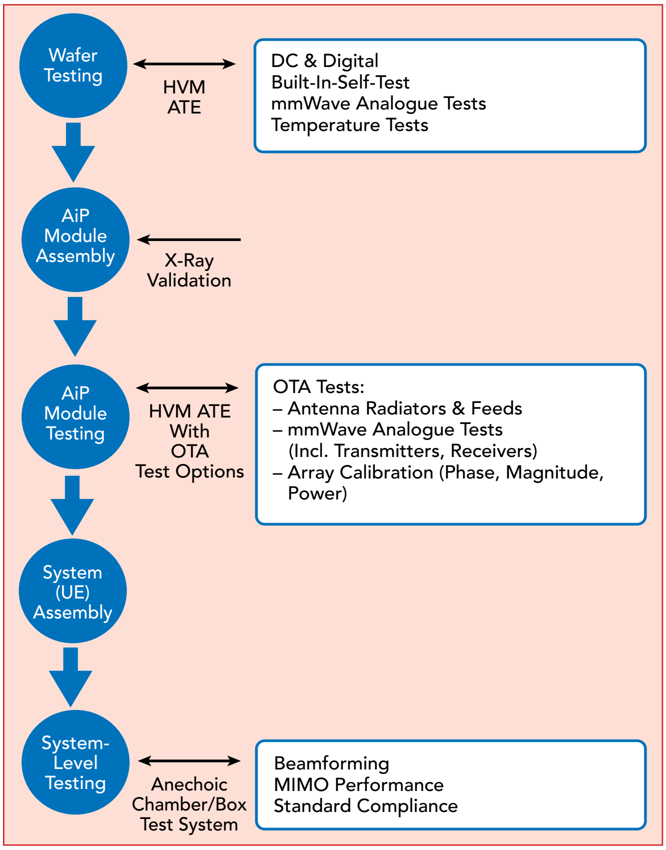

Fig. 3 Example of a manufacturing test flow for an AiP module.

TABLE 1

TYPICAL PARAMETRIC TESTS IN HVM OTA TESTING

Transmitter	***Receiver***	***Radiator Array***
Power	Power	Aperture phase distribution
Gain	Gain	Aperture magnitude distribution
Gain steps	Gain steps	Polarization (per-radiator)
Phase shift	Phase shift	Cross polarization (per-radiator)
P1dB	IP3	Coupling between radiators
Flatness	Flatness	Variation over temperature
EVM	EVM	
Spurs	Noise figure	
ACPR		

module, including the antenna array, can be tested. Again, at this stage, the test can be very basic (e.g., DC parametric and some built-in self-test) or it can include an OTA loopback test or full OTA parametric testing.

Table 1 lists typical tests performed at this stage in complete OTA parametric testing. Note that this test list differs from the one conducted in an anechoic chamber when characterizing the AiP antenna array or validating compliance testing with a specific standard. This test flow tests for good or bad devices and does not characterize the design. Finally, after the AiP module is tested, it is assembled as part of the final consumer device, such as a cell phone, and further testing is performed that may also include OTA testing of the complete final product.

From a CoT perspective, it is better to identify a bad DUT earlier in the manufacturing flow (shown in Figure 3), as it enables avoidance of expensive packaging, assembly or additional testing steps. Each AiP module manufacturer decides the exact test strategy and how much testing is done at each step.

HIGH VOLUME ATE OTA TEST OPTIONS

Production testing of mmWave components has traditionally been performed using bench equipment and rack-and-stack measurement setups with manual handling of the DUTs. This approach was feasible before the CoT pressure of consumer applications was present, but this changed with the usage of mmWave technologies in wireless consumer applications.

Achieving a low CoT with high failure coverage in HVM testing of AiP modules for 5G NR applications is not trivial. The semiconductor test industry has developed several


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strategies over the years to continuously reduce the CoT for consumer applications. One common technique is the use of multi-site testing. The challenge is how to apply these established strategies to HVM OTA testing.

Typical test strategies for HVM OTA testing are listed in ***Table 2***. The most straightforward approach is to use a measurement antenna in the far-field region. This is very close to the typical setup used in anechoic chambers. However, in HVM OTA testing, the measurement antenna is fixed in a single position, which is usually perpendicular to the DUT antenna array. This approach has all the advantages of traditional antenna testing, but it presents several complex mechanical challenges for integration in a standard ATE test cell, especially for multi-site implementation. Single-site implementation in a commercial handler is feasible.[1]

The second approach addresses the mechanical challenge of integrating the OTA measurement setup into a standard ATE test cell by shrinking the physical distance between the AiP DUT and the measurement antenna, which can bring the measurement antenna into the radiating near-field region. This approach allows for a multi-site integration on a standard ATE test cell, which can result in a significant CoT improvement. However, there can be technical disadvantages associated with this approach, starting with the need to use a golden device calibration technique.

The final strategy is loopback testing. Loopback testing is a widespread approach for high speed digital and RF testing. It allows for a low-cost test approach since it does not require any mmWave measurement instrumentation. Usually, the objective is to be able to move to a loopback testing strategy once a product reaches a certain maturity level with the addition of some parametric OTA testing done on a sampling basis. The end user of the AiP module may expect a zero parts per million failure rate. However, OTA loopback testing can have several significant limitations,[1] which makes its usage challenging.

Selecting the right strategy for OTA HVM production testing depends on various factors, for example, which stage the production ramp-up the device is in, experience with production testing of similar devices, etc. Because of this, the strategy may change depending on the stage of the DUT testing lifecycle.

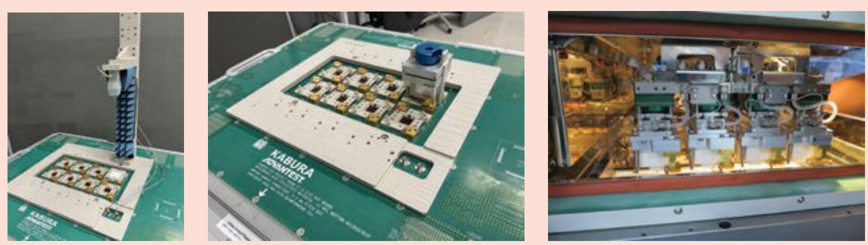
Advantest has developed an HVM OTA test solution portfolio that can support the different test strategies described in Table 2 using commercially available ATE systems and standard handlers employed by outsourced semiconductor assembly and test companies. This is exemplified in ***Figure 4***, which shows three different setups. Note that the DUT PCB test fixture is common to all three setups and contains eight DUT sockets that will allow parallel testing of eight AiP DUTs in production testing.

The setup shown in Figure 4a corresponds to a far-field measurement arrangement using an off-the-shelf dual polarized measurement antenna. The antenna opening is located 25 cm from the DUT antenna array. The measurement antenna is fixed perpendicular to the DUT antenna array. This setup is effective for performing OTA parametric measurements since it can be calibrated using standard antenna measurement techniques. This setup allows the test engineer to develop an initial test program and build the confidence needed on the ATE measurement instrumentation by validating a correlation with the bench reference measurement setup. This correlation only identifies good and bad devices and does not characterize the DUT or the antenna array design. This is why having a single position for the measurement antenna is acceptable for production testing.

TABLE 2

TEST STRATEGIES FOR ATE OTA HVM PRODUCTION TESTING

OTA Test Strategy	***Advantages***	***Disadvantages***
Far-Field Antenna	• Far-field measurement • DUT antenna array is not impacted (detuned) by the measurement antenna • Easiest setup to correlate with measured data using 3GPP compliant methods	• Integration in standard ATE test cell is difficult due to mechanical dimensions • Multisite implementation is more complex • High cost of test for volume production
Radiating Near-Field Antenna	• Easy integration on standard ATE test cell • Easy multisite implementation • Low cost	• Measurement antenna might have an impact on the DUT antenna performance (detuning and standing wave effect) • Possible different distances between the measurement antenna and DUT antenna array elements • Golden device calibration is required
OTA Loopback	• Very low cost	• Reduced test coverage compared to parametric OTA testing • Power/phase calibration is very challenging



(a) (b) (c)

Fig. 4 **Different OTA test setups using the same DUT test fixture and program.**

Following the completion of this step, it is possible to move to the next setup, a near-field socket (Figure 4b). The small physical size of the socket allows for multi-site testing in production while still providing OTA parametric measurement results. At this stage, the test engineer can correlate the measured results using this setup with the previous far-field setup results to define the appropriate correlation/correction factors and pass/fail thresholds. Note that the test program, PCB test fixture and measurement instruments are the same as for the far-field setup, significantly reducing the test engineer's development effort.

The final setup (Figure 4c) is the complete HVM multi-site production test cell, including the robotic handler where high volumes of AiP DUTs can be tested and automatically binned into good and failed devices.

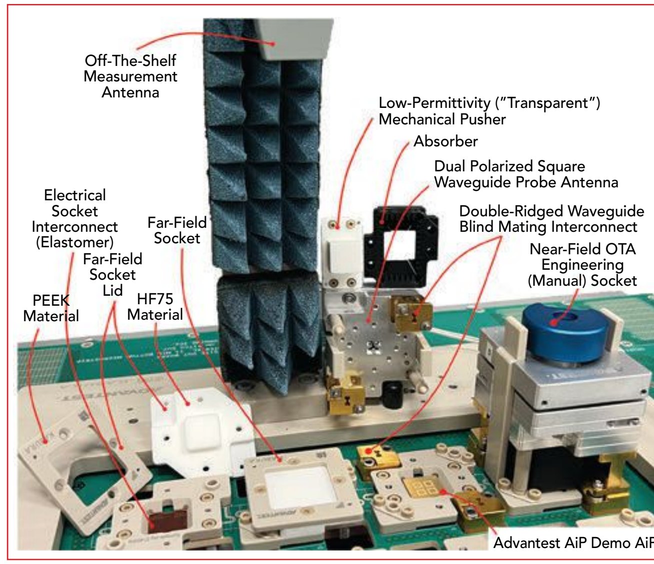
RADIATING NEAR-FIELD OTA HVM TESTING

As previously mentioned, using a near-field OTA socket provides OTA parametric measurements while allowing multi-site integration on a standard commercial ATE test cell due to the small physical size of the socket compared to a far-field measurement setup.

Figure 5 details the manual far-field and near-field OTA sockets. The far-field socket comprises a traditional electrical socket base (e.g., spring pin or elastomer) and a lid to push the DUT into the socket for reliable electrical contact. The challenge in OTA testing is that the socket body matters, and the lid material directly impacts the DUT antenna array performance.[1]

Special care must be taken in the choice of socket body materials and the socket design to minimize the impact on the DUT antenna array performance. This is not trivial since one needs to optimize between the electromagnetic requirements that prioritize having no material close to the antenna array and the mechanical requirements that mandate a lid on the socket, as well as some self-alignment features for reliable insertion of the DUT in the socket.[4]

Any material close to the DUT antenna array must have a very low dielectric constant, which often means low mechanical strength. For example, a typical lid material is Rohacell HF75 with a dielectric constant of 1.09 but a Young's modulus of 92 MPa. A typical socket material is PEEK because of its mechanical strength (35000 MPa Young's modulus), but it has a dielectric constant of 3.2. This means OTA sockets are usually a hybrid of different materials, as shown in Figure 5.



▲ Fig. 5 Far-field and near-field OTA sockets.

Another critical part of the near-field socket is the measurement antenna, as shown in Figure 5. The measurement antenna aperture in this example is located 3 cm from the DUT antenna array. The measurement antenna not only has to cover the application frequency range (e.g., 24 to 56 GHz for 5G frequency range 2) and polarization (such as dual linear polarization), but also must have a low profile due to mechanical requirements for later integration in a multi-site production handler. Because of these

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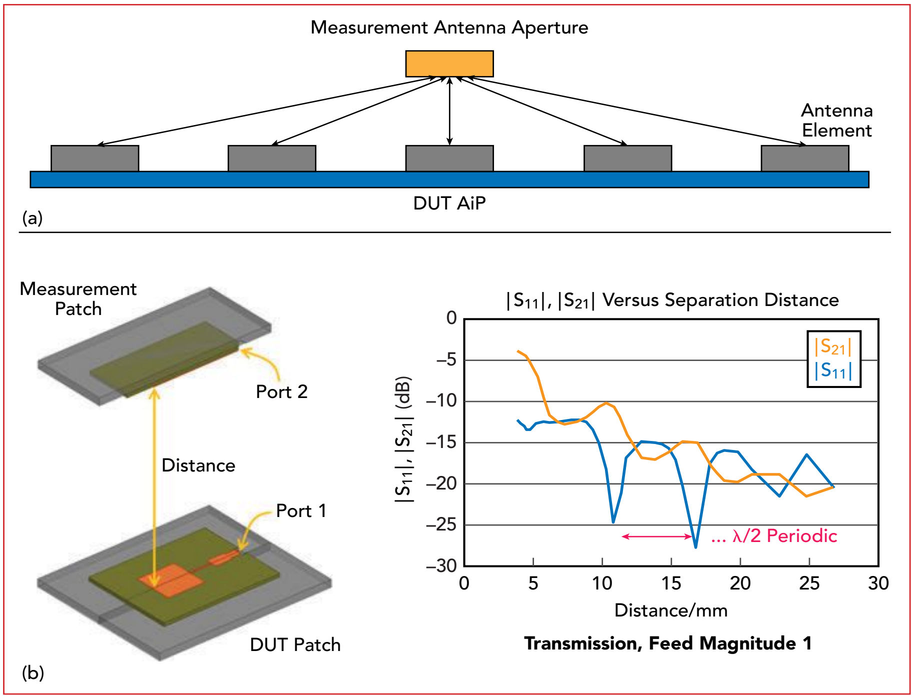

Fig. 6 **Near-field measurement variation due to (a) the antenna element position and (b) the standing wave effect between the socket measurement antenna and the AiP antenna array.**

requirements, the socket antenna design is unique compared to traditional antenna designs.[5]

Figure 6 illustrates two significant challenges associated with a near-field OTA socket testing approach. The first (Figure 6a), is that the measurement antenna will not be able to measure all the antenna elements equally, as in the case of far-field OTA testing. This is where golden device calibration is critical for properly correlating the measured results for each antenna element. The second challenge is that the measurement antenna is now so close to the AiP DUT antenna array that it might impact the DUT AiP antenna elements (antenna detuning) and result in a standing-wave effect. This is shown in Figure 6b, where two patch antennas are simulated with varying distances between them. This challenge is addressed by correctly choosing the distance between the measurement antenna and the DUT antenna array in the socket. The objective is to avoid the test frequencies used in the test plan being located at the resonant standing wave frequencies. Advantest has developed an automated procedure to determine the optimized distance given a set of test frequencies.[6] Note that, if properly designed, the absorber structure inside the socket, shown in Figure 5, can significantly help to mitigate this problem.[1]

HANDLER INTEGRATION

To enable OTA testing in HVM, it is necessary to integrate the OTA socket, including the measurement antenna, into a standard commercial handler. There are two potential options (see ***Figure 7***). One approach uses a dead-bug configuration, as shown in Figure 7a.[7] This approach can initially be appealing because it avoids the challenge of integrating the measurement antenna into the handler arm, making it a part of the DUT test fixture instead. Unfortunately, it significantly increases the complexity of the DUT test fixture assembly and requires a more electrically complex socket.

The second option is to use the traditional live-bug approach, as shown in Figure 7b, where the handler arm picks the DUT and pushes it into the DUT socket. In an OTA setup, because the antenna is integrated on the handler arm, it requires an mmWave blind-mate interconnect that can handle many docking cycles.[8,9]

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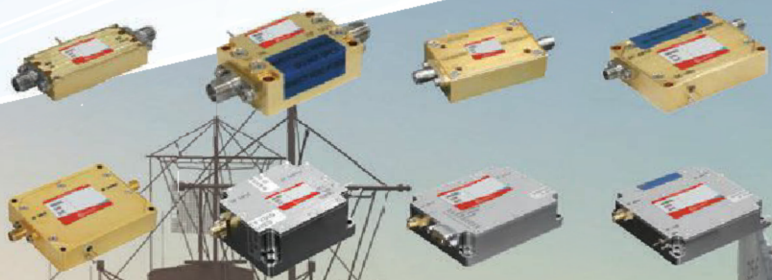

LNA's & MPA's

Model Number	Frequency Range	Power dBm	Gain dB
AMP10072	9 kHz-1.0 GHz	33	33
AMP10140	10 MHz-6.0 GHz	33	33
LNA70001	50 MHz-6.0 GHz	25	25
MPA10135	0.2-20.0 GHz	33	33
MPA10134	0.5-26.5 GHz	30	30
MPA10136	1.0-18.0 GHz	30	30
MPA10132	2.0-8.0 GHz	33	33
LNA70008	2.0-18.0 GHz	20	20
MPA10133	4.0-8.0 GHz	33	40
LNA70013	18.0-40.0 GHz	10	20
AMP30040	18.0-26.5 GHz	34	36
AMP30039	26.5-40.0 GHz	30	36
AMP40048	18.0-40.0 GHz	27	30
AMP40002	41.0-47.0 GHz	33	33

Popular Models

Model Number	Frequency Range	Power dBm	Gain dB
AMP20093	10 kHz-250 MHz	300	55
AMP20095	10 kHz-250 MHz	600	58
AMP20081	80-1000 MHz	500	57
AMP20083	80-1000 MHz	750	60
AMP20079	0.7-6.0 GHz	100	50
AMP20080	1.0-6.0 GHz	200	53
AMP20098	2.0-8.0 GHz	120	51
AMP20102	2.0-8.0 GHz	400	56
AMP20072	6.0-18.0 GHz	300	55
AMP20154	6.0-18.0 GHz	700	58
AMP40013	18.0-26.5 GHz	10	40
AMP40028	18.0-26.5 GHz	150	52
AMP40038	26.5-40.0 GHz	20	43
AMP40035	26.5-40.0 GHz	120	52
AMP20005	18.0-40.0 GHz	25	44
AMP20167	18.0-40.0 GHz	60	48
AMP40049	40.0-50.0 GHz	1	30
AMP20057	1.0-2.0 GHz	4 KW	66
AMP20144	2.0-4.0 GHz	4 KW	66
AMP20097	4.0-8.0 GHz	2 KW	63
AMP40053	8.0-12.0 GHz	2 KW	63

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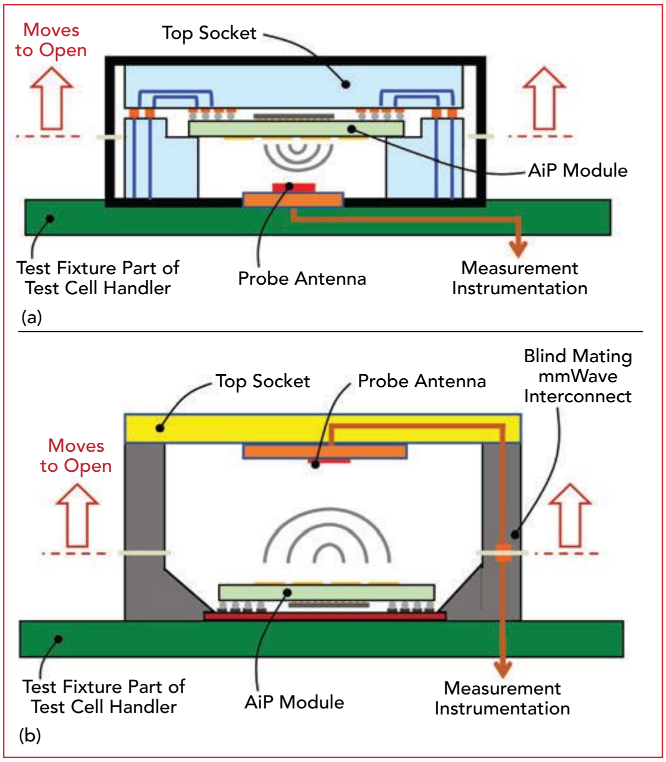

Fig. 7 **Diagram of handler integrations for OTA testing: (a) dead-bug and (b) live-bug.**

Figure 8 provides an example of such an implementation for an 8-site OTA change kit in a Hontech HT-9046LS handler. One arm is used to pick and place the DUTs on the sockets and the other arm is used for the OTA testing and contains the measurement antenna and blind mating waveguide interconnects.

Figure 9 shows the handler OTA change kit attached to each handler arm in more detail. In this picture, the absorber element is not shown, but it is critical not only to address the unwanted effects inside the small socket space but also to improve isolation between the adjacent sites, as shown in ***Figure 10***.[1]

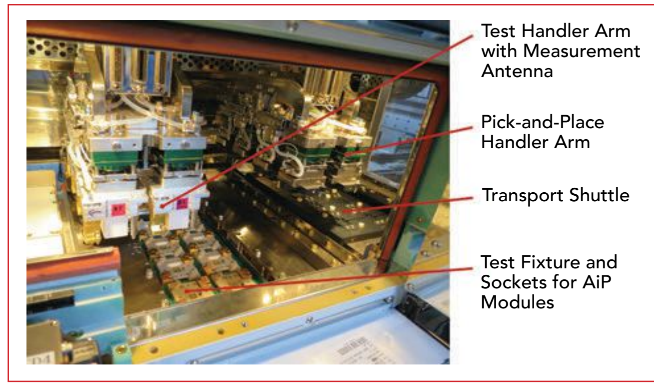

Fig. 8 **Hontech handler with the Advantest OTA change kit.**

Another critical point in the handler integration is DUT temperature control — not only to control the integrated die temperature during testing, which can impact the measured performance, but also, in specific applications, to test the DUT at cold and hot temperatures. This can be done by directly controlling the temperature of each DUT or by controlling the temperature in the handler chamber.

Another OTA challenge for handler integration is the testing of L-shaped AiP modules.[10] These modules can also be tested with a standard commercial handler.[11] Although this article has not shown measurement results, see Reference 12, a custom-designed AiP demo vehicle is used to demonstrate some possible OTA measurements and correlation results.[12]

CONCLUSION

The presented HVM OTA test solution from Advantest uses the established testing infrastructure at the back end of the semiconductor manufacturing industry to test mmWave AiP modules with a high failure coverage by using OTA parametric measurements. With the use of multisite configurations on standard ATE test cells, the solution delivers a lower CoT. ■

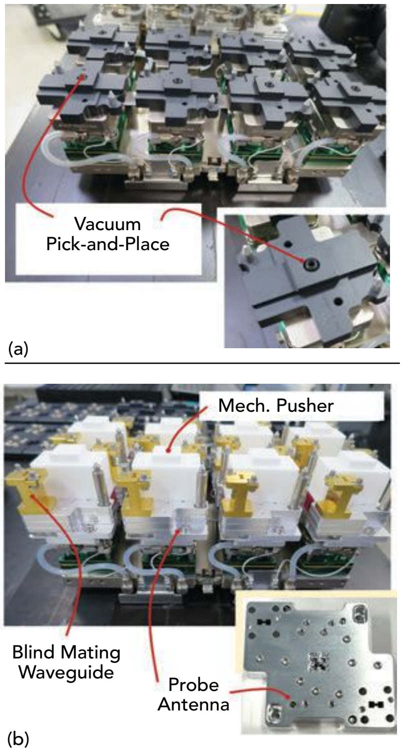

Fig. 9 **Handler integration showing (a) pick-and-place handler arm and (b) handler arm with socket lids and probe antennas.**

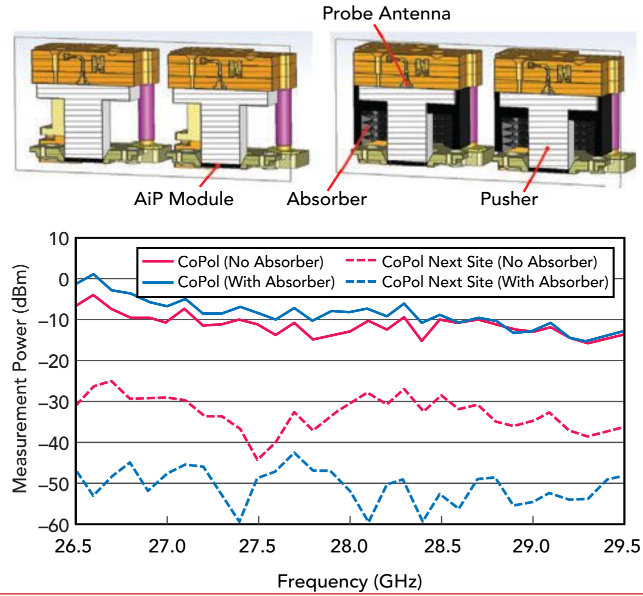

Fig. 10 **Simulation of the crosstalk between two adjacent sites with and without the RF absorber element.**

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INVITED PAPER

More Than Logistics: How Distribution Powers the RF and Microwave Industry

Carrie Obedzinski
Times Microwave, Wallingford, Conn.

Innovation doesn't happen in isolation; it requires speed, resources and trusted collaboration. The traditional view of distribution is being redefined as the RF and microwave industry shifts toward faster development cycles and increasing design complexity. Distribution has evolved beyond simple product delivery; it now plays a central role in enabling rapid design, innovation and market responsiveness. By bridging the gap between manufacturers and engineers, distributors have become strategic partners in product development and market alignment.

ENABLING FAST DESIGN AND INNOVATION

Distribution plays a crucial role in supporting the RF and microwave industry by ensuring immediate access to essential products. Such accessibility minimizes lead times and supports engineers needing small quantities or quick-turn assemblies. Distributors often provide technical resources like CAD drawings, specification documents and testing requirements, making it easier for customers to compare products and make informed design decisions. With the increasing complexity of RF systems, this accessibility helps engineers select the ideal components for their system without needing to commit to large purchases.

Additionally, distribution channels serve as an important bridge between customers and manufacturers. For engineers and designers, getting their hands on a physical sample — even if it is not the exact spec or length — provides a real-world advantage over relying solely on 2D documentation. Distributors are often the first point of contact for emerging companies or smaller customers, helping them navigate the technical landscape and connect with the right people at an OEM. This speed and support make it easier to test new technologies and enable faster prototyping and validation. By optimizing what distributors carry, manufacturers free up internal resources to focus on innovating and developing the next generation of RF, microwave and mmWave solutions.

DISTRIBUTION AS A STRATEGIC SOURCING ADVANTAGE

Distributors present a more viable option for customers needing value-added solutions. Customers can avoid minimum order requirements found directly with a manufacturer by purchasing through a distributor. Manufacturers typically support distributor pricing to improve the cost of the solution for those smaller quantity orders.

Distributors can also dampen the adverse effects of price and supply chain fluctuations, keeping costs and lead times steady. For example, with the recent changes in global tariffs, distributors are stocking material to support price stability.

DISTRIBUTION AS A TECHNICAL RESOURCE

Historically, the distribution role was aimed only at stocking products, but today's strategy involves educating the distribution channels to cultivate a network of RF-proficient professionals as a technical resource. This approach enables distributors to deliver comprehensive support, including quick access to product data, design tools and technical guidance when manufacturers may not be directly accessible. By ensuring distributors understand the breadth of available products and supplementary design tools, they become resources capable of swiftly addressing customer needs and navigating the complexities of RF applications. Times Microwave Systems partners with distributors who not only stock products but also receive ongoing training to support customers with product knowledge and access to informative resources.

Furthermore, the evolving distribution landscape sees larger companies seeking value-added resources and tailored solutions. Strategic partnerships with distributors capable of providing advanced support can include on-site presence and inventory management. Selecting distributors with deep RF and microwave knowledge is paramount, as they can effectively leverage their line card and design resources to meet diverse customer demands. In some instances, distributors may offer in-house design expertise, further solidifying their position as essential partners in the RF and microwave community. By aligning with knowledgeable distributors who can offer comprehensive support, manufacturers can streamline operations and optimize resource utilization.

DIGITAL TRANSFORMATION AND E-COMMERCE

The strength of distributors lies in their sophisticated e-commerce infrastructure, featuring real-time inventory and user-friendly interfaces. While manufacturers concentrate on providing in-depth technical resources, distributors prioritize a smooth, efficient online purchasing experience. By focusing on complementary strengths, manufacturers and distributors can streamline the procurement process and enhance customer experience.

Additionally, the dynamics of technological development have transformed. Historically, military applications drove innovation, but today, commercial sectors are also at the forefront. This shift necessitates agile procurement strategies, particularly for companies in rapidly evolving fields like satellite and UAV technology. Distributors facilitate this agility by offering immediate access to prototypes and small-quantity orders, supporting these rapid development cycles. This crucial advantage allows companies to quickly validate concepts before engaging manufacturers for specialized, larger-scale production. Contributing to this agile development environment, Times Microwave Systems is not changing its technological approach but instead streamlining the process for engineers to quickly validate early design, augmenting an already existing resource.

QUALITY, TRUST AND COMPLIANCE

Working with an authorized distributor channel means more than just buying a part, but purchasing the confidence that the component is genuine. This is especially critical as counterfeit RF cables — including fake versions of popular products like LMR® — continue to enter the market, posing serious risks to system reliability, performance and safety. Counterfeit cables often mimic the appearance of genuine products but fail to meet critical electrical and mechanical specifications, leading to potential system failures and costly downtime. To ensure they work with a legitimate partner, buyers should verify their authorization through the manufacturer's website, where official distributors are typically listed. For example, Times Microwave Systems offers a verified list of authorized partners to ensure customers receive authentic, properly labeled and manufactured products.

Authorized distributors also play a key role in ensuring traceability for compliance. Every component is traceable to the manufacturer, so they have access to any documentation a customer might need. The framework for traceability facilitates quality assurance and efficient root cause analysis in the event of a failure.

BUILDING THE FUTURE TOGETHER

The role of distributors has significantly expanded to meet evolving customer needs. Their sales teams now provide essential direct support to OEMs, often surpassing the reach of manufacturers' own sales forces. Distributors excel at bridging the gap between customers and manufacturers, leveraging established relationships to facilitate communication and access to information. Manufacturers utilize distributors as a primary channel for introducing new products, positioning them as the go-to resource for the latest market offerings. This strategic shift underscores the growing importance of distributors as key partners in product dissemination, future design and customer support.

Distribution is no longer just about fulfillment, it is about enablement. The manufacturers, engineers and innovators who embrace distribution as a strategic asset will move faster, scale smarter and build better in 2025 and beyond. ■

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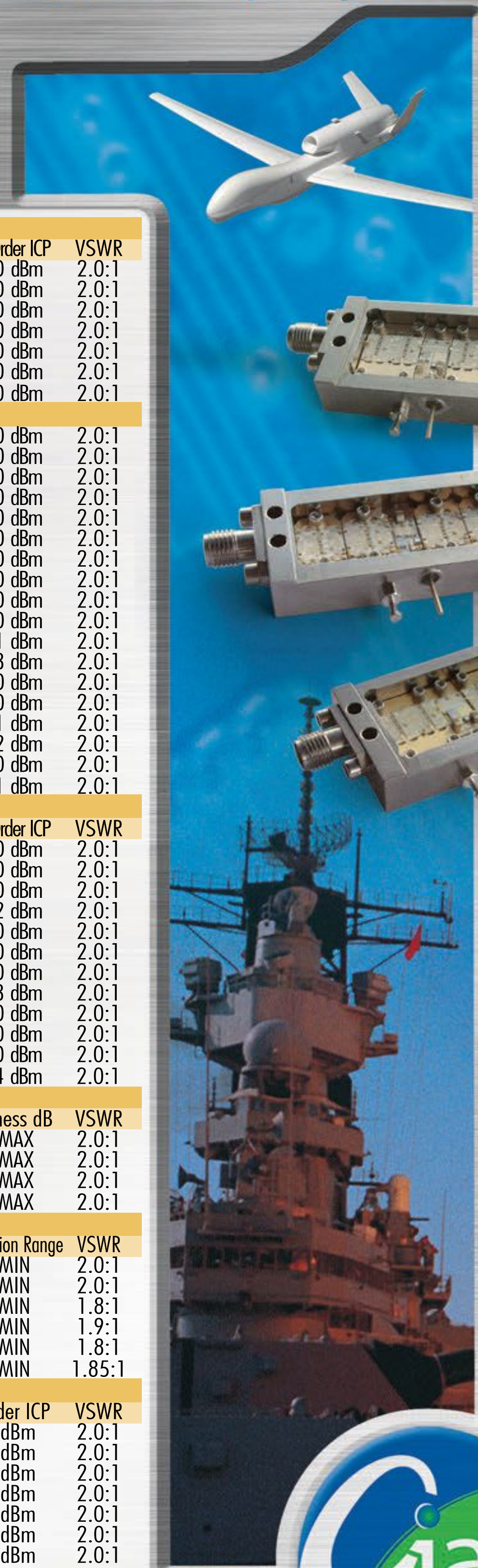

OCTAVE BAND LOW NOISE AMPLIFIERS

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

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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

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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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Raytheon Completes First Flight Test for PhantomStrike Radar

Raytheon, an RTX business, has successfully completed the first flight test of its PhantomStrike radar on its Multi-Program Testbed aircraft in Ontario, Calif. PhantomStrike successfully tracked several airborne targets and accurately mapped the terrain.

PhantomStrike is a first-of-its-kind, fully air-cooled fire control radar that's designed to provide long-range threat detection, tracking and targeting. At nearly half the cost of a typical fire control radar, it delivers superior radar capability due to its faster, more agile digital beam, advanced target detection and resistance to jamming.

PhantomStrike (Source: RTX)

"The threat environment is evolving, and this test demonstrates how PhantomStrike can make enhanced situational awareness available to a broader set of our partners and allies — offering unparalleled performance and potential U.S. weapons integration — at an affordable price," said Bryan Rosselli, president of Advanced Products and Solutions at Raytheon. "This next-generation radar dramatically changes how we identify and respond to threats."

PhantomStrike is a GaN powered radar that enables aircrew to see farther. It's designed for a range of platforms, including uncrewed and light-attack aircraft, fighter jets, helicopters and ground-based towers. It harnesses the fire control power of a fighter in its lightest form factor ever — weighing nearly half of a modern active electronically scanned array radar.

Production of the radars takes place in Forest, Miss.; Tucson, Ariz.; and Scotland, with support from Raytheon UK.

Indra Group Raises European Space Capabilities to a New Level to Enhance Defense and Security

Indra Group is driving its space activity to position itself as a key player in Europe by reinforcing its most advanced capabilities for Earth observation missions, secure communications, geopositioning systems, space surveillance and the

Mini4EOsatellite (Source: Indra)

protection of strategic assets. These technologies are key to enhancing security and operational effectiveness in complex environments, and they're designed to provide tactical and strategic superiority in the land, air, sea and space domains.

With the creation of Indra Space, Indra Group will progress toward becoming one of the largest companies in the space domain on the continent, with the capacity to cover the entire space project value chain, including the design of the mission, the development and manufacture of the satellite, the design and deployment of the ground segment and the operation of the mission.

One of its cutting-edge solutions is the Mini4EOsatellite, a space-based signals intelligence platform designed to perform effectively during high-throughput Earth observation missions that features excellent precision targeting and object focusing. It facilitates rapid deployment and adapts to a wide range of security and defense missions, such as border surveillance, controls of unlawful activities, monitoring of strategic movements and support for operations in remote areas.

Indra Group also provides advanced space surveillance and tracking capabilities, tools that are key to improving situational awareness to combat the threat of spy satellites and protect critical strategic assets. Its systems can analyze objects in all orbital regimes to assess the risk of a collision and monitor space debris. It also develops solutions for securing communications in space, an area of growing importance in the military and civilian worlds.

Another of its innovative systems is NAVISHIELD, an advanced protection solution for GNSS satellite navigation systems that is equipped with a next-generation controlled reception pattern antenna to guarantee the integrity of critical navigation signals, including Galileo Public Regulated Service, Galileo Open Service and GPS, in the event of any interference or signal spoofing, thus ensuring the reliability of positioning operations.

With its state-of-the-art technology, Indra Group is reinforcing its standing as a flagship supplier of space technology applied to defense in its commitment to innovation and national and European technological sovereignty.

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World's First Combat-Proven Laser Interceptions

During the Swords of Iron War, the Israel Ministry of Defense (IMOD) Directorate of Defense Research & Development (DDR&D), the Israeli Air Force (IAF) and RAFAEL Advanced Defense Systems executed an accelerated development program to deploy revolutionary interception systems. As a result of this initiative, soldiers from the IAF Aerial Defense Array operated high-power laser system prototypes in the field, successfully intercepting scores of enemy threats.

These systems are based on technological breakthroughs developed over decades at RAFAEL, in close cooperation with the R&D Division of the DDR&D.

The deployed laser systems are part of RAFAEL's portfolio of directed energy weapon systems, developed in collaboration with the IMOD and complement the more powerful IRON BEAM™ system, currently under development, which is expected to be delivered to the Israeli Defense Force later this year.

Throughout the current war, the IAF, including its Aerial Defense Array soldiers, studied and deployed the laser systems in the field, achieving outstanding interception rates that saved civilian lives and protected national assets.

Laser Interceptor (Source: RAFAEL Advanced Defense Systems/IDF Spokesperson's Unit)

RAFAEL CEO Yoav Tourgeman said, "RAFAEL is leading the energy weapon revolution, with operational laser systems among the most advanced of their kind worldwide. The ingenuity and boldness of Rafael's top scientists and the company's massive investment in R&D have resulted in a monumental operational and technological accomplishment. Rafael's defense and strike systems have proven their effectiveness on the battlefield, making a meaningful contribution to Israel's national security, particularly during the current war. Later this year, we will deliver the first IRON BEAM system from RAFAEL's production lines to the IMOD. This system will fundamentally change the defense equation by enabling fast, precise, cost-effective interceptions, unmatched by any existing system."


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Advancements in In-Cabin Sensing: 3D Sensing is the Way, But Radar or 3D Cameras?

In-cabin sensing technologies are reshaping the automotive landscape, driven by the need for enhanced safety, regulatory compliance and personalized user experiences. In 2025, Tesla, Seeing Machines and LG Electronics introduced groundbreaking innovations in this space, leveraging radar, 3D cameras and AI to redefine vehicle interiors. This article provides an overview. More details are included in IDTechEx's report "In-Cabin Sensing 2025-2035: Technologies, Opportunities, and Markets."

In February 2025, Tesla activated its in-cabin radar in the Model Y via software update 2025.2.6, utilizing a 60 to 64 GHz mmWave radar powered by Texas Instruments' AWR6843 chip. Positioned above the passenger dome light, this radar enhances first-row cabin sensing, improving passenger classification by detecting size, position and movement. This enables dynamic airbag deployment and precise seatbelt reminders, replacing less reliable seat sensors. The radar's ability to detect vital signs, such as heart rate and breathing, supports Tesla's upcoming "Child Left Alone Detection" feature, expected in Q3 2025, which restricts vehicle controls, activates HVAC and alerts owners or emergency services if a child is detected.

In April 2025, Seeing Machines, in collaboration with Airy3D, launched a 3D camera technology for in-cabin monitoring, integrating 5MP RGBIR 2D and 3D sensing in a single module. Using Airy3D's DepthIQ™ technology, the system employs a diffractive optical element on a 2D sensor, delivering cost-effective 3D vision. This supports precision eye-tracking and occupant monitoring across the cabin, enabling integration with passive safety systems like airbags and seatbelts. The technology addresses future safety standards, such as Euro NCAP's 2025 requirements, which incentivize 3D sensing for child presence detection.

The AI In-Vehicle Experience begins by detecting and analyzing both the driver and vehicle interior in real-time through two key systems: the Driver Monitoring System (DMS) and the Driver and Interior Monitoring System (DIMS). Central to LG's vision for mobility innovation, the AI-powered in-cabin sensing solution intuitively adapts to individual preferences and needs, delivering tailored services such as personalized driving routes, real-time updates on road conditions and information on nearby infrastructure and points of interest. The DMS can identify a driver's physical health and emotional state through real-time heart rate monitoring and facial expression recognition.

IDTechEx forecasts that the integration of AI, radar and 3D cameras will accelerate, not only because of the regulatory requirements such as Euro NCAP's 2025 protocols, but also because leading players want to use their in-cabin hardware and features to differentiate themselves from others. Tesla's radar adoption, Seeing Machines' cost-effective 3D cameras, LG's AI solution and many other players' similar strategies align with this trajectory, but each faces unique hurdles.

Detection Category	3D ToF Camera	In-Cabin Radar
Privacy	Poor	Good
Breathing Detection	Good	Good
Motion Detection	Good	Good
Out of Position	Poor (requires recalibration)	Good
Under Blanket Detection	No	Yes
Sensor Resolution	Medium to High	Medium to Low
Processing Cost	Medium to High	Low
Gesture Control	Yes	Yes
Cost	High	High

3D Camera vs. In-Cabin Radar (Source: IDTechEx)

Top Satellite Operators Innovating in the IoT Market

ABI Research awarded eight satellite operators a "Hot Tech Innovator" title for their contributions to the satellite IoT industry. Each operator has been instrumental in maturing the satellite IoT ecosystem, creating new standards-based services or investing in large, IoT-compatible constellations to expand IoT customers' options beyond terrestrial limits.

One innovator, Globalstar, is known for its affordable IoT services. Its historical focus on one-way messaging in IoT-heavy markets, like asset tracking, has allowed the company to become an expert in low-cost, low-data communications. It will continue its accessible legacy by introducing a new two-way messaging offering. Globalstar's accompanying LTE and 5G terrestrial spectrum for private networks is also an important differentiator, allowing the company to become a comprehensive connectivity provider. Iridium, another award-winning innovator, has focused its IoT innovation efforts around multi-mode capabilities, announcing in January 2024 its own 3GPP non-terrestrial network (NTN) service. This service will shake up the satellite IoT competitive landscape, as it competes directly with the 3GPP NTN services offered by two other innovators, Sateliot and OQ Technology.

Though fairly new to the market, Sateliot and OQ Technology have been at the forefront of 3GPP NTN adoption, building LEO constellations based on the new standard. Both companies are forming cellular partnerships with influential mobile network operators and mobile vertical network operators to grow their platforms as their satellite infrastructure ramps up.

The LoRa NTN standard is also pertinent to satellites'

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uptake in the IoT world, serving as an NTN technology that suits the IoT's cost and power constraints. Hot tech innovators Lacuna Space and EchoStar Mobile are taking different paths to the standard's adoption, with EchoStar Mobile primarily focusing on its pan-European LoRa NTN while Lacuna Space builds its constellation and expands into new markets.

Starlink is another influential player in the satellite IoT market, with plans to offer an IoT service in 2025. The company has an impressive mega-constellation of 6,791 LEO satellites as of October 2024. However, Starlink's dominance could face competition from Amazon Project Kuiper. Amazon Project Kuiper plans to use a huge constellation of LEO satellites to support a wide range of customer segments, from broadband services to IoT devices.

New 5G Satellite Technology by an International Research Team Advances Global Mobile Connectivity

Five organizations, the Singapore University of Technology and Design (SUTD), SKY Perfect JSAT (JSAT), TMY Technology, Inc. (TMYTEK), Rohde & Schwarz and VIAVI Solutions, have jointly developed a new 5G NTN satellite technology to advance mobile connectivity in remote locations. The research team conducted a live demonstration at the World Expo 2025 Singapore Pavilion in Osaka, Japan, showcasing the deployment of an end-to-end cross-country 5G new radio (NR) NTN. This is the first such transmission between the two countries. The live demonstration was witnessed by the guest of honor, Ong Eng Chuan, Ambassador of the Republic of Singapore to Japan.

The live demonstration showed that a 5G signal can be transmitted from end-user equipment, such as a communication device, located in SUTD, Singapore, via a satellite antenna, to a geostationary (GEO) satellite operated by JSAT. This signal was then forwarded from the satellite to a ground station in JSAT, Japan, which connects to a 5G base station and 5G core network emulator, demonstrating the feasibility of communications between NTN and terrestrial networks (TNs).

The live demonstration successfully showed that an existing GEO satellite can reliably support the 5G NR standards as defined by the 3GPP, which is a consortium that develops global standards for mobile telecommunications. Although current 5G deployments primarily rely on TN, upcoming 6G networks are expected to be a convergence of both TN and NTN to achieve global coverage and resilient connectivity. This demonstration will lay the foundation for future extensions to medium Earth orbit and LEO satellites, as well as 6G converged TN and NTN.


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Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

COLLABORATIONS

Keysight Technologies Inc. has collaborated with **SPHEREA** to offer customers improved testing capabilities in the aerospace and defence (A&D) sector. By joining forces, Keysight will combine its expertise in high performance electronics tests and measuring systems with SPHEREA's design and integration capabilities to support the shifting requirements in the A&D space. As European nations increasingly prioritize defence independence and aim to remain compliant with stringent export control regulations, this collaboration offers a timely and strategic response to these needs. The deployment of next-generation measurement technologies is critical to national security, but it is also essential to align with the need for EU-designed solutions to support self-sufficient and strategic autonomy.

Sivers Semiconductors AB announced that it has signed an agreement with **Nisko Projects** to expand sales presence for its wireless business unit in Israel. Nisko Projects is a subsidiary of the Nisko Ardan Group and acts as a leading distribution, representation and integration company within the Israeli market. Aside from offering a wide range of products from market-leading companies, Nisko Projects has a vast selection of in-house capabilities that allows the optimal match of products and solutions to customers for their requirements.

Pickering Interfaces announced a strategic collaboration with **Trescal**, the leader in calibration services. Effective May 22, Trescal officially serves as an authorized service provider for calibration services of Pickering Interfaces products across the U.S. This initiative eliminates the need to ship modules to the U.K., streamlining support for U.S. customers. In choosing Trescal as a preferred partner, Pickering Interfaces ensures its customers have access to ISO/IEC 17025-accredited calibration services. Trescal's expertise spans over 20,000 brands and 150,000 types of instruments, backed by 1100+ accreditations across 28 metrological and test domains. This partnership is designed to maintain the accuracy and reliability of Pickering Interfaces' products while minimizing customer downtime.

Quadsat has entered a strategic collaboration with **Skyeton**, a Ukrainian manufacturer of unmanned aerial systems (UAS), to deliver solutions for monitoring the electromagnetic spectrum. Together the companies are supporting electromagnetic warfare operations, enhancing situational awareness and strengthening threat response in contested electromagnetic environments. The partnership combines Skyeton's fixed-wing UAS platform, Raybird, known for its battlefield-proven performance in Ukraine, with Quadsat's industry-validated RF payload and spectrum monitoring technology. Raybird has proven unmatched endurance and exceptional resilience, making it a natural choice for gathering battlefield intelligence. Quadsat's test and measurement solutions are relied upon by satellite companies to ensure a high level of equipment performance.

WIN Semiconductors Corp. announced the inclusion of U.K.-based **Viper RF** in its WIN Alliance Program. This collaboration will provide WIN customers with trusted, custom design services, including MMIC designs from 1 to 150 GHz. The partnership between Viper RF and WIN Semiconductors satisfies WIN customer requests for a trusted design partner well-versed in WIN's innovative technology. This alliance ensures that customers have access to the design solutions they need to optimize performance and maximize their product portfolios. This partnership offers design support for customers seeking trusted custom design solutions from an experienced partner like Viper RF.

ACHIEVEMENTS

Celestia has announced that it has successfully completed the testing of its multi-beam Ka-Band gateway with JoeySat, marking a major milestone in the evolution of satellite communications infrastructure. The system has been operational for nine months without the need for maintenance, reinforcing its robustness, reliability and performance in real-world conditions. The testing carried out by the Celestia team demonstrated the gateway's ability to communicate successfully with spacecraft over an extended duration, highlighting the benefits of its design, which eliminates the need for moving parts. The system has been shown to be effective across a range of climate conditions, further validating its long-term viability.

Anywaves marks a significant milestone in the space industry by becoming the world's first commercial equipment provider to deploy a reflectarray in orbit. This achievement follows Anywaves' selection by the French Space Agency, CNES, in 2020, to demonstrate the technological feasibility of this type of antenna, tailored for nanosatellites. The reflectarray antenna, featuring a deployable configuration and compact form factor, delivers exceptional gain and enhanced reliability through a simple, robust passive deployment mechanism. First used by NASA on the ISARA, MarCO-A and MarCO-B missions, this type of antenna is now being deployed in orbit by Anywaves.

Triad RF Systems announced it has achieved ISO 9001:2015 certification. This certification validates Triad RF's commitment to delivering high-quality, reliable products and services that consistently meet customer expectations. ISO 9001:2015 is the international standard for quality management systems, recognized globally as a mark of excellence. Certification is awarded to organizations that demonstrate robust processes for ensuring quality, continuous improvement, customer satisfaction and adherence to rigorous international standards. The certification comes after

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an extensive audit of Triad RF's design, manufacturing, testing and customer support processes. This accomplishment aligns closely with Triad's long-standing mission of enhancing communications performance in the most demanding environments, including unmanned systems, ISR operations, electronic warfare and tactical data links.

Finwave Semiconductor Inc. announced a new $8.2 million bridge investment round, led by Fine Structure Ventures, Engine Ventures and Safar Partners — with strategic participation from technology partner GlobalFoundries. This new funding signals strong conviction from investors and industry leaders in the market potential of Finwave's unique GaN-on-Si technology as the company transitions from a technology-centric innovator to a product-driven company poised to deliver real-world solutions. Finwave will use this investment to accelerate revenue generation, expand its product portfolio and continue developing innovative GaN-on-Si technology for the following targeted market segments: high-power RF switches, power amplifiers for communications infrastructure and power amplifiers for mobile devices.

CONTRACTS

Raytheon, an RTX business, was awarded a $1.1 billion contract from the **U.S. Navy** to produce AIM-9X Block II missiles. This is the largest contract awarded for the program and will increase production to 2,500 missiles per year. AIM-9X is the most advanced infrared-tracking, short-range, air-to-air and surface-to-air missile that is combat-proven in several theaters around the world. It is configured for easy installation on a wide range of modern aircraft and provides proven layered defense with ground-launched capabilities, including the National Advanced Surface-to-Air Missile System. A U.S. Navy-led joint program with the U.S. Air Force, AIM-9X is used by over 30 allied and partner nations and continues to gain international interest.

The **U.S. Navy** has awarded **BAE Systems** $30 million to refresh the AN/APX-123A(V) Common Transponder (CXP), which provides time-critical insights that help prevent friendly fire incidents. The refreshed CXP will support the U.S. Navy fleet and joint forces for air defense, weapon systems, air traffic control and range instrumentation. The upgrade will serve as a replacement option for currently installed Identification Friend or Foe (IFF) transponders on existing and emerging platforms, including unmanned aerial vehicles, ships, fixed-wing aircraft and helicopters. As a form, fit and function replacement, its design will address obsolescence and processing capacity to support future needs.

PEOPLE

Naprotek LLC appointed **Freddie W. Chavez Jr.** as vice president of business development. Chavez brings over 20 years of experience in sales and business development, including roles in general management and

Around the **Circuit**

▲ *Freddie W. Chavez Jr.*

operations. In his new role, Chavez will drive Naprotek's top-line growth by leveraging the company's unique offering of mission-critical electronic components and assembly services. He will work closely with the executive leadership team to formulate and execute growth strategies that promote its East Coast center of excellence in RF components, micro-e assembly and fabrication services including wafer dicing, lithography and thin film circuits, along with its West Coast center of excellence in high-mix, high-complexity PCB assembly, integration and testing.

▲ *Ulrich L. Rohde*

Dr. Ulrich L. Rohde, professor, IEEE life fellow, partner of Rohde & Schwarz and chairman of Synergy Microwave Corp., known for his expertise in microwave systems and RF, is the **Microsystems Technology Laboratories (MTL)**'s newest visiting scientist. In his role within MTL, Dr. Rohde will be collaborating closely with MTL Director Prof. Tomas Palacios and other faculty members, advising MTL students and supporting the MTL community. With his background in RF and microwave engineering, particularly in circuits and systems, as well as his experience as an educator, he looks forward to working with students at MIT as they develop world-class technologies, offering guidance on key parameters and optimal applications of emerging innovations.

▲ *Diane M. Bryant*

mmTron Inc. announced the appointment of **Diane M. Bryant** to its board of directors. With a 35-year legacy of technology leadership at Intel, Google Cloud, Broadcom and Nova Signal, Bryant brings strategic and operational expertise that aligns with mmTron's mission to extend the reach of mmWave communications. Her appointment is at a pivotal time as mmTron deploys its products with Tier 1 customers and enables growing markets like satcom.

REP APPOINTMENT

Insight SIP announced it has signed a distribution agreement with **New Yorker Electronics**, a broad-line distributor serving the North American markets headquartered in Northvale, N.J. Founded in 1948, New Yorker Electronics is a third-generation, family-run distributor that serves customers in the defense, aerospace, automotive, medical, IoT and energy industries. The company maintains a wholly U.S.-based staff across its offices in New Jersey and Texas.

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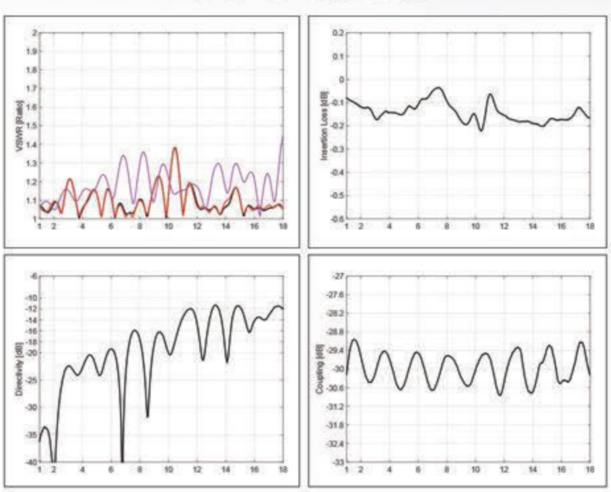

Freq. Range (GHz)	P/N	Coupling Max.(dB)	Main Line VSWR Max.(:1)	Coupling VSWR Max.(:1)	Insertion Loss* Max.(dB)	Flatness Max.(dB)	Directivity Min.(dB)	Power Max.(W)
High Power Directional Coupler								
0.3-6	D3012H003060	30±0.9	1.4	1.4	0.6	±1.2	15	600
	D4012H003060	40±1.0	1.4	1.4	0.6	±1.3	15	600
0.5-6	D3012H005060	30±0.7	1.3	1.3	0.4	±1.0	15	600
	D4012H005060	40±0.8	1.3	1.3	0.4	±1.1	15	600
0.5-18	D3008H005180	30±1.2	1.5	1.6	1.0	±1.2	10	400
	D4008H005180	40±1.2	1.5	1.6	1.0	±1.4	10	400
0.7-8	D3012H007080	30±0.8	1.4	1.4	0.5	±1.0	14	600
	D4012H007080	40±0.8	1.4	1.4	0.5	±1.0	14	600
1-8	D3012H010080	30±0.8	1.4	1.4	0.4	±0.9	14	600
	D4012H010080	40±0.8	1.4	1.4	0.4	±0.9	14	600
1-18	D3008H010180	30±1.2	1.5	1.6	0.6	±1.0	10	400
	D4008H010180	40±1.2	1.5	1.6	0.6	±1.0	10	400
6-18	D3008H060180	30±1.0	1.5	1.6	0.5	±0.7	10	400
	D4008H060180	40±1.0	1.5	1.6	0.5	±0.7	10	400
High Power Dual-Directional Coupler								
0.3-6	D3012HB003060	30±0.9	1.4	1.4	0.7	±1.5	15	600
	D4012HB003060	40±1.0	1.4	1.4	0.7	±1.6	15	600
0.5-6	D3012HB005060	30±0.7	1.3	1.3	0.6	±1.2	15	600
	D4012HB005060	40±0.8	1.3	1.3	0.6	±1.3	15	600
0.5-18	D3008HB005180	30±1.2	1.5	1.6	1.0	±1.5	10	400
	D4008HB005180	40±1.2	1.5	1.6	1.0	±1.7	10	400
0.7-8	D3012HB007080	30±0.8	1.4	1.4	0.6	±1.2	14	600
	D4012HB007080	40±0.8	1.4	1.4	0.6	±1.2	14	600
1-8	D3012HB010080	30±0.8	1.4	1.4	0.6	±1.1	14	600
	D4012HB010080	40±0.8	1.4	1.4	0.6	±1.1	14	600
1-18	D3008HB010180	30±1.2	1.5	1.6	0.8	±1.2	10	400
	D4008HB010180	40±1.0	1.5	1.6	0.6	±1.0	10	400
6-18	D3008HB060180	30±1.0	1.5	1.6	0.5	±0.9	10	400
	D4008HB060180	40±1.0	1.5	1.6	0.5	±0.9	10	400

*Theoretical Insertion Loss Included

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INVITED PAPER

Reimagining Possibilities for Next-Gen Simulation in RF EDA

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STRATISET, San Antonio, Texas

Historically, engineers procured CAD software with the implicit understanding that their hardware design process must conform to how a given software tool works. Vendors define their user interface and functionality, hoping to cover as much of the design process as possible. Engineering teams have a variety of tasks in their workflow and find or create tools for those tasks. Switching any tool in the suite usually means changing the steps required to complete a task, and sometimes the entire design workflow.

As hardware evolved in complexity, designers started to need multiple software tools to complete all the tasks in their workflow. Customers often settle on combinations of vendor and homegrown tools fitting their specific EDA needs, increasing the difficulty of adding or switching tools. Industry interoperability initiatives such as Si2 with OpenAccess implementations for EDA data repositories and APIs made tighter vendor-supplied integration and better growth paths feasible. Still, integrating RF simulators into modern workflows remains challenging, prompting a solution.

Keysight researchers are imagining a different direction for an all-new RF simulator suited for complex high frequency RF design, retaining integration benefits with a new programmatically-controlled, extensible platform. This research deepens the ties between measurement and simulation technology. Keysight explores the motives for developing a next-generation RF simulator, how designer productivity is shifting with help from research insights and the possibilities this simulator offers in automated RF design workflows, including roles for AI.

MOTIVES FOR PROGRAMMATICALLY CONTROLLED RF SIMULATION

Software development teams seek to combine and prioritize customer needs and align them with research and development knowledge, a product's inner implementation secrets and the resources needed to effect changes. If a software tool finds widespread adoption, it becomes difficult to simultaneously morph into different design spaces while maintaining a state-of-the-art core engine. Technological expansion may suggest advanced capabilities, but required engine modifications limit or preclude adding them without substantial risk or costs. At some point, breaking with the past and creating an all-new engine architecture and code base becomes a better option for developers and users, similar to how buying a new computer can be more cost-effective than upgrading.

An RF simulator, the engine driving any modern RF EDA workflow, is no exception. Keysight's RF simulation technology evolves in lockstep with its measurement science. That philosophy helped Advanced Design System (ADS) become a key platform for complex RF design with extensive circuit electromagnetic (EM) co-simulation capability.

Still, more is possible. Reimagining the possibilities for next-generation simulation in RF EDA began with the realization that Keysight's previous RF simulator engine is sophisticated but traps an immense amount

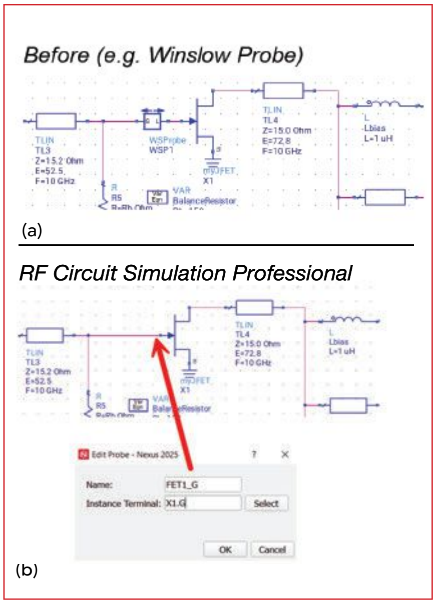


Fig. 1 **Schematics of (a) a Winslow probe inserted directly versus (b) virtual insertion via the user interface.**

of information behind its interface, rendering it inaccessible. Keysight researchers, inspired by measurement workflows, asked what might be possible by re-architecting a streamlined RF simulator, creating more hooks for programmatic execution control, leveraging interstitial data and matching features to real-world engineering design processes. In this light, a simulation engine becomes more like a measurement instrument: portable, automatable and pluggable into many different workflows. This curiosity reveals several motives for a high-stakes project.

- **Modernizing the user interface and uncluttering schematics:** User interface design directly affects user perceptions of ease of use. Powerful tools would start simulations directly from the schematic interface and avoid the creation of spin-off schematics to handle specific simulations. Layout versus schematic (LVS) verification could be more straightforward; the previous RF simulator inserts simulator controllers, probes (see ***Figure 1***) and other info on a schematic, requiring stripping that information back out for error-free verification.
- **Providing methods to control user interfaces and simulation invocation:** Python scripts calling an API are a popular addition to the previous simulator. Still, more opportunities exist to expand and customize user interfaces and introduce standard Python analysis functions. There is also the possibility for command-stream invocation of simulations, even bypassing the simulator user interface (headless), with calls issued by ADS or other workflow tools.
- **Separating simulation analysis from workflow tasks and speeding up analyses:** Semantics aside, simulation has two distinct steps: picking an analysis, like S-parameters, envelope or harmonic balance, and setting up a task, which is a sequence of analyses, like sweeps or optimization. In short, an analysis defines behavior evaluation, and tasks control how analyses execute (see ***Figure 2***). Once that distinction is made, more efficient parallelization and significant speedups become possible.
- **Pre-processing for defining sweeps, optimization and visualization:** Fine-grained parameter control of simulations via a user interface is necessary, but is not enough to make simulations more efficient. Users commonly apply post-processing for data display to extract and visualize subsets of data (for instance, zooming in on a range of frequencies), yet the simulation runs across the entire data set. Pre-processing could define reusable expressions evaluated during simulation, in analyses or tasks, with enhanced Python filtering capability for results (see ***Figure 3***). Automatically tying simulation pre-processing to optimization and plotting could also save more steps in the workflow.
- **Capturing and sharing simulation, display and optimization parameters:** Control of numerous simulation parameters is a plus, but it also introduces a potential traceability issue. Reproducing simulations run yesterday, last week or last month with the exact same parameter settings can be daunting. In the measurement domain, routines embedded in instruments provide reproducible specification compliance testing. A similar approach introduces Performances, which capture settings, expressions, filters, optimizations and specifications for traceable, reusable and sharable simulations.
- **Unlocking 10x better optimization speed with parallelization:** Although good algorithms exist in the previous RF simulator, optimization remains challenging as frequencies rise, heterogeneous technologies integrate and specifications tighten. A significant hurdle is shifting from individually optimized subsystems to larger problems in the global optimization of an entire design. An example is band filters, with perhaps ten or more working together, and leakage from one band can affect the performance of others. Another could be optimizing on different corners to find values to minimize the impact of process impairments. Joint optimization increases the domain space and the multi-dimensional surface for optimization. It is also possible

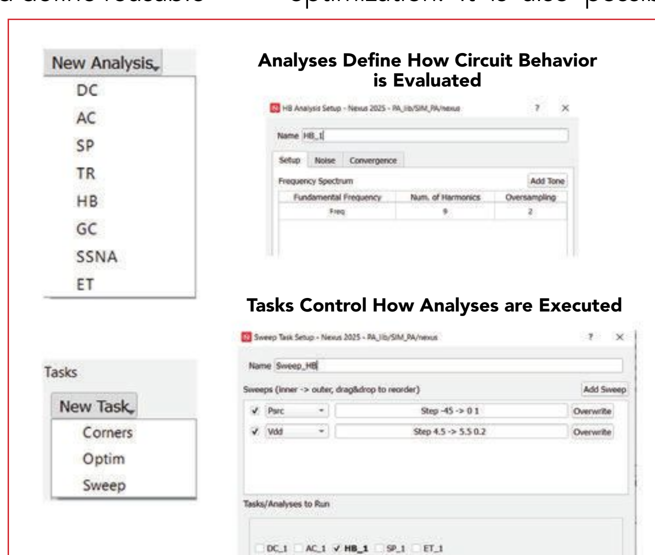


Fig. 2 **Separation between analyses and tasks in the simulator user interface.**

that, in a heterogeneous scenario, individual subsystems come from different design platforms, making global optimization more difficult. New algorithms and multi-threaded parallel execution could boost execution speed by an order of magnitude.

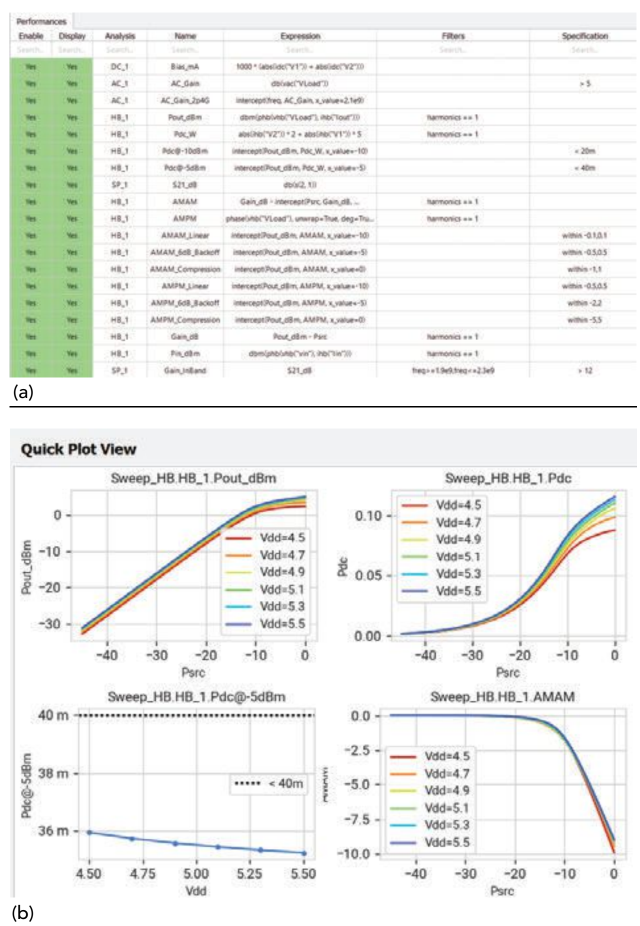
- **Setting up flexible licensing for immediate team access to features as introduced:** Licensing has also held back simulation users in some situations. An industry trend recognizes different lifecycles. Teams desire more stable design platforms with updates once, twice or maybe three times a year. RF designers tend to want on-demand simulator updates within weeks or even days of fix and feature releases. A modular simulator that can update without changing the underlying platform solves some issues. Flexible licensing that allows using any simulator feature without relicensing, including the latest feature releases, would be an improvement as design workflows morph.

Of course, these motives coexist with ongoing efforts to add and enhance simulator analysis types and improve their raw execution speed. For instance, work continues on gain compression enhancements and a revamped memory model for effects on high bandwidth signals. The primary mission of the RF simulator remains to deliver accuracy but not sacrifice time. Addressing these motives for programmatic control unlocks another level in workflow productivity while enabling intense analysis of complex RF designs.

ENHANCING DESIGNER PRODUCTIVITY AROUND RF SIMULATORS

Some of these productivity gains are achievable in Keysight's previous RF simulator, with notable differences between Keysight and non-Keysight platforms. The next-generation RF simulator, RF Circuit Simulation Professional, further expands the possibilities for users of various design and layout platforms with its modularity. Design teams now get the same core RF simulator capability regardless of their platform choice.

Allowing design teams more access to the RF simulator opens new solutions to complex problems, even solutions that teams may have avoided or worked around before in a "good-enough" workflow with some compromises, assumptions or best guesses. Four examples illustrate what is immediately possible with programmatic control in an API-enabled design platform.

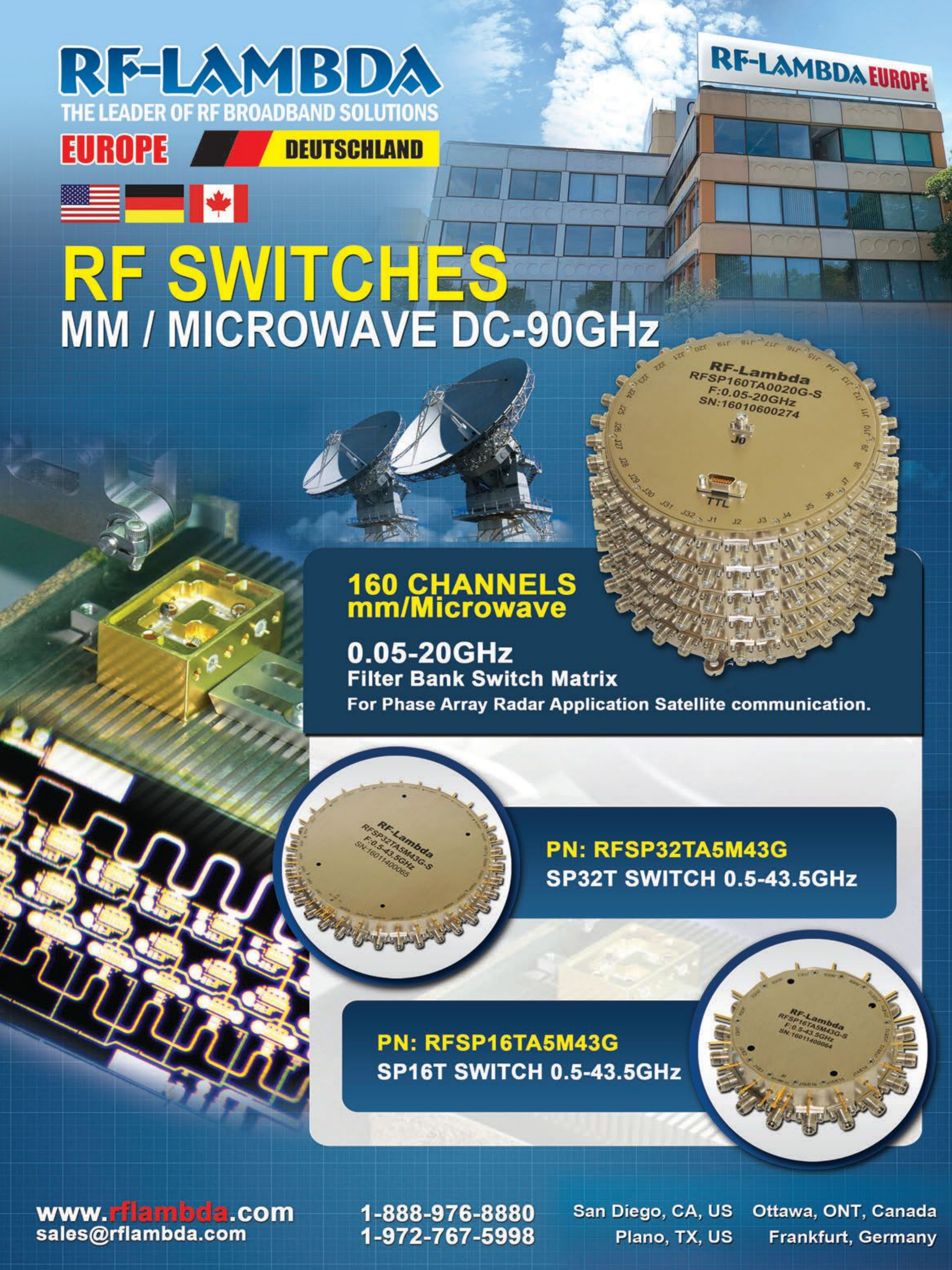

Performances

Enable	Display	Analysis	Name	Expression	Filters	Specification
Yes	Yes	DC_1	Bias_mA	1000 * (abs(idc("V1")) + abs(idc("V2")))		
Yes	Yes	AC_1	AC_Gain	db(vac("VLoad"))		> 5
Yes	Yes	AC_1	AC_Gain_2p4G	intercept(freq, AC_Gain, x_value=2.1e9)		
Yes	Yes	HB_1	Pout_dBm	dbm(phb(vhb("VLoad"), ihb("Iout")))	harmonics == 1	
Yes	Yes	HB_1	Pdc_W	abs(ihb("V2")) * 2 + abs(ihb("V1")) * 5	harmonics == 1	
Yes	Yes	HB_1	Pdc@-10dBm	intercept(Pout_dBm, Pdc_W, x_value=-10)		< 20m
Yes	Yes	HB_1	Pdc@-5dBm	intercept(Pout_dBm, Pdc_W, x_value=-5)		< 40m
Yes	Yes	SP_1	S21_dB	db(s(2, 1))		
Yes	Yes	HB_1	AMAM	Gain_dB - intercept(Psrc, Gain_dB, ...	harmonics == 1	
Yes	Yes	HB_1	AMPM	phase(vhb("VLoad"), unwrap=True, deg=Tru...	harmonics == 1	
Yes	Yes	HB_1	AMAM_Linear	intercept(Pout_dBm, AMAM, x_value=-10)		within -0.1,0.1
Yes	Yes	HB_1	AMAM_6dB_Backoff	intercept(Pout_dBm, AMAM, x_value=-5)		within -0.5,0.5
Yes	Yes	HB_1	AMAM_Compression	intercept(Pout_dBm, AMAM, x_value=0)		within -1,1
Yes	Yes	HB_1	AMPM_Linear	intercept(Pout_dBm, AMPM, x_value=-10)		within -0.5,0.5
Yes	Yes	HB_1	AMPM_6dB_Backoff	intercept(Pout_dBm, AMPM, x_value=-5)		within -2,2
Yes	Yes	HB_1	AMPM_Compression	intercept(Pout_dBm, AMPM, x_value=0)		within -5,5
Yes	Yes	HB_1	Gain_dB	Pout_dBm - Psrc	harmonics == 1	
Yes	Yes	HB_1	Pin_dBm	dbm(phb(vhb("vin"), ihb("Iin")))	harmonics == 1	
Yes	Yes	SP_1	Gain_InBand	S21_dB	freq>=1.9e9,freq<=2.3e9	> 12

(a)

(b)

Fig. 3 (a) Expressions evaluated during analyses in simulations, and (b) Python filters on curves in displayed results.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Adapting access to simulations with Python

Many users are familiar with Python scripting for basic user interface customization, data visualization and oft-repeated format conversions. Rapid development in the Python ecosystem introduces powerful capabilities that designers can easily stitch into their workflow. Adding post-processing functions and using them as if they were built-in simulator functions is a new capability. For instance, designers can remove dozens of equations in the simulator's Data Display and replace them with a single, reusable, upgradable SciPy function.

More possibilities open when the RF simulator stops being a black box and offers Python control over execution. Many users stick with Keysight's optimizers, but others develop their own for specific problems. Bolting in an external optimizer has meant months of joint customization work between Keysight application and R&D teams, designers and any third parties involved in developing the algorithm. Now, using a third-party optimizer to access the RF simulator's API via Python scripts and a wrapper becomes seamless. AI-written Python code offers another level of productivity gains.

Tying simulations to areas of circuit layouts for troubleshooting

Designers celebrate simulation success. However, experience says things don't go smoothly the first time through a design. Bumps in the flow become more common when subsystems come from various sources, some designed by third parties, such as in many 3DHI projects. Designers have their layout and less-than-good simulations, but where in the circuit or layout are the problems and what fixes can make them go away?

Troubleshooting is perhaps more crucial in a workflow than efficient simulation because it consumes time and drives schedules out of control if not solved quickly. Answering the question becomes straightforward when information previously hidden in the simulator is visible. In ADS, designers can see highlighted layout segments contributing to any out-of-bounds simulation results. Instead of guessing where the problem might be, they can dive directly into a specific spot to fix it.

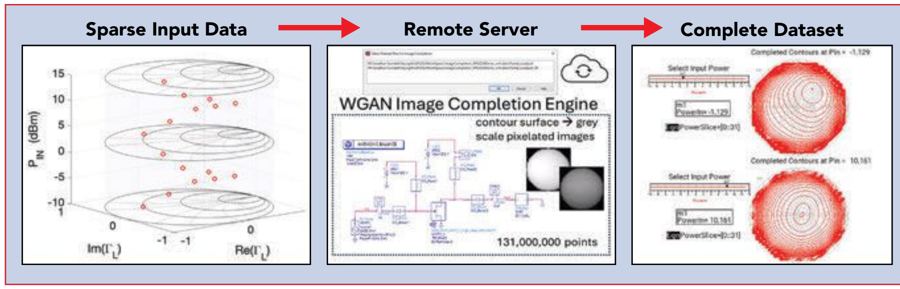
Gaining workflow flexibility through greater access

Seeing inside structures has granular benefits. Modifying a physical layout typically requires a labor-intensive manual sequence of steps, making it challenging to create perturbations essential for many model training workflows. With access, a set of API commands can alternatively represent any physical layout or schematic, enabling modification of all the information in the design programmatically, as if the physical design were a Python function. To illustrate this, Keysight developers devised a utility that extracts an API-based Python script from a physical design or schematic — running the script recreates the schematic or layout accurately. From there, a human or AI coder can manipulate the design by changing the function, rather than the physical design itself.

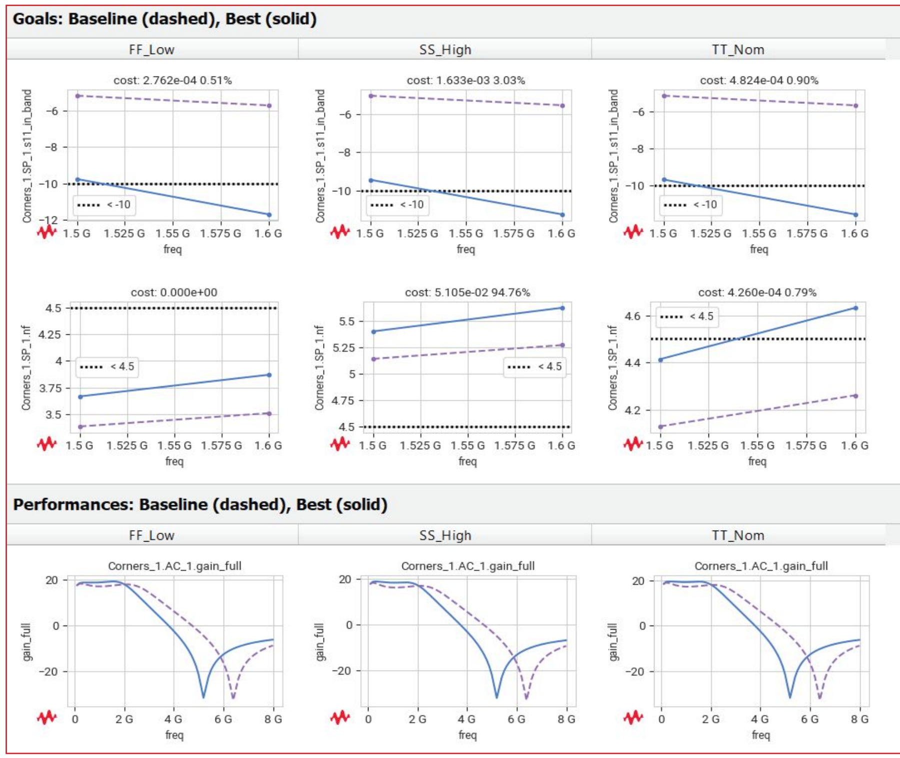
Functional automation provides a pathway to decrease simulation or measurement time by pretraining surrogate models. Researchers at Baylor University recently illustrated the concept using load-pull data.[1] Their approach uses an automated simulation workflow built on a functionalized schematic to generate contours for various conditions on an MWT-1 transistor. Upfront simulation collects 131 million points to create images that train an AI engine using a Wasserstein Generative Adversarial Network (WGAN). The pretrained model derives complete simulation or measurement contours from an extremely sparse data set (see ***Figure 4***), using 1500x fewer points. Pretraining surrogate modeling approaches can potentially capture EM and multiphysics effects, cutting physical design time.

Enabling parallel optimization and visualization

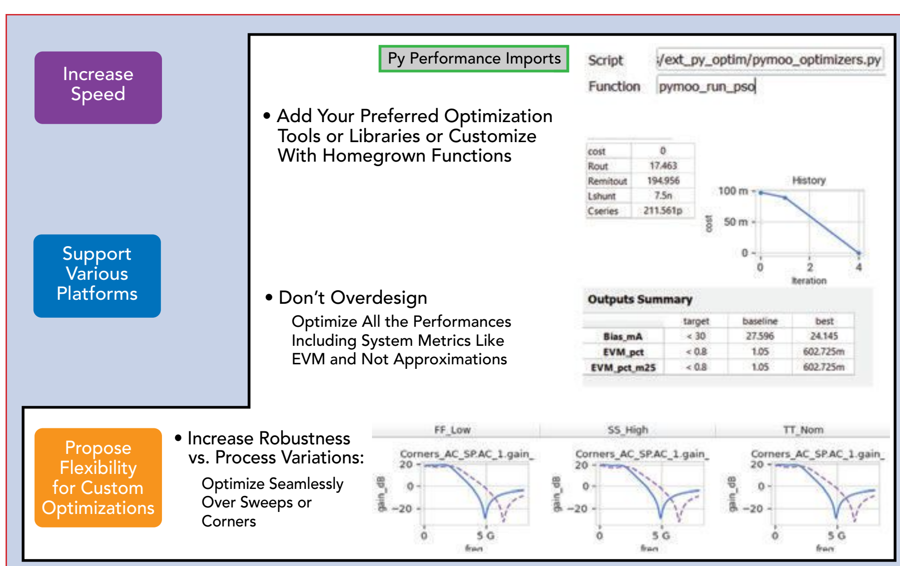
Bringing all optimization capabilities into RF Circuit Simulation Professional with any imported Python extensions means all the algorithms, parallelization and visualization tools are available on any design platform. Teams on different



▲ Fig. 4 Load pull contours derived from a pretrained model. *Source:* Jonathan Swindell, Baylor University.



▲ Fig. 5 Live optimization compares simulation progress to goals, showing algorithm effectiveness.



▲ Fig. 6 Revamped optimization sets the stage for an optimizer ecosystem.

platforms can also share their optimization setups seamlessly.

Live visualization progress (see ***Figure 5***) also allows teams to see if and how results converge during simulation runs, determining at a glance if the algorithm is effective or needs changing. Optima feed back into the design on the host platform automatically. These visualizations are helpful in several scenarios. One is employing live retrieval of measurements. Another is where system metrics such as error vector magnitude (EVM) are in play, where it's crucial to avoid overdesign triggered by approximations. A third case is analyzing process variations to enhance manufacturing yield.

POSSIBILITIES FOR AUTOMATED RF DESIGN WORKFLOWS

The biggest wins for design teams deploying programmatically controlled simulation in RF EDA workflows may be in the near future. The first logical outcome is an optimizer ecosystem, with more RF researchers participating. Innovative third parties or in-house research teams can identify and mechanize new algorithms in familiar Python code (see ***Figure 6***). Additionally, a new business model will likely emerge for optimization add-ons that are marketable to customers on many platforms, except for previously required and lengthy platform customization cycles.

The following two possibilities exist in a post-Python space where customization becomes more intuitive. Keysight is working on a no-code solution for sequencing simulations using a visual, flowchart-like solution that captures requirements and workflow in a single diagram. A defining feature of this approach is conditional execution, which can adapt workflows on the fly based on simulation results. Designers will not need to understand the API syntax to make a sequence work, although using Python calls to the API remains an option. This no-code capability would make it easier for less experienced designers to use the simulator and for design teams to share their simulation knowledge.

Finally, there is AI. Exposing simulator control sets the stage for AI training, as mentioned previously. It also allows natural-language queries from an AI front-end to run simulations in a design workflow or call a specific design exploration ad-hoc. Imagine sitting in a design review or a customer meeting, fielding a question not answered in the presentation, calling the simulator and refining the prompts until the answer appears within minutes. Combining accuracy, speed and control puts RF simulation within reach for more designers, and the outcomes will be stunning as better first-pass design success and more realistic virtual twins help manage burgeoning RF system complexity. ■

References

1. Swindell et al.,"Multi-dimensional Load-Pull Extrapolation for Accelerated Computer-Aided Design (CAD) Simulations," *USNC-URSI NRSM*, January 2025.

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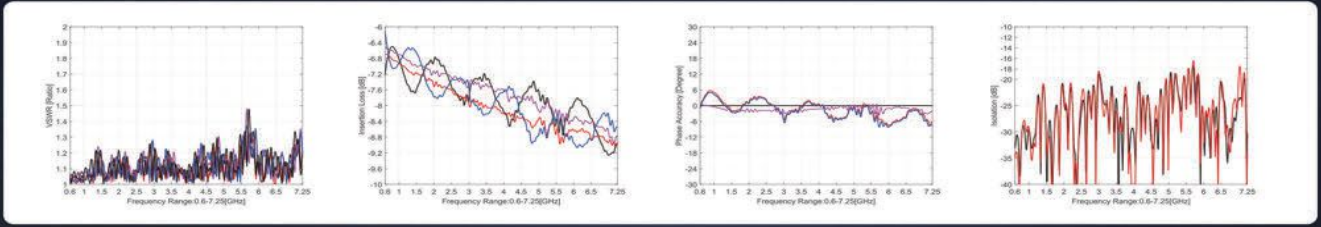
SA-07-4B006073	4x4	0.617-0.96	1.4	8.2	±1.1	±0.8	±11	17
		1.427-2.69	1.5	8.7	±1	±1	±10	14
		3.3-5	1.5	9.2	±1	±1	±12	14
		5.15-7.25	1.6	9.8	±1.1	±1.1	±12	13
SA-07-8B006073	8x8	0.617-0.96	1.4	12	±1.5	±1.4	±13	17
		1.427-2.69	1.5	13.2	±1.4	±1.6	±12	14
		3.3-5	1.5	14.6	±1.4	±1.6	±14	14
		5.15-7.25	1.6	15.9	±1.5	±1.7	±14	13

*Theoretical Insertion Loss Included

Typical Test Curve**
SA-07-4B006073



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Wideband IQ Emulation and Analysis for RF Design and Debug

Siglent Technologies
Solon, Ohio

Complex signal generation and analysis are critical test functions for RF design. As products adopt more advanced signal types, the requirements for testing transmit and receive subsystems, including interference and modulation analysis, increase. Newer signal types, such as 5G New Radio (NR), Wi-Fi 6 and Wi-Fi 7 standards require higher carrier frequencies, wider bandwidth and higher symbol rates in more complex schemes. Different solutions exist for capturing and simulating these signals for design verification and debugging. Emerging protocols, modulations and channels require the next generation of baseband production and analysis solutions to advance RF design and debug testing.

SIGNAL EMULATION LIMITATIONS AND WIDEBAND SOLUTIONS

Traditional RF signal sources enable signal emulation within a bandwidth of approximately 150 MHz. This bandwidth limitation coincides with a similar symbol rate limit. For standard SSG5000X-V models, the maximum symbol rate is 60 MSymbols/sec. Signal development software, such as SigIQPro, can import, create and transfer signals to the instrument directly, however, these limitations impact the types of signals that can be emulated. For example, ***Figures 1*** and ***2*** both show a standard 64QAM test signal with pseudo-random data on a 5 GHz carrier at 40 MSymbols/sec. Users can check the error vector magnitude (EVM), which is influenced by various factors, using different signal generators. Figures 1 and 2 have reduced some of these impacts by using the same analyzer to measure both signals. Frequency accuracy, time since calibration and phase noise all impact the EVM of the signal. However, the sample rate and bandwidth of the IQ baseband generator have a significant impact on signal integrity, as shown in Figures 1 and 2. Figure 1 demonstrates this example on the SSG5000X-V model and shows 3.14 percent rms EVM, while Figure 2 demonstrates this example on the SSG6082A-V model and shows 1.75 percent rms EVM.

Across all the specified typical and measured IQ EVM signals, including W-CDMA, LTE, GSM, edge, QAM, QPSK and CDM2000 signals, the SSG6082A-V demonstrates between one- and two-thirds of the error compared to the SSG5000X-V.

Errors caused by speed and bandwidth limitations in the baseband generator have impacts on applications, such as interference, noise and multiband tones and channels. Applications for additive white Gaussian noise are directly limited by the signal bandwidth. The IQ bandwidth is the maximum width of the noise, as the sample rate of the baseband is sufficient to generate at least that limit.

Complex interference signals that require multiple tones or IQ signals in multiple channels require advanced sampling and memory capabilities. For these applications, users must start looking beyond the sampling rate and consider the baseband sample memory. Longer arbitrary playback makes it possible to build longer, more dynamic signals with higher sample rates. For example, the SSG6082A-V is capable of baseband signals with more than 2 billion samples. This is often more than 10x the memory of standard IQ generators. Consequently, users can generate more than 1000x as many tones in a single IQ pattern. Up to 65,536 tones can be

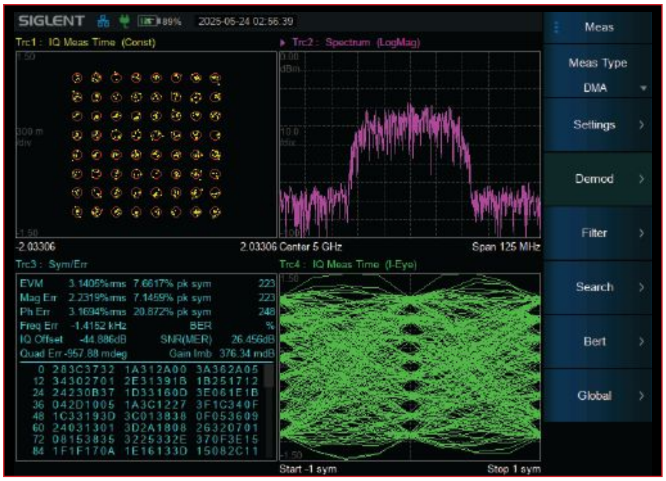

Fig. 1 64QAM with 40 MSa/s on SSG5000X.

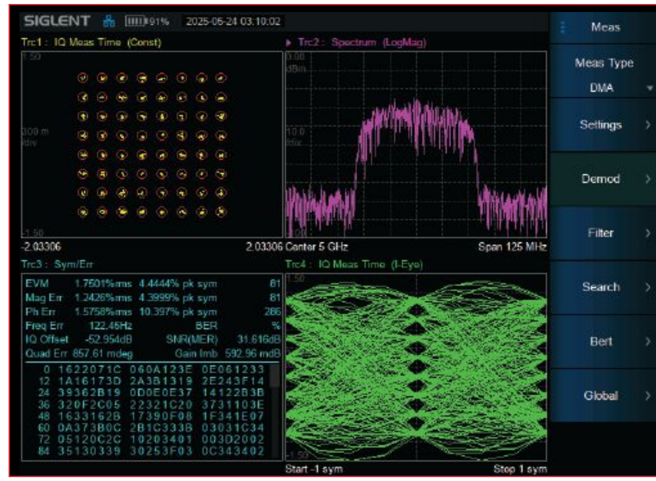

Fig. 2 64QAM with 40 MSa/s on SSG6082A-V.

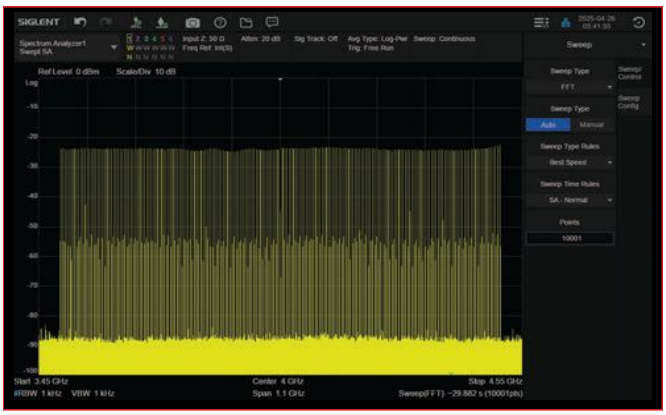

Fig. 3 100 tones at 5 MHz.

Fig. 4 IQ signals in channels simultaneously.

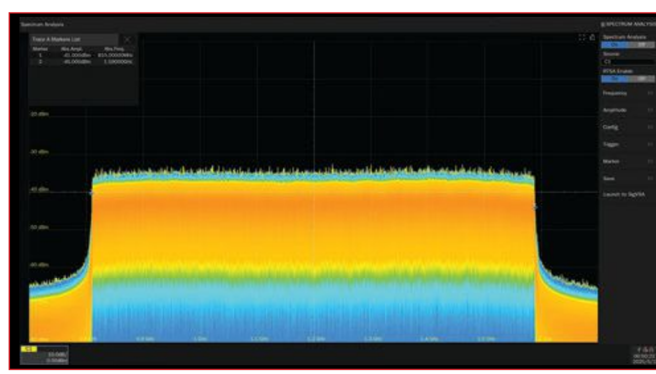

Fig. 5 Wideband real-time visualization with a high-resolution oscilloscope.

generated simultaneously in this way. ***Figure 3*** shows 100 tones at 5 MHz spacing on a 4 GHz carrier.

Wi-Fi interference applications often require standardized active signals in channels to monitor channel switching and throughput behaviors. The combination of bandwidth, symbol rate and memory depth has the added benefit of enabling multiple channels with separate waveforms to be combined into a single pattern, as shown in ***Figure 4***.

Lastly, there are protocols that require wideband modulation. Traditional LTE signals typically use 20 MHz channels. Newer 5G NR channels utilize 100 MHz of bandwidth and 802.11be signals for Wi-Fi 7 use up to 320 MHz. The SSG6082A-V can generate these more complex signals at higher symbol rates in standard modulations, including 1024QAM. These new schemes are designed to improve throughput for data-intensive applications. The combination of bandwidth, symbol rate and complex modulation schemes that have more bits per symbol are the chief methods available for increasing throughput. EVM, bit error rate and data throughput are the resulting metrics for using this bandwidth efficiently.

In summary, wideband generation enables a more complete evaluation of bandwidth use efficiency by enabling custom and high performance signal evaluation with improved accuracy and fidelity in real-world environments.

REAL-TIME ANALYSIS AND DIGITAL DEMODULATION

Similar to the ongoing expansion of capabilities for RF generation, analyzers continue to improve speed and accuracy. This includes expanded memory, measurement fidelity and analysis bandwidth.

One visualization technique for dynamic RF signals is a real-time density view. Real-time views are generated by high speed Fast Fourier Transforms (FFTs) of the time domain samples within a given spectrum. Important considerations here include the 100 percent probability of intercept (POI). This defines the shortest RF pulse that will be measured accurately in power by the analysis mode. POI is impacted by sample rate and the interleaving or overlapping of the FFTs.

Instruments like the SHA862A, as shown in Figures 1 and 2, can generate 110 MHz real-time bandwidth views in addition to the demodulation views displayed. A wider analysis bandwidth, when matched with higher and more accurate sampling, ultimately leads to better evaluation of transmitted signals.

Wider band captures are available using modern, high speed oscilloscopes as the backbone of the analysis system. With up to 8 GHz of near-DC bandwidth, an oscilloscope like the SDS7000A series provides wide bandwidth and fast sampling at 20 billion points per second with 12 bits per sample.

▲ **Fig. 6** **SigVSA embedded scope RF analysis software.**

These samples can be used to visualize 1 GHz of bandwidth, as shown in ***Figure 5***, a wideband real-time visualization with a high-resolution oscilloscope view of the channel in the RF space. Digital downconversion techniques can then be used for additional analysis. This enables the extraction of IQ data from the carrier and the utilization of high speed sampling to demodulate complex, wideband waves.

For example, this 5G NR signal shown in ***Figure 6*** can be analyzed for EVM and bit level accuracy. The digital down-conversion techniques can reduce systemic errors that may otherwise be added by analog conversion techniques. Bit level validation and error vector analysis in both time and spectrum can be shown visually for debugging and failure analysis. Higher-level custom protocol validation tests, for example channel and lane measurements, can then also be added.

CONCLUSION

Increased sample and symbol rates, memory depth and overall signal fidelity highlight advances in IQ baseband generation and analysis capabilities. These digital advances combine with expanding analysis bandwidth and higher-frequency carriers in RF analog design. This lays the foundation for RF testing using the latest protocols, modulations and channels. Together, these improve RF design and debug by simplifying high-throughput, high signal fidelity emulation and analysis.

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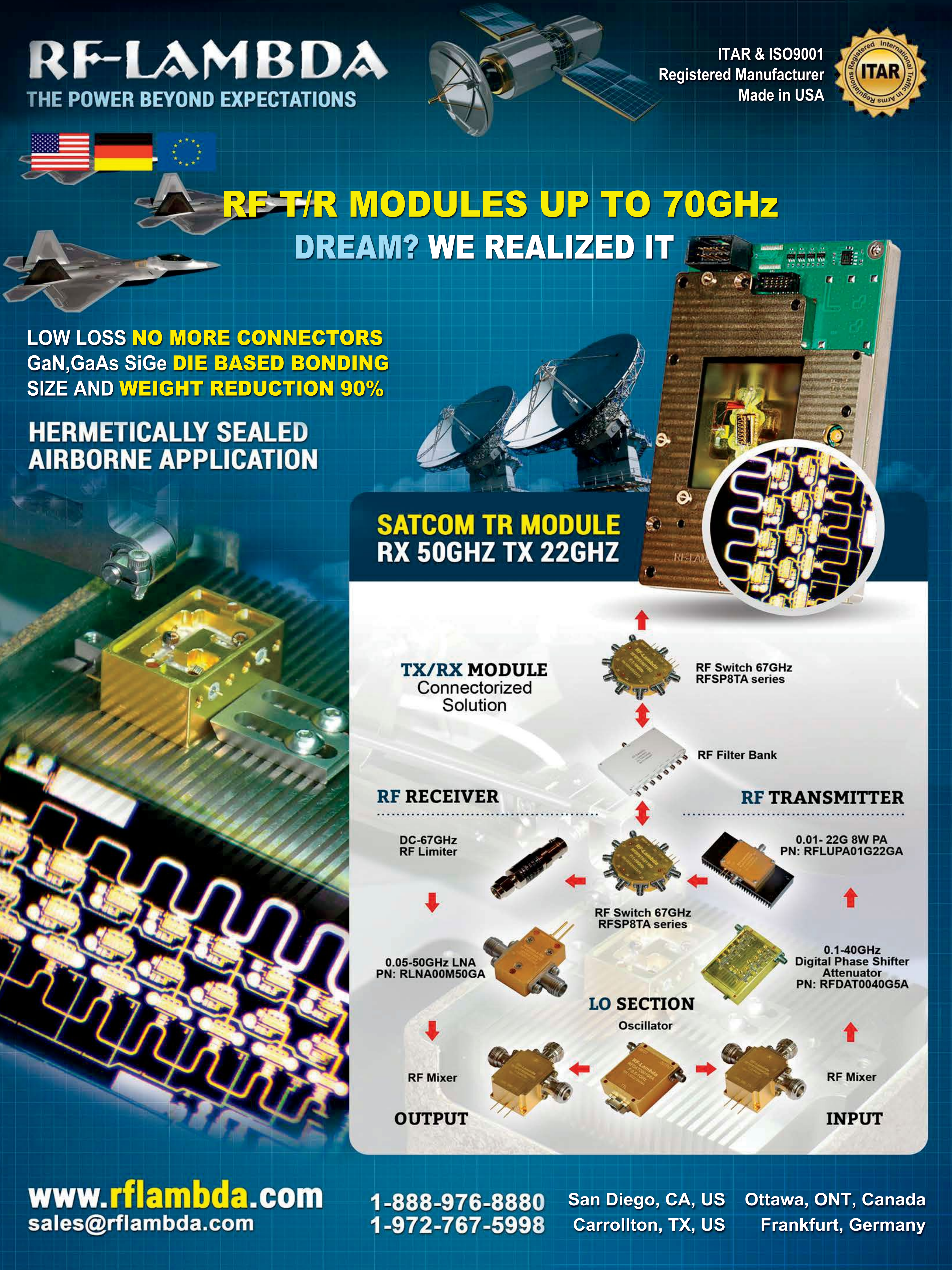

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Improvements to the Phase Noise Test Reference

Rohde & Schwarz
Munich, Germany

Emerging technologies and advanced applications drive the need for increasing data rates and the trend towards higher frequencies. When RF engineers develop devices, phase noise testers help gain critical insights into a signal's frequency stability and purity. Rohde & Schwarz (R&S) offers the industry reference for phase noise testing, the R&S FSWP phase noise and VCO tester. Thus far, the instrument features a maximum frequency of 50 GHz without external frequency extenders. Although extenders are available to measure phase noise up to 325 GHz at the push of a button, they add complexity to the setup.[1]

EMERGING APPLICATIONS UP TO 56 GHZ

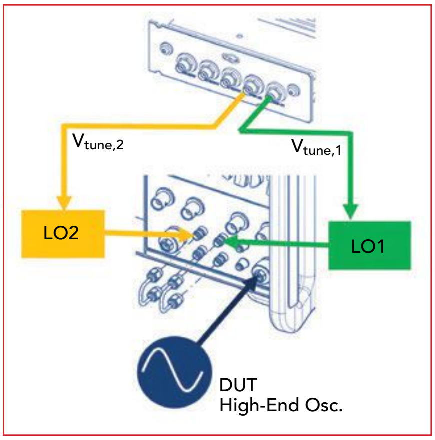
Applications are emerging in the range up to 56 GHz, such as satellite communication between 50.4 GHz and 52.4 GHz, jitter measurements for ultra-fast LAN IEEE 802.3dj at 53 GHz and CEI-224G (Common Electrical I/O) at 56 GHz. To address these new testing needs, Rohde & Schwarz has extended the R&S FSWP with a new option, R&S FSWP-B56G, which extends the frequency range for absolute phase noise measurements up to 56 GHz, eliminating the need for external frequency converters.

ENHANCEMENTS FOR PHASE NOISE MEASUREMENTS

The R&S FSWP-B56G option also extends the instrument's capability for additive/residual phase noise measurements on amplifiers or other components up to 56 GHz with frequency offsets up to 40 MHz. The frequency range of the internal source for this application is now extended to 50 GHz (previously 18 GHz) and up to 54 GHz with the R&S FSWP-B56G option. Users can easily measure the added noise of an amplifier by simply connecting it between the output of the signal source and the input of the R&S FSWP. Instead of using the internal source, an external signal source, such as a high-end signal generator or oscillator, can be added to the setup to be used as a local oscillator.

UTILIZING EXTERNAL SIGNAL SOURCES

Besides extending the frequency range to 56 GHz, the R&S FSWP now supports external signal sources as local oscillators for absolute phase noise measurements. Engineers often prefer using in-house high-end sources instead of the R&S FSWP's internal sources, which, while covering a wide range from a few MHz to 56 GHz, may not match the performance of specialized oscillators designed for narrower frequency ranges. Utilizing these high-end external sources allows for faster results, as fewer cross-correlations are needed to measure the phase noise of the device under test (DUT), which could be another high-end oscillator. Depending on the quality of the sources, measurements can be up to 1000x faster than internal sources. ***Figure 1*** shows a typical setup using two external sources as local

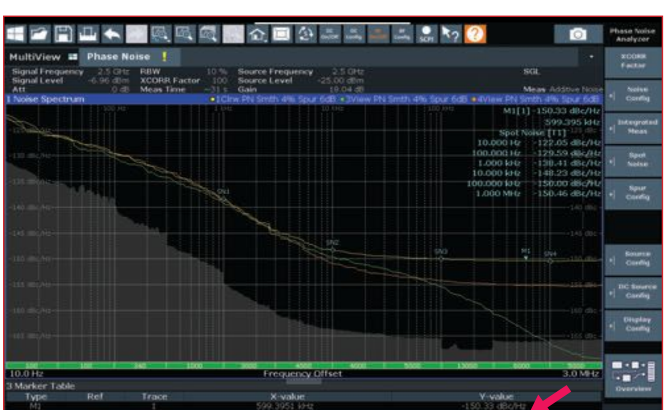


▲ Fig. 1 **Setup with two external signal sources to measure a high-end DUT.**

oscillators to measure a high-end DUT. The signal sources can be locked to the DUT frequency using the tuning outputs of the R&S FSWP.

In this mode, users can measure with two external oscillators to fully benefit from cross-correlations, or they can measure two identical sources against each other (two DUT method) and adjust the results by 3 dB. This mode is effective up to 56 GHz. If the sources cannot be tuned and locked to the DUT, measurements can still be performed with a constant offset between the sources.[2] However, the maximum offset is limited to around 10 MHz. ***Figure 2*** illustrates a typical measurement where two sapphire-loaded cavity oscillators (SLCOs) are measured against each other. The green trace shows the performance of an SLCO measured with the internal sources with 100 averages applied. The yellow trace shows the result with just one correlation measured with two SLCOs (two DUT method). Only one cross-correlation is needed to reveal the performance of the high-end oscillators, compared to potentially needing up to 100 correlations with internal sources.

▲ Fig. 2 **Typical measurement of two SLCOs, applying the two DUT method.**



▲ Fig. 3 **Additive/residual phase noise of an amplifier.**

INTRODUCING THE NOISE FIGURE MARKER

A new marker function, the noise figure marker, has been added for additive/residual phase noise measurements on amplifiers. The phase noise at lower input power directly reflects the noise figure of the amplifier.[3,4] The only parameter that needs to be known is the input power at the amplifier's input, which can be set at the signal source output or measured directly with a power sensor. The noise figure of the amplifier can then be calculated using this formula:

$$NF = -(-177\ dBm/Hz) + Pin + Phase\ noise$$

This new method, based on phase demodulation, provides a way to measure the small signal noise figure of amplifiers, in addition to the cold source method commonly used in network analyzers and the Y-factor method used in signal and spectrum analyzers. The R&S FSWP, now covering frequencies up to 56 GHz, offers both the Y-factor method — using noise sources with a calibrated ENR in the spectrum analyzer — and noise figure measurement based on demodulation in the phase noise tester.

Figure 3 shows a typical measurement, where the noise figure marker result (here 1.67 dB) can be seen in the table. The green trace shows the added phase noise at high input levels. The orange and yellow traces with lower input level are dominated by the wideband noise at offsets > 100 kHz, which can be used to calculate the small signal noise figure.

FUTURE ENHANCEMENTS AND MODEL UPDATES

With its new enhancements, the R&S FSWP phase noise and VCO tester expands its applications through an extended frequency range and features like the noise figure marker. By supporting external sources as local oscillators, it combines the user-friendly nature of a signal source analyzer with the capabilities of a high-end phase noise tester. Previously, such instruments were complex and required significant time to set up and run measurements. Now, the R&S FSWP simplifies this process.

The other models, R&S FSWP8 and R&S FSWP26, will receive the same enhancements in the coming weeks. Further improvements to the R&S FSWP are planned and will be announced over the next 12 months.

References

1. Dr. W. Wendler and M. Schmähling, Application Note, 1EF101, 2018.
2. M. Giunta, B. Rauf, S. Pucher, S. Afrem, W. Wendler, A. Roth, J. Kornprobst, S. Peschl, J. Schulz, J. Schorer, M. Fischer and R. Holzwarth, "Cross-spectrum Phase Noise Measurements of 10-15-level Stability Photonic Microwave Oscillators, *IEEE MTT-S International Microwave Symposium (IMS) 2025*, Th2D-4.
3. K. Gheen, Application Note, 1EF100, 10.2017.
4. Application Card, Version 01.00, Dynamic noise figure measurements.

VENDORVIEW

Rohde & Schwarz
Munich, Germany
www.rohde-schwarz.com

Modular SMPX Interconnects up to 110 GHz

The increasing complexity of next-generation high speed systems is pushing the limits of traditional interconnect technologies. As 5G, mmWave and 224 Gbps/lane PAM4 applications become the new normal, RF engineers face mounting challenges in maintaining signal integrity, minimizing skew and enabling repeatable connections across dense multiport test and system environments. These design hurdles are especially pronounced in semiconductor validation, ATE, probe card interfaces and defense systems, where even minor discontinuities or mismatched phase delays can undermine performance.

Rosenberger's SMPX interconnect system addresses these issues head-on with a blend of precision, flexibility and robustness. This high frequency push-on solution is rated to 110 GHz and incorporates a solderless compression-mount design that eliminates variability from solder joints while simplifying field maintenance. The SMPX series supports over 10,000 mating cycles, allowing for high volume test and characterization without performance degradation.

One of the defining advantages of the SMPX interconnect is its electrical performance in a high-density format. The 54 mm pitch multiport architecture is offered in more than two dozen standard configurations with tight phase matching — pair-matched within 1 ps by default — ensuring minimal electrical skew across all channels. Engineers can further fine-tune this performance for mission-critical designs requiring tighter tolerances.

The system's field-replaceable channel design also solves a common pain point: the need to replace entire cable assemblies when only one channel fails. With SMPX, any single channel can be independently removed and replaced, saving time and reducing overall system cost.

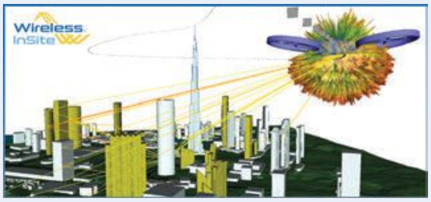
In short, the SMPX interconnect solution combines mechanical simplicity, electrical precision and modular serviceability, all requirements for RF engineers tasked with advancing high speed system designs while staying within budget constraints. Contact your local RFMW sales member for more information.

VENDORVIEW

RFMW
San Jose, Calif.
www.rfmw.com

Rosenberger
Akron, Pa.
www.rosenberger.com

Simulating Time-Based Mobility of RF Systems



Remcom's new version of Wireless InSite® 3D Wireless Prediction Software introduces advanced capabilities, including time-based mobility, lunar propagation modeling and wideband ray tracing with S-parameter outputs. The new release (Release 4.0) supports dynamic and complex RF environment simulation, including on-body propagation and NASA Artemis missions.

Wireless InSite 4.0 leverages a robust mobility framework that accurately models the movement of transceivers and objects within a user-defined scene. Mobile platforms now enable precise evaluation of dynamic scenarios where mounted antennas on scatterers like vehicles and humans affect channel conditions. Time-based outputs, rendered as plots or animations, provide detailed insights into multipath and fading, received power, SINR and data throughput across time as RF systems and vehicle platforms move through a scene.

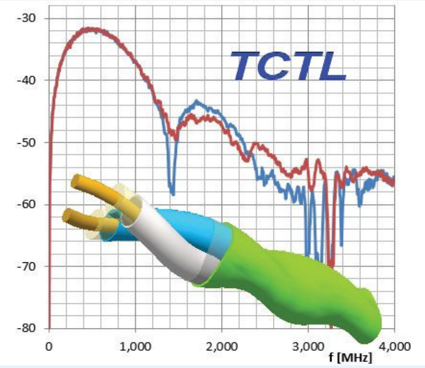
To support NASA's Artemis mission, Wireless InSite ensures accurate simulation of RF propagation on the Moon by providing the ability to import Lunar Reconnaissance Orbiter (LRO) Lunar Orbiter Laser Altimeter (LOLA) terrain datasets and transform the coordinates of RF mobile systems upon the lunar terrain, while also incorporating a lunar materials database. By capturing the reflection and refraction characteristics inherent to the Moon's landscape, these capabilities are essential for future lunar missions.

Utilizing full-wave Huygens antennas, Wireless InSite also leverages data generated by Remcom's XFdtd® full-wave 3D electromagnetic solver to capture interactions with people, vehicles and structures in the near-field of the antenna. The transfer to Wireless InSite preserves the precise physical relationship between the antenna, geometry, materials and near-field data. Additionally, support for refraction into volumetric materials further refines the simulation of complex electromagnetic interactions with the body or nearby structures for technologies such as 6G, GNSS, WLAN, lunar missions and on-body communication while in motion.

VENDORVIEW

Remcom Inc.
State College, Pa.
www.remcom.com

New Software to Optimize Cable Design



OptEM Cable Designer is a software tool that enables engineers to model, analyze and optimize cable designs accurately, reducing costly prototypes and speeding up production. At its core, OptEM Cable Designer extrudes a 3D model of the cable, considering lay lengths and realistic enclosure shapes. This ensures an accurate representation of real-world cable configurations. The software then performs electromagnetic (EM) field analysis, extracting key transmission parameters such as L, R, C and G values, which vary based on frequency and cable position. Further analysis produces S-parameter outputs like insertion loss, return loss, NEXT and FEXT, helping engineers evaluate signal integrity. OptEM Cable Designer has a hierarchical design concept, allowing engineers to build complex cable structures using existing design elements. Each component is tagged with key properties, including conductor and dielectric materials, plating thickness and positioning details such as twisting, back-twisting and enclosure shaping. This flexibility ensures a realistic simulation of multi-conductor cable configurations. Unlike static field solvers, OptEM's high frequency EM solver is based on the Helmholtz equation, capturing skin effects, proximity effects, eddy currents in shields and dielectric losses. This results in accurate frequency-dependent transmission models that align closely with real-world measurements. By reducing the need for physical prototypes, engineers can lower overall production cost and time to market. With its robust 3D modeling, high frequency EM analysis and measurement modification capabilities, OptEM Cable Designer is a useful tool for engineers looking to design high performance, cost-effective cable solutions.

OptEM Engineering Inc.
Calgary, Alberta
www.optem.com

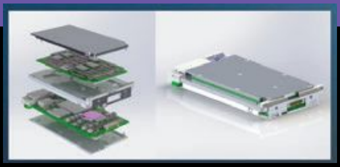
MAKING WAVES

Disruptive Technology, Transformative Solutions: ADSY1100

This system enables wideband digitization up to 5 GSPS data rates per channel covering a frequency tuning range between 0.1 to 20 GHz and is comprised of both a digitizer base card and a tuner personality card.

Analog Devices

www.analog.com/en/resources/media-center/videos/6355240460112.html

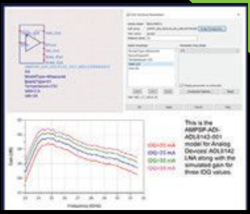


Model Rap Blog: mmWave Amplifier Model Adapts to Many Tasks

Among the amplifier models offered by Modelithics is the AMPSP-ADI-ADL8142-001 linear behavioral model for Analog Devices's ADL8142 mmWave LNA. This model is unique because it can be simulated across a wide range of user-defined conditions. In this blog post, learn how this model provides designers with a great deal of flexibility because of its multi-bias, multi-temperature and multi-substrate functionality.

Modelithics

www.modelithics.com/FreeDownloads/Blogs/Modelithics_Model_Rap_May2025_Final.pdf



Qualcomm's 40th Anniversary

A commemoration of innovation and building the future, the milestone was met with a celebration in NYC, ringing the NASDAQ opening bell and a look into the next era of tech.

Qualcomm

www.qualcomm.com

RCS of Hellfire Missile: Comparison of X3D PO MEC to XFdtd

This example details the setup and execution of RCS calculations using XGtd's X3D PO MEC model and compares the predictions to those made using XFdtd.

Remcom

www.remcom.com/resources/examples/rcs-of-hellfire-missile-comparison-of-x3d-po-mec-to-xfdtd

The Metaverse and XR - a Killer Application for 5G & 6G Networks?

Rohde & Schwarz delves into the fundamental ideas of the Metaverse and its symbiotic relationship with extended reality (XR). Discover how these emerging paradigms promise to reshape our reality and propel us into a new era of connectivity and experience.

Rohde & Schwarz **www.youtube.com/watch?v=3ZMz-n9wWc4**

generatorNETBOX Products (AWGs) by Spectrum Instrumentation

Check out Spectrum Instrumentation's new arbitrary waveform generators (AWGs) in this video.

Spectrum Instrumentation **https://youtu.be/2DCQbx99BIo**

European Microwave Week 2025

The only European event dedicated to the Microwave and RF industry

The European Microwave Week 2025 takes place in the city of Utrecht. Bringing industry and academia together, the European Microwave Week 2025 is a SIX day event, including THREE cutting edge conferences, THREE Forums and ONE exciting trade and technology Exhibition featuring leading players from across the globe. EuMW 2025 provides access to the very latest products, research and initiatives in the microwave sector. It also offers you the opportunity for face-to-face interaction with those driving the future of microwave technology. EuMW 2025 will see an estimated 1,600 conference delegates, over 4,000 attendees and in excess of 300 international exhibitors (inc. Asia & US).

The Exhibition

Registration to the exhibition is FREE!

- Over 300 International Companies - meet the industry's biggest names and network on a global scale
- Cutting-edge Technology - exhibitors showcase their latest product innovations, offer hands-on demonstrations and provide the opportunity to talk technical with the experts
- Industrial Workshops - get first hand technical advice and guidance from some of the industry's leading innovators

Entry to the exhibition is FREE.
Register at: www.eumw.eu

Be There

Exhibition Dates	Opening Times
Tuesday 23 September 2025	09:30 - 18:00
Wednesday 24 September 2025	09:30 - 17:30
Thursday 25 September 2025	09:30 - 16:30

The Conferences

The EuMW 2025 consists of three conferences, three forums and associated workshops:

- European Microwave Integrated Circuits Conference (EuMIC) 22-23 September 2025
- European Microwave Conference (EuMC) 23-25 September 2025
- European Radar Conference (EuRAD) 24-26 September 2025
- Plus Workshops and Short Courses (From 21 September 2025)
- In addition, EuMW 2025 will include the Defence, Security and Space Forum, the Automotive Forum and the 6G Forum

The three conferences specifically target ground breaking innovation in microwave research. The presentations cover the latest trends in the field, driven by industry roadmaps. The result is three superb conferences created from the very best papers submitted. For the full and up to date conference programme including a detailed description of the conferences, workshops and short courses, please visit www.eumw.eu. There you will also find details of our partner programme and other social events during the week.

TO SEE THE CONFERENCE SESSION MATRIX please visit: www.eumw.eu

How to Register

Registering as a Conference Delegate or Exhibition Visitor couldn't be easier. Register online and print out your badge in seconds onsite at the Fast Track Check In Desk. Online registration is open now, up to and during the event until 26 September 2025.

- Register online at **www.eumw.eu**
- Receive an email receipt with QR code attached
- Bring your email, QR code and photo ID with you to the event
- Go to the Fast Track Check In Desk and print out your badge
- Alternatively, you can register onsite at the self service terminals during the registration.

Please note: NO badges will be mailed out prior to the event.

On-site registration opening times:

- Saturday 20 September 2025 (16:00 - 19:00)
- Sunday 21 - Thursday 25 September 2025 (08:00 - 17:00)
- Friday 26 September 2025 (08:00 - 10.00)

Registration Fees

Full Week ticket:

Get the most out of this year's Microwave Week with a Full Week ticket. Combine all three conferences with access to the Defence, Security and Space Forum and the 6G Forum (the Automotive Forum and the Schools are not included) as well as all the Workshops or Short Courses.

Registration at one conference does not allow access to the sessions of the other conferences.

Reduced rates are offered if you have society membership to any of the following: EuMA✪, GAAS, IET or IEEE. Reduced rates for the conferences are also offered if you are a Student/Senior (Full-time students 30 years or younger and Seniors 65 or older as of 26 September 2025). The fees shown below are invoiced in the name and on behalf of the European Microwave Association. All payments must be in € Euros – cards will be debited in € Euros.

ALL FEES ARE EXEMPT OF DUTCH VAT.

Lunches are included with all conference/forum and workshop registrations:

- **Sunday: lunch boxes provided to delegates**
- **Monday–Friday: delegates receive a seated 3 course lunch**

CONFERENCES REGISTRATION	ADVANCE DISCOUNTED RATE (FROM NOW UP TO & INCLUDING 22 August 2025)				STANDARD RATE (FROM 23 August 2025 & ONSITE)			
	Society Member ✪		Non-Member		Society Member ✪		Non-Member	
1 Conference	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.
EuMC	€ 710	€ 200	€ 1,000	€ 280	€ 1,000	€ 280	€ 1,400	€ 400
EuMIC	€ 540	€ 180	€ 760	€ 250	€ 760	€ 250	€ 1,060	€ 350
EuRAD	€ 490	€ 170	€ 680	€ 240	€ 680	€ 240	€ 950	€ 330
2 Conferences	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.
EuMC + EuMIC	€ 1,000	€ 250	€ 1,400	€ 350	€ 1,400	€ 350	€ 1,970	€ 450
EuMC + EuRAD	€ 960	€ 250	€ 1,340	€ 350	€ 1,340	€ 350	€ 1,880	€ 450
EuMIC + EuRAD	€ 820	€ 250	€ 1,150	€ 350	€ 1,150	€ 350	€ 1,610	€ 450
3 Conferences	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.
EuMC + EuMIC + EuRAD	€ 1,220	€ 300	€ 1,710	€ 400	€ 1,710	€ 400	€ 2,390	€ 500
Full Week Ticket	€ 2,070	€ 500	€ 2,680	€ 600	€ 2,680	€ 600	€ 3,510	€ 700

✪ BECOME A MEMBER - **NOW!**

EuMA membership fees: Professional € 25 / year, Student € 15 / year.

One can apply for EuMA membership by ticking the appropriate box during registration for EuMW. Membership is valid for one year, starting when the subscription is completed. The discount for the EuMW fees applies immediately. Members have full e-access to the International Journal of Microwave and Wireless Technologies.

EUMA KNOWLEDGE CENTRE
The EuMA website has its Knowledge Centre which presently contains over 24,000 papers published under the EuMA umbrella. Full texts are available to EuMA members only, who can make as many copies as they wish, at no extra-cost.

SPECIAL FORUMS AND SESSIONS REGISTRATION		ADVANCE DISCOUNTED RATE (UP TO & INCLUDING 22 August 2025)		STANDARD RATE (FROM 23 August 2025 & ONSITE)	
	Date	Delegates*	All Others**	Delegates*	All Others**
Automotive Forum	23 September 2025	€ 365	€ 515	€ 510	€ 720
Defence, Security & Space Forum	24 September 2025	€ 180	€ 250	€ 250	€ 350
6G Forum	22 September 2025	€ 365	€ 515	€ 510	€ 720
Design School	21 September 2025	€ 40	€ 40	€ 55	€ 55
Radar School	22 September 2025	€ 40	€ 40	€ 55	€ 55
EuMW Experience	24 September 2025	€ 60	€ 60	€ 60	€ 60

*those registered for EuMC, EuMIC or EuRAD **those not registered for a conference

Workshops and Short Courses

Despite the organiser's best efforts to ensure the availability of all listed workshops and short courses, the list below may be subject to change. Also workshop numbering is subject to change. Please refer to www.eumw.eu at the time of registration for final workshop availability and numbering.

Sunday 21 September 2025			
SS-01	Full day	EuMIC	**Fundamentals of Microwave PA Design**
SS-02	Half-day	EuMC	**Wearable Antenna Systems for Joint Body-Centric Communication, Powering and Sensing**
WS-01	Full day	EuMC/EuMIC	**Advancements in Technologies and Circuits Leading to 6G**
WS-02	Full day	EUMC	**Polymer Microwave Fiber (PMF) Communication for Sub-THz, Low-Cost High Data Rate Short-Range Systems**
WS-03	Full day	EuMC	**Acoustic Wave Filters for Space Applications**
WS-04	Full day	EuMC	**Additive Manufacturing for Microwave Components and Systems**
WS-05	Full day	EuMC/EuMIC	**Opportunities and Challenges for the Cryogenic Microwave Control of Quantum Processors**
WS-06	Full day	EuMC/EuMIC	**RFIC Design, Packaging and Antenna Solutions for mm-Wave and Sub-THz Communication and Radar**
WS-07	Full day	EuMC	**Integrated Microwave Photonics**
WS-08	Full day	EuMC/EuMIC	**Thermal Effects and Heat Management in Active Phased Arrays: Chip, Package and Antenna Level Concepts**
WS-09	Full day	EuMC/EuMIC	**Innovations in Load-Pull Techniques for Wideband and High-Frequency Applications**
WS-10	Full day	EuMC/EuMIC	**Advanced mm-Wave IC Design: A Step Ahead**
WS-11	Half-day	EuMC/EuMIC	**The Path to 2030: Joint Communication and Sensing in the 6G Internet-of-Everything Era**
WS-12	Half-day	EuMC/EuMIC	**AI and Data-Driven Modeling for RF/MW Design**

Monday 22 September 2025			
SM-01	Half-day	EuMC	**Architecture and Applications for Emerging SATCOM and NTN Communication Networks**
WM-01	Full day	EuMC	**Photonic Technologies and Systems for RF Applications**
WM-02	Full day	EuMC	**Latest Advancements in Microwave Measurement Techniques for Future Communications and Quantum Applications**
WM-03	Half-day	EuMC/EuRAD	**Standard, Prototype, and Measurement for Integrated Sensing and Communications in the COST Action INTERACT**
WM-04	Half-day	EuMC	**Microwave Carbon Footprint of Wireless Communincations - From Energy Efficiency to Embedded Emissions**

Wednesday 24 September 2025			
SW-01	Half-day	EuMC	**Radiative Wireless Power Transfer Basics and Implementation**
SW-02	Full day	EuMC/EuMIC	**Embedding Sustainability into RF Technologies**
SW-03	Half-day	EuMC	**Flexible Beamforming for Direct Radiating Arrays in Satellite Communications**
WW-01	Half-day	EuMC	**Innovative Semiconductor Device Architectures and Accurate Modeling for Emerging Applications - Bridging the Gap Between Circuit Design Challenges and Practical Commercialization**
WW-02	Half-day	EuMC/EuRAD	**High Resolution Radar Technologies for Future Automotive Systems**
WW-03	Half-day	EuMC/EuMIC	**RF & Sub-THz Heterogeneous Integration**
WW-04	Half-day	EuMC	**Recent Progress in Compact, Ultra-Low Phase Noise Microwave-Photonic Frequency Synthesis**

Thursday 25 September 2025			
STh-01	Full day	EuMC/EuRAD	**Basics of Systems Engineering for the Microwave Engineering Community**
STh-02	Half-day	EuRAD	**Synchronization in Distributed Radar – Prospective and Problems**
WTh-01	Full day	EuRAD	**Automotive Radar Research Trends**
WTh-02	Half-day	EuRAD	**Multistatic/Distributed Radar Systems**

Friday 26 September 2025			
SF-01	Half-day	EuRAD	**Integrated Sensing and Communications: Fundamentals, State-of-the-Art and the Road Ahead**
SF-02	Half-day	EuRAD	**Nonlinear Radar: From Concepts to Applications**

WORKSHOPS AND SHORT COURSES	IN COMBINATION WITH CONFERENCE REGISTRATION				WITHOUT CONFERENCE REGISTRATION			
	Society Member		Non-Member		Society Member		Non-Member	
	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.
Half Day	€ 120	€ 90	€ 170	€ 120	€ 170	€ 120	€ 220	€ 170
Full Day	€ 180	€ 130	€ 240	€ 180	€ 240	€ 180	€ 320	€ 240

NEW PRODUCTS

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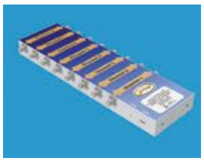
DEVICES/ COMPONENTS/MODULES

USB Programmable Attenuator

VENDORVIEW



JFW model 50P-2140 SMA is an 8-channel USB programmable attenuator. It operates from 200 to 6000 MHz with attenuation range 0 to 95 dB in 1 dB steps. All eight attenuators are individually controlled. Test software is provided with the USB attenuator. If you would like to integrate the USB attenuator into your script testing, we do offer a JFW Python library upon request.

JFW Industries
www.jfwindustries.com

RF Fixed Attenuators

VENDORVIEW

Pasternack announced the launch of their new RF fixed attenuators and terminations for cryogenic applications. Designed to deliver superior performance in extreme environments, these components support frequencies up to 40 GHz with robust durability and precision. Pasternack's latest attenuators and terminations feature SMA and 2.92 mm connectorized designs, offering secure and reliable connections for high frequency RF systems. These components operate efficiently across a wide temperature range, from 4 Kelvin to 125°C, making them ideal for cryogenic applications in quantum computing, aerospace and scientific research.

Pasternack
www.pasternack.com

Precision Motorized Programmable Attenuators

QuinStar's QPE Series delivers highly accurate, programmable attenuation across 18 to 170 GHz in nine waveguide bands. Ideal for automated test systems, each unit offers 0.05 dB resolution, digital readout and IEEE-488 remote control, all in a compact, self-contained module. Built-in calibration memory ensures linearity. Say goodbye to manual guesswork and bulky test setups. QPE gives engineers precise, repeatable control for faster, cleaner and more reliable RF measurements.

Quinstar
www.quinstar.com

Dual 1000 W Directional Coupler

Sigatek introduces a dual high power 50 dB directional coupler with an operating frequency of 80 to 1000 MHz. Forward and reverse coupling is 50 dB and flatness is ±1 dB with low insertion loss of 0.35 dB maximum. Directivity is 20 dB minimum on each direction and VSWR is 1.20:1 in/out. Power handling is 1000 W CW. In/out connectors are N female and coupling port are SMA female. Dimensions are 3 × 2 × 1.25 in. Finish is clear chemical conversion coating.

Sigatek LLC
www.sigatek.com

CABLES & CONNECTORS

Semi-Rigid Cable Assembly

VENDORVIEW

This high performance 67 GHz mmWave cable assembly utilizes .070 in. low loss semi-rigid cable. The connector screw nut is designed with a movable feature, enabling visual, fast and accurate positioning to prevent contact damage during installation and save processing time. Custom 3D pre-form is available upon request, and phase matching is optional. The electrical performance of this product is outstanding, featuring low loss and low VSWR even after formed, there are no wrinkles on the surface after being bent and the appearance looks exquisite. This assembly is highly suitable for both internal and external connections in mmWave equipment, testing instruments and test fixtures, especially panel mounting.

MIcable Inc.
www.micable.cn

Vertical Launch 0.8 mm Connectors

WithWave's Vertical Launch 0.8 mm connectors are specially designed for solderless vertical PCB launch on test and measurement board. These connectors have excellent electrical transition performance up to 145 GHz, respectively, as well as reduce installation time by eliminating soldering. Features include a frequency range of DC to 145 GHz, excellent vertical transition (VSWR < 2.0 at 145 GHz) and easy and solderless installation.

withwave co., ltd
www.with-wave.com

AMPLIFIERS

C-UAS Module

VENDORVIEW

Empower RF Systems' 11212 module for fielded C-UAS applications is now available.

This solid-state power amplifier operates from 2000 to 6000 MHz with 50 W minimum output and showcases Empower RF's expertise in designing compact and reliable high-power amplifiers for EW systems. The 1212 is part of Empower's smart module family, offering digital controls and reporting, simplifying integration for cutting-edge C-UAS solutions. Its compact design, utilizing GaN on SiC technology, ensures high reliability and performance in demanding electromagnetic response scenarios.

Empower RF
www.empowerrf.com

Low Noise Amplifier

VENDORVIEW

With a noise figure of 8.5 dB and WR-03 waveguide input and output ports, model SBL-2242741585-0303-E1 is a low noise amplifier that boosts signals from 220 to 270 GHz with 15 dB gain. The supply voltage is +8 VDC at 50 mA. Applications include passive imaging systems, radar sensors and advanced instrumentation.

Eravant
www.eravant.com

Exodus AMP20078, 1.0–6.0 GHz, 150 W, 100 W P1

VENDORVIEW

Exodus AMP20078, ideal for broadband EMI-Lab, communication and EW applications. Class A/AB linear design for all modulations and industry standards. It covers 1.0 to 6.0 GHz, producing 150 W minimum, 100 W P1dB and 52 dB minimum gain. Excellent flatness, optional monitoring parameters for forward/reflected power, VSWR, voltage, current and temperature sensing for superb reliability and ruggedness. Integrated in a compact 3U chassis weighing ≈25 kg.

Exodus
www.exoduscomm.com

NewProducts

GaN Transistors

Infineon Technologies AG announced the first of a new family of radiation-hardened GaN transistors, fabricated at Infineon's own foundry, based on its proven CoolGan™ technology. Designed to operate in harsh space environments, the company's new product is the first in-house manufactured GaN transistor to earn the highest quality certification of reliability assigned by the U.S. Defense Logistics Agency to the Joint Army Navy Space Specification MIL-PRF-19500/794.

Infineon Technologies AG
www.infineon.com

700 W GaN HEMT for S-Band Pulsed Radar Systems

VENDORVIEW

Engineered for high performance S-Band radar systems, the Ampleon CLS3H2731L-700 delivers 700 W of pulsed output power across 2.7 to 3.1 GHz. This GaN on SiC HEMT transistor supports long-pulse operation up to 300 µs at 10 percent duty cycle, making it ideal for air traffic control, weather and defense radar. With internal pre-matching, high input impedance and excellent thermal stability, it streamlines amplifier design while offering outstanding ruggedness and efficiency in demanding RF environments. Available at RFMW.

RFMW
www.rfmw.com

SOURCES

Single-Loop Frequency Synthesizer

Luff Research, an Ironwave Technologies company, introduces the SLSM8-1217 — an advanced single-loop frequency synthesizer designed for precision RF and microwave systems. Offering frequency coverage from 1 to 20 GHz and multiplied output to 40 GHz, the SLSM8-1217 delivers improved phase noise and spurious performance in a compact 2.50 × 2.50 × 0.65 in. package. Operating on a single 5 V input, this unit combines high performance, efficiency and value.

Luff Research
www.ironwavetech.com/luff-research

Arbitrary Waveform Generators

VENDORVIEW

Spectrum Instrumentation announced four new high performance arbitrary waveform generators (AWGs), marking a significant milestone in the company's product portfolio. Designed for demanding applications in RF and microwave signal generation, the new AWGs deliver output rates up to 10 GSPS with exceptional 16-bit vertical resolution and bandwidths reaching up to 3.9 GHz. The new products are aimed at engineers and scientists working in cutting-edge fields such as wireless communications, radar system development, quantum research and aerospace testing.

Spectrum Instrumentation
www.spectrum-instrumentation.com

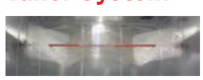
TEST & MEASUREMENT

Simultaneous Sweep Capability

Anritsu announced the launch of a new Simultaneous Sweep capability for its ShockLine™ MS46131A Vector Network Analyzer (VNA) — the world's first 1-port VNA supporting frequencies up to 43.5 GHz. This advanced capability enables simultaneous 1-port S-parameter measurements across up to four MS46131A units. Each unit can be independently configured with custom test settings — such as start and stop frequencies, IF bandwidth and number of points — while all units perform sweeps in parallel. The result is significantly reduced test time and enhanced flexibility for a wide range of measurement scenarios. The Simultaneous Sweep feature allows coordinated sweep triggering through an external signal, synchronizing the start of sweeps across multiple VNAs.

Anritsu
www.anritsu.com

Ultra-High Speed Reverberation Tuner System



ETS-Lindgren's new Model 5903-HST is an ultra-high speed Reverberation Tuner System (20 to 100 RPM) designed for uniform electromagnetic testing. When used with EMCenter™ EM8 and EMSense™ Platinum Probes, it supports ISO 11451-5, Annex G compliance testing with high speed, multi-axis data collection from up to eight probes — accelerating test cycles and reducing time to market for advanced automotive electronics. Other models of reverberation tuners available for varied EMC testing needs. For more details, contact your ETS-Lindgren representative.

ETS-Lindgren
www.ets-lindgren.com

Dual-Band Signal Generator for X-Band Test Applications

VENDORVIEW

Mini-Circuits' SSG-8N12GD-RC dual-band synthesized signal generator provides two independently controlled outputs from 8 to 12.5 GHz over a dynamic range from -55 dBm to +23 dBm in coherent and non-coherent modes with 360 degrees phase control. Controlled via USB, Ethernet and PoE, it offers CW, pulsed, AM, FM and chirp modulation, sweep and hop sequences and daisy-chain connection of multiple modules.

Mini-Circuits
www.minicircuits.com

Review by Brian Rautio

Bookend

Cognitive Electronic Warfare: An Artificial Intelligence Approach

Karen Zita Haigh & Julia Andrusenko

In sports car racing, there's excitement, speed and adrenaline as you see on TV, but there's another interesting side to the sport you don't know: logistics. Races happen worldwide, and teams need to arrive entirely self-sufficient with a tremendous amount of equipment. Trucks and trailers carry not just cars, parts and fuel, but also tents, tools, clipboards…there are even snacks and umbrellas. Everything needed for the event packs up tight and moves around the world with relative ease.

Cognitive Electronic Warfare: An Artificial Intelligence Approach by Haigh and Andrusenko had many parallels to this concept. I was not reading a book; I was unpacking an operation. The race car is there, as the core material on cognitive warfare is abundant, but the umbrella is there too. The authors cover everything at a high level, moving fluidly between topics like data management, software architecture and computer hardware.

Incredibly, neither depth nor breadth feel sacrificed in this pursuit. The chapter introducing AI programming was more informative and accurate than some entire books on the topic. There are two main drivers for this success. First, the book is algorithm-centric. The underlying concepts are taught at a high level to be understood, as opposed to the specific ins and outs to be memorized. There are also more figures and charts than equations; if desired, users can write code and derive equations on their own time. Second, parallels are often leveraged — electronic attack and protection, for example, are traditionally separate topics, but they are successfully discussed as two ends of the same spectrum.

However, just like the race trailer, unpacking everything will take some effort. I found myself re-reading pages and analyzing figures. The time was well spent, but don't judge the moderate thickness and expect to finish this book in one sitting. It is best read with patience and the understanding that things will eventually just "click." Overall, *Cognitive Electronic Warfare: An Artificial Intelligence Approach* is a clear and concise book, and something I would recommend as a primer or a desk reference for anyone looking to grow their skills in either electronic warfare or AI. And the best part? Unlike unloading a race trailer on a hot summer day, you can read it in an air-conditioned office.

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FABS and LABS

Werbel Microwave: Excellence in Every Product

Ernest Werbel founded Werbel Microwave in 2014. From its origins as a garage start-up in New Jersey, Werbel Microwave has made significant progress in the last 10+ years to become a reliable source for domestically manufactured microwave components. Ernest Werbel remains at the helm as chief engineer and president and continues to define and expand Werbel's COTS and custom products. Werbel Microwave's small size permits close design collaboration and customer service from ideation to production, a point of pride for the company.

Werbel Microwave offers a variety of passive and active microwave products for defense, commercial and test applications, including directional couplers, power splitters, hybrids, bias tees, monopulse comparators and more. Werbel Microwave is ISO 9001:2015 certified and manufactures components using a mix of hand assembly and automation techniques.

The fundamental component of each Werbel Microwave product is hidden within the robust coaxial packaging. Printed circuit boards (PCBs), the essential components for proper RF matching, have extremely tight tolerances that get smaller as frequencies increase. Additionally, tuning and matching often necessitate the precise placement of external resistive chips, creating a consistency concern across different microassemblers and tools. To solve these challenges, Werbel Microwave invested in laser etching instruments, pick and place machines and reflow ovens. Laser etching is more precise than chemical etching, creating straighter lines to enhance RF performance. This is crucial with filter and coupler networks, as the industry increases operating frequencies. The pick and place machines ensure external chips are placed with tight tolerancing, and the reflow ovens create an even bond without damaging the PCB base material. With this equipment, Werbel Microwave achieves consistency and processes hundreds of PCBs per day.

In tandem with PCB design and construction, Werbel Microwave designs and manufactures the housing needed for the final connectorized product. Werbel uses 3D simulation to determine PCB board and housing dimensions, as well as 3D printing for mechanical prototyping. Finally, connectors are attached using precise, computerized screwdrivers for a tight connection.

In addition to processing in-house products, Werbel Microwave offers manufacturing as a service for externally designed boards or finished products. Werbel Microwave maintains a stock of common RF materials to produce prototypes for quick customer testing. This further demonstrates Werbel Microwave's dedication to being more than just a supplier, but a trusted partner.

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Automated Bioinspired Design of a Pixelated Metasurface via MATLAB–CST Integration for Diverse Applications – The Use of Particle Swarm Optimization

Yugesh Chandrakapure, Anand Kumar, Alok Chandra Joshi and Debdeep Sarkar
Indian Institute of Science, Bengaluru, India

Akhlesh Lakhtakia
Pennsylvania State University, University Park, Pa., USA

An approach for the automated design of pixelated metasurfaces for applications such as bandpass filtering and polarization conversion (linear-to-linear/circular/elliptical) is formulated. Leveraging bioinspired Particle Swarm Optimization (PSO) within a MATLAB–CST co-simulation environment, the approach efficiently optimizes pixel configurations for the meta-atom of a metasurface. The user-friendly MATLAB interface allows the specification of design parameters, including pixel grid size, constitutive parameters and mean-square-error (MSE) thresholds. The framework iteratively performs CST simulations guided by PSO, enabling high performance designs. Experiments on prototypes operating at 28 GHz confirm the ability to achieve specific electromagnetic response characteristics while providing flexibility for application-specific refinements.

Metasurfaces are two-dimensional structures that enable unprecedented control over electromagnetic waves. Comprising sub-wavelength elements known as meta-atoms arranged in a bi-periodic pattern, a metasurface can manipulate the amplitude, phase and polarization state of plane waves in a specific spectral regime with high precision. These capabilities have led to diverse applications, including efficient absorbers for stealth technology and shielding against electromagnetic interference,[1,2] frequency-selective filters to isolate a desired spectral regime for communication systems and sensing systems[3] and polarization controllers for polarization-sensitive communication and imaging systems.[4]

The design of a metasurface requires numerous iterations of numerical simulations to meet desired performance criteria. Pixelated metasurfaces offer a streamlined approach by discretizing the meta-atom into a square or rectangular grid of pixels.[5] This pixelation simplifies the design process while permitting control over the metasurface's plane-wave response characteristics.[6-10] However, determining the optimal pixel configuration within this grid remains computationally intensive, demanding sophisticated optimization techniques.

PSO provides an effective solution. Inspired by the collective behavior of flocks of birds and schools of fish, PSO explores vast

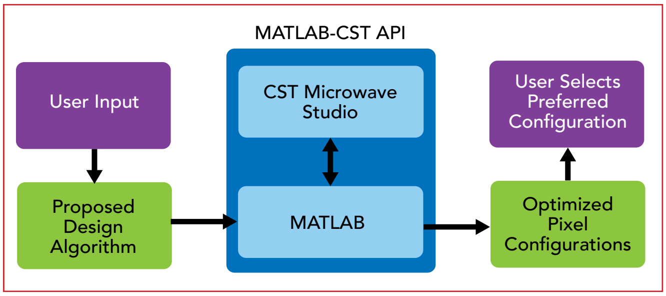


Fig. 1 Block diagram of the MATLAB-CST co-simulation design environment.

search spaces by iteratively refining solutions based on individual and swarm experiences.[11-16] The algorithm balances exploration and exploitation,[17,18] making it particularly suitable for solving complex problems such as metasurface design.

This article describes an automated approach for designing pixelated metasurfaces using PSO within a MATLAB–CST co-simulation environment. It efficiently optimizes pixel configurations, enabling various functionalities such as polarization conversion and energy transmission. Experimental validation on a metasurface prototype operating at 28 GHz demonstrates its accuracy and flexibility, offering a scalable solution for advancing metasurface design.

ALGORITHM FOR PIXELATED METASURFACE DESIGN

The approach integrates MATLAB with the CST Microwave Studio Suite through the MATLAB–CST Application Programming Interface (API),[19] enabling automated creation and control of meta-atom pixelation and extraction of S-parameters from numerical simulations. This seamless integration facilitates the efficient development of pixelated metasurfaces with tailored functionalities as seen in ***Figure 1***.

The design algorithm provides flexibility that allows users to select from multiple metasurface functionalities, such as:

- Reflective or transmissive linear-to-linear polarization state conversion (e.g., horizontal-to-vertical or vertical-to-horizontal) with a specified polarization conversion ratio (PCR)
- Bandpass filtering with linear-to-linear polarization state conversion and a desired transmission efficiency (TE)
- Linear-to-circular polarization state conversion, achieving an ellipticity of ±1
- Linear-to-elliptical polarization state conversion with a specified ellipticity.

The meta-atom design begins by arranging pixels in a bi-periodic grid on a substrate to achieve the desired functionality. The user specifies various input parameters, including pixel count (nPix), meta-atom size, substrate thickness, substrate dielectric constant (ε_r) and MSE threshold (MSE_t).

In the remainder of this article, a pixel is either patched entirely by a perfect electrical conductor (PEC) or is unpatched. The dielectric substrate could be backed by a thick PEC sheet to suppress transmission for reflective and absorptive metasurfaces.

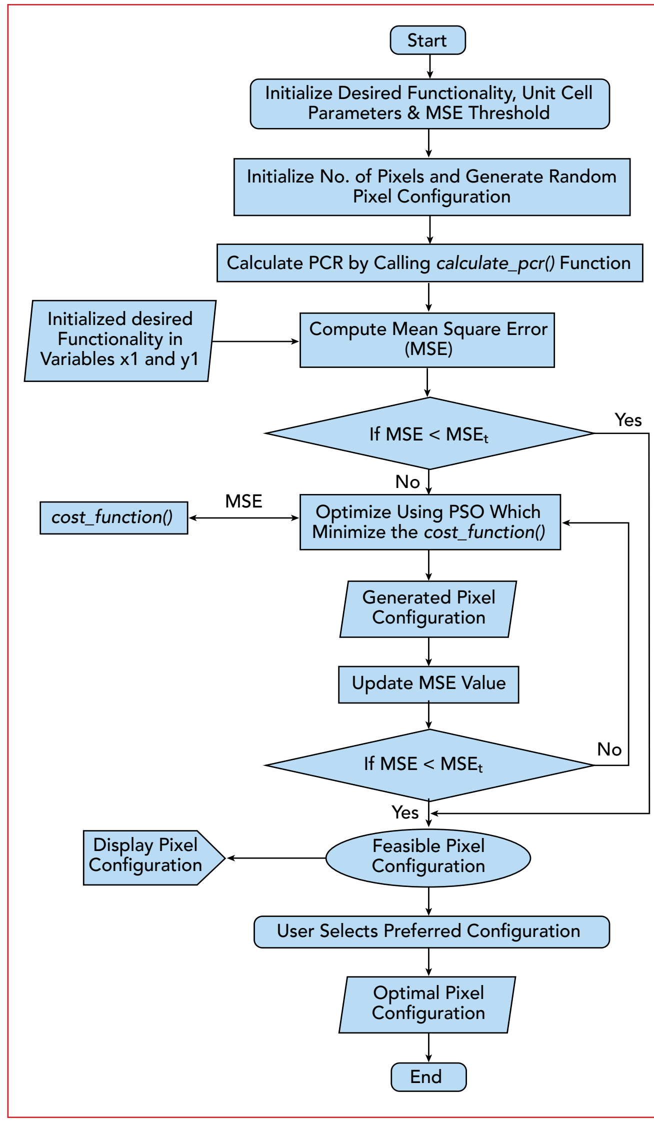


Fig. 2 Design algorithm flowchart.

STEP-BY-STEP EXECUTION

Initialization

The design algorithm starts by initializing a binary nPix × nPix matrix with random values of 1 (indicating the presence of a PEC patch) or 0 (indicating the absence of a PEC patch). Containing a maximum of $nPix^2$ PEC patches, the resulting matrix delineates the initial configuration for the meta-atom.

The meta-atom is then designed with this configuration, and the plane-wave response characteristics of the metasurface are then simulated using CST to yield four S-parameters: the co- and cross-polarized reflection coefficients, S_{11xx} and S_{11xy}, and the co- and cross-polarized transmission coefficients S_{21xx} and S_{21xy}.

Performance Parameter Calculation

With the known S-parameters, a pre-defined function, *calculate_pcr()*, computes the relevant performance parameter: PCR, TE or ellipticity, depending on the specified functionality. The target response is defined by variables x1 and y1, where x1 represents

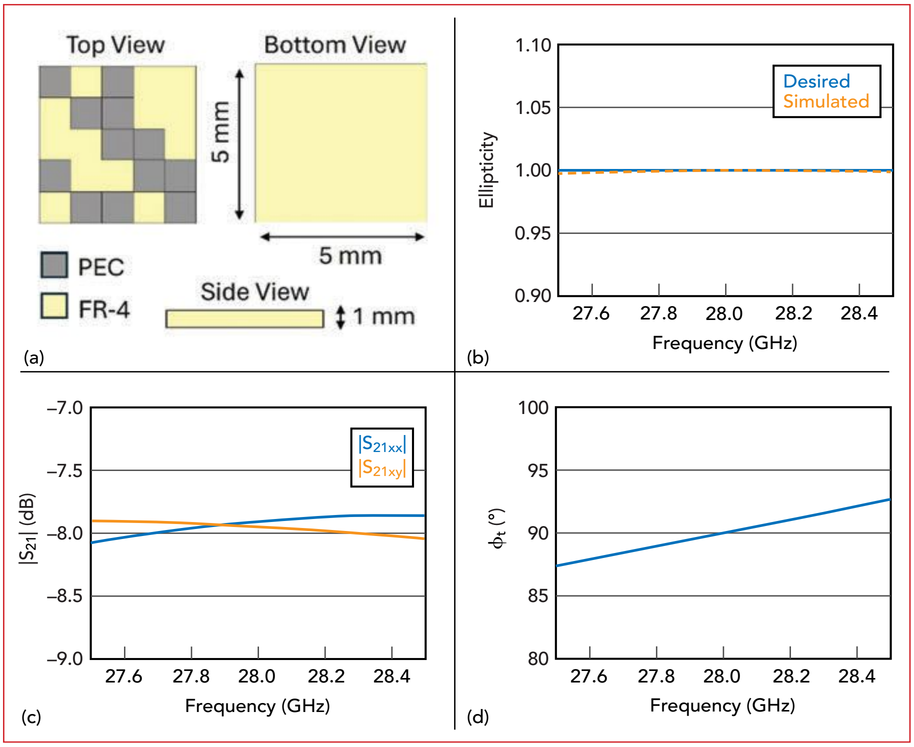


Fig. 3 **Optimal pixelated meta-atom for LP-to-RHCP conversion at f_0 = 28 GHz: (a) pixel configuration and meta-atom design, (b) desired and simulated ellipticity of the transmitted plane wave, (c) simulated $|S_{21xx}|$ and $|S_{21xy}|$ (d) and simulated ϕ_t.**

the working frequency range and y1 represents either a Gaussian response for PCR/TE or a constant value for ellipticity.

To optimize the PCR of a reflected plane wave, the *calculate_pcr()* function computes PCR(R) using ***Equation 1***. For a transmitted plane wave, PCR(T) is calculated similarly in ***Equation 2***.

$$PCR(R) = \frac{|S_{11xy}|^2}{|S_{11xx}|^2 + |S_{11xy}|^2} \quad (1)$$

$$PCR(T) = \frac{|S_{21xy}|^2}{|S_{21xx}|^2 + |S_{21xy}|^2} \quad (2)$$

To optimize TE, the algorithm uses the function defined in ***Equation 3***. Of course, S_{21xx} = 0 and S_{21xy} = 0 if the dielectric substrate is backed by a PEC sheet.

$$TE = \frac{|S_{21xx}|^2}{|S_{21xx}|^2 + |S_{11xx}|^2} \quad (3)$$

For linear-to-circular polarization conversion, the ellipticity V_t/I_t of the transmitted plane wave is determined, where $V_t = 2|S_{21xx}||S_{21xy}|\sin(\phi_t)$, $I_t = |S_{21xx}\mathrm{vert}|^2 + |S_{21xy}|^2$ and $\phi_t = \angle S_{21xx} - \angle S_{21xy}$. An ellipticity of -1 represents a right-hand circularly polarized (RHCP) plane wave and an ellipticity of +1 corresponds to a left-hand circularly polarized (LHCP) plane wave.

Error Computation and Optimization Using PSO

The MSE quantifies the deviation between the simulated response and the desired response. If the computed MSE exceeds MSE_t, the PSO algorithm is employed. This algorithm minimizes a tailored cost function *cost_function()* by iteratively adjusting the pixel configuration.

The PSO algorithm optimizes the pixel configuration by generating fractional values between 0 and 1 that are rounded to the nearest integer to form a binary row of size $1 \times nPix^2$. This vector is then reshaped into a binary nPix×nPix matrix. The iterative procedure continues until the computed MSE falls below MSE_t.

Output

Once the optimization process concludes, all meta-atom configurations meeting the threshold ($MSE < MSE_t$) are presented to the user. The output includes the pixel configurations and additional performance metrics such as the number of PEC patches, co- and cross-polarized insertion loss (IL) and co- and cross-polarized return loss (RL). The iterative procedure ensures the efficient design of the pixelated meta-atom for a desired functionality. The design algorithm is robust for developing non-intuitive metasurfaces for microwave and antenna engineering applications. A flowchart of the algorithm is provided in ***Figure 2***.

RESULTS AND DISCUSSION

This approach is versatile and capable of designing pixelated metasurfaces for a range of applications, including polarization conversion (e.g., VP/HP-to-HP/VP, LP-to-CP (LHCP/RHCP), CP-to-LP (VP/HP), and LP-to-EP (LHEP/RHEP) with specified ellipticity).

To demonstrate its effectiveness, the design of a transmissive metasurface for LP-to-RHCP is used as an example. The substrate is unbacked FR-4 with PEC patches. The meta-atom dimensions are approximately $\lambda_0/2 \times \lambda_0/2$ (5 × 5 mm, with λ_0 = 10.7 mm at f_0 = 28 GHz). This area is divided into a 5×5 grid (nPix = 5), yielding 25 pixel positions and thus 25 optimization variables.

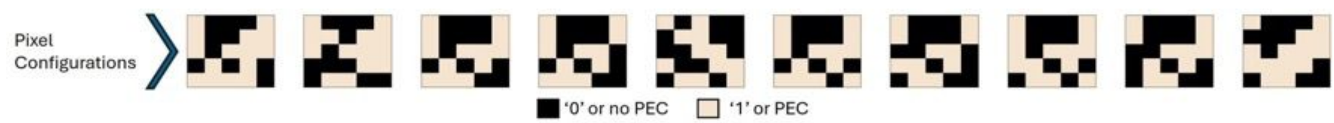
After the optimization process, the design algorithm presents configurations that meet the constraint $MSE < MSE_t$, enabling the user to select the most appropriate design. Each configuration's details, including the number of metallic patches, co- and cross-polarized IL and co- and cross-polarized RL, are displayed for user evaluation. A summary of possible pixel configurations presented to the user is shown in ***Table 1*** for all ten 25-pixel configurations that meet the threshold ($MSE < MSE_t$).

Multiple pixel configurations can result in similar values of MSE below MSE_t, demonstrating the flexibility and robustness of this approach in achieving the desired plane-wave response.[6-10] This flexibility allows further refinement based on application-specific requirements. The selected pixel configuration (Configuration 5 in Table 1) is shown in ***Figure 3*** along with the calculated ellipticity of the transmitted plane

TABLE 1

PIXEL CONFIGURATIONS AND SIMULATED PERFORMANCE METRICS

	Config. 1	Config. 2	Config. 3	Config. 4	Config. 5	Config. 6	Config. 7	Config. 8	Config. 9	Config. 10
No. of Pixels	15	14	13	12	12	14	11	14	11	14
Co-Pol IL (dB)	7.57	9.11	7.42	6.82	7.87	6.83	6.73	6.46	7.27	7.37
Cross-Pol IL (dB)	7.64	9.30	7.39	7.52	7.92	7.22	7.39	7.28	7.24	7.58
Co-Pol RL (dB)	2.91	1.74	3.00	3.15	2.90	3.29	3.18	3.43	3.06	3.04
Cross-Pol RL (dB)	10.82	12.48	10.57	10.70	9.69	10.39	10.56	10.45	10.42	10.76
MSE (x10^5)	8.60	1.64	1.15	3.27	0.03	1.57	4.56	7.94	3.81	1.20



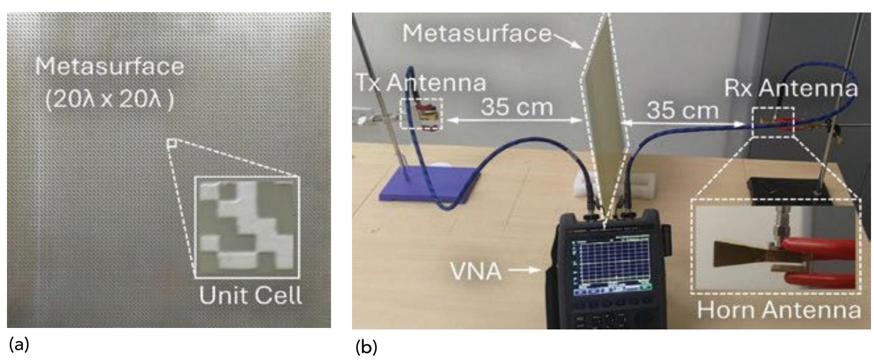


Fig. 4 **Experimental validation of the transmissive LP-to-RHCP converter metasurface: (a) fabricated prototype based on the meta-atom design in Figure 3a and (b) measurement setup.**

wave, $|S_{21xx}|$, $|S_{21xy}|$ and ϕ_t.

To validate the design methodology, a prototype metasurface is fabricated based on the pixel configuration in Figure 3. The metasurface, measuring $20\lambda_0 \times 20\lambda_0$ (20 × 20 cm), contains 6400 (80 × 80) meta-atoms (see ***Figure 4a***).

For measurements of S_{21xx} and S_{21xy}, a transmitting horn antenna (THA) and a receiving horn antenna (RHA) are positioned on opposite sides of the fabricated metasurface (see ***Figure 4b***). The THA is connected to Port 1 and the RHA to Port 2 of a vector network analyzer. Both antennas are 35 cm from the metasurface.

Figure 5 shows the measured $|S_{21xx}|$ and $|S_{21xy}|$ for the LP-to-RHCP converter of Figure 3 after incorporating path-loss compensation. This compares favorably with simulation (see Figure 3c), thereby validating the accuracy of the automated bio-inspired design approach.

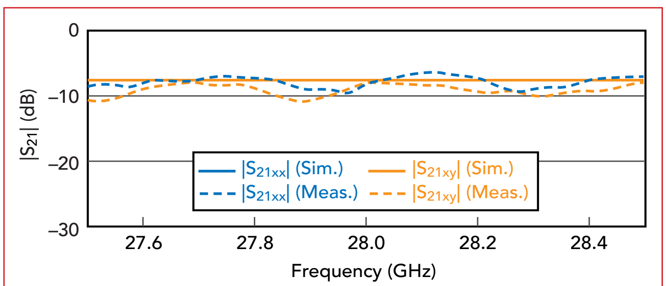


Fig. 5 **Measured $|S_{21xx}|$ and $|S_{21xy}|$ compared with simulation.**

The MSE between the simulated ellipticity and the measured ellipticity (transmissive) is 3.126 × 10^{-7} over the 1 GHz range. At 28 GHz, the transmissive ellipticity is 1.000, with ϕ_t = +89.9526 degrees, $|S_{21xx}|$ = -7.87 dB, and $|S_{21xy}|$ = -7.91 dB. However, the data also indicates that further experimental exploration is needed to fine-tune the convergence with respect to the number of pixels, highlighting an area for future improvement.

CONCLUSION

A bioinspired approach for the automated design of pixelated metasurfaces uses PSO within a MATLAB–CST co-simulation environment to iteratively optimize the pixel configuration of the meta-atom for chosen functionality and performance requirements while offering flexibility in design evaluation based on metrics like IL and material-utilization efficiency.

Experimental investigation of a transmissive LP-to-RHCP converter design at 28 GHz demonstrates a strong correlation between simulation and the measurement, underscoring the reliability of the proposed approach. The ability to generate multiple viable configurations highlights the robustness of this approach for application-specific refinements. Although each pixel can be either unpatched or PEC-patched in the example, the approach can incorporate patches made of several different materials[2,3] for multifunctional and multi-controllable metasurfaces.[5] ■

ACKNOWLEDGMENT

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