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U.S. Export Control Reform: Getting It Right This Time

OVERHAUL OF U.S. EXPORT CONTROL

The Obama Administration has launched a very comprehensive and well thought-out game plan to modernize the complex and often confusing United States Export Control System's set of Rules and Regulations. The administration's plan for Export Control Reform (ECR) — to make the system work for us as part of our national security strategy, not against us – is indeed a visionary approach for those of us who have been involved in this bureaucratic nightmare for many years. The administration's effort is to create an export control system that is responsive to the national security, technology and commercial imperatives of the 21st century. The goal is also to be better able to monitor and enforce controls on technology transfers with real security implications while helping to speed the provision of equipment to allies and partners who fight alongside us in coalition operations.

THE GAME HAS CHANGED

The Cold War is over and so are most of the assumptions that led us to this point in the evolution of Export Control Laws and Regulations. We now have to look at Export Controls in the context of a new reality and recast them to support how we globally engage our enemies and our friends. Today, we fight in "cyberspace domains at the speed of light." And our Export Control Systems must be brought up to new standards and be re-evaluated in that context. It should reflect how we deal with our closest allies internationally, both as close friends and as military coalition partners. We must protect the critical technology in the U.S. in the proper fashion from all the "bad guys." But our Export Control laws must reflect the world we live in today. The context for this discussion is clear – our laws need to keep pace with advancing technology in a globally connected world economy. U.S. military supremacy depends on our warfighters having a clear technological advantage. Technology is the critical factor that determines support for our national military strategy, and most importantly, is the key underpinning used to protect and support our warfighters on the battlefield.

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THE ADMINISTRATION'S EXPORT CONTROL REFORM (ECR)

Let's explore some of the critical issues surrounding Export Control Reform, focus on some of the real problems companies face every day and take a closer look at what's being proposed to fix Export Control by our government leaders. What are President Obama, the Administration, Secretary of Defense Gates and others doing to attack this problem? The good news is that they have been at this task for more than a year. The better news is I think they are making significant progress and are on the right track. The not so good news is the toughest part of the work still lies ahead. This whole discussion is really all about one thing – "a big reset" that is coming – on how we will come together and implement Export Control Reform. And this issue is very serious for all of us in the microwave industry, and we need to understand what is happening. Make no mistake about it, dismissing this issue as "not your problem and somebody else's to worry about" is not good. This is a critical business issue that has direct implications on our business plans.

THE PLAYERS, PLAYGROUNDS AND PROBLEMS

Responsibility for U.S. Technology Export Controls are scattered across four major agencies and several lesser ones. The Department of Commerce's Bureau of Industry and Security (BIS) is responsible for implementing and enforcing Export Administration regulations, which pertain to the export and re-export of "dual use" commercial items. There are also several lists associated with this effort. The U.S. Munitions List (USML) and the Commerce Control/Critical Commodities List (CCL) are the most prominent ones. The Department of State is technically responsible for approving military sales. It enforces the ITAR sales, which are governed by the Arms Export Control Act (22 U.S.C. 2778). Items governed by ITAR relate to the USML. These two agencies (and how these two lists are used) are the main players involved with regulating American technology and military exports. And the DoD, along with Department of Homeland Security (DHS), the U.S. Treasury and other departments, are involved in most of

The U.S. Takes Violations Seriously – BAE Systems and ITT

Recently the U.K.-based military contractor BAE Systems PLC recently agreed to pay $79 M, the largest fine in the history of the U.S. Department of State, to settle civil allegations of export control violations, a year after the company pled guilty in related criminal cases. This was reported in the press and covered in several news releases from the company. According to the U.S. State Department, BAE, the largest military contractor in Europe, committed more than 2591 violations of the Arms Export Control Act and the International Traffic in Arms Regulations (ITAR), including unauthorized brokering of U.S. defense articles and failure to maintain proper records. It ends a long-running corruption investigation into the company, Europe's biggest arms maker by sales, on both sides of the Atlantic. The department cleared BAE's fast-growing U.S. unit and its subsidiaries of all charges against the parent company, based in Farnborough, outside London. But it said a lack of full cooperation from the parent had left it "unable to assess fully the potential harm to U.S. national security" from the unauthorized resale of U.S. weapons and technology know-how to more than a dozen countries.

The U.S. subsidiary, BAE Systems Inc., accounts for about 52 percent of the company's worldwide sales and is among the Pentagon's top 10 suppliers. It operates a separate export compliance program under a special security pact that governs its dealings inside and outside the U.S. BAE also failed to cooperate fully for the 14 months since the criminal pleadings set the stage for the parallel civil investigation, the department said. It followed the global settlement announced in February 2010 of criminal cases brought by the U.S. Department of Justice and Britain's Serious Fraud Office. Under its agreement last year with the Justice Department, the company pleaded guilty to one charge of conspiring to make false statements to the U.S. government and paid a fine of $400 M.

In London, BAE pleaded guilty to one charge of failing to keep records of payments made to a marketing advisor in Tanzania and paid about $50 M. The cases grew from criminal investigations into arms deals in Saudi Arabia, Tanzania, Sweden, the Czech Republic and Hungary. The State Department said it is releasing an administrative hold it imposed, after the criminal conviction, on license applications by the parent company to export U.S.-origin arms and services. But it declared a policy of presumptive denial on three BAE subsidiaries "because of their substantial involvement in activities related to the conviction." The units' export license requests would be approved only if they were determined to be in the U.S. national interest.

ITT Corp. several years ago revealed in a news release that it had agreed to a final settlement relating to an investigation that began in 2001 regarding ITT Night Vision's compliance with ITAR. As part of the agreement, the company paid a $50 M fine and pleaded guilty to one ITAR violation relating to the improper handling of sensitive documents, and one ITAR violation of making misleading statements. The government has agreed to defer action regarding a third count of ITAR violations pending ITT's implementation of remedial actions. ITT agreed to cooperate with the government to continue to invest in research and development and capital improvements for its Night Vision products so it can continue to provide the most advanced night vision technology to the U.S. military and its allies.

The value of these investments is $50 M over the next five years. In addition, the company has been engaged in a comprehensive review of its policies, practices, training programs and procedures, including complete audits of all business units. New monitoring approaches, communications and training initiatives have already begun as a result of this review and more are expected. ITT's CEO said at the time, "We have been cooperating with the government in this investigation and we have voluntarily disclosed all discrepancies that our internal reviews revealed." And, he said, "while this settlement relates to the actions of a few individuals in one of our 15 business units, we regret very much that these serious violations occurred." He added, "Our renewed commitment to a culture of integrity and compliance applies to the entire company. ITT has a long track record as a trusted employer, supplier and partner, and we are firmly committed to ensuring that this will not happen again. These violations have made it clear that we had gaps in our compliance programs. The steps we are taking now will address these issues in a comprehensive way." The company has already begun implementing stricter new measures such as: Insuring that all personnel understand and follow applicable regulations governing the export of critical technology, naming a new compliance officer, instituting a required ethics and compliance training program for all employees worldwide, developing a comprehensive computer tracking program to monitor all packages sent from ITT facilities and working with independent experts to refine and enhance the effectiveness of these measures. In a related action, the Department of State has placed restrictions on certain exports of night vision equipment and technical data and ITT Night Vision will not be allowed to ship devices to specific parties for a period of not less than one year.

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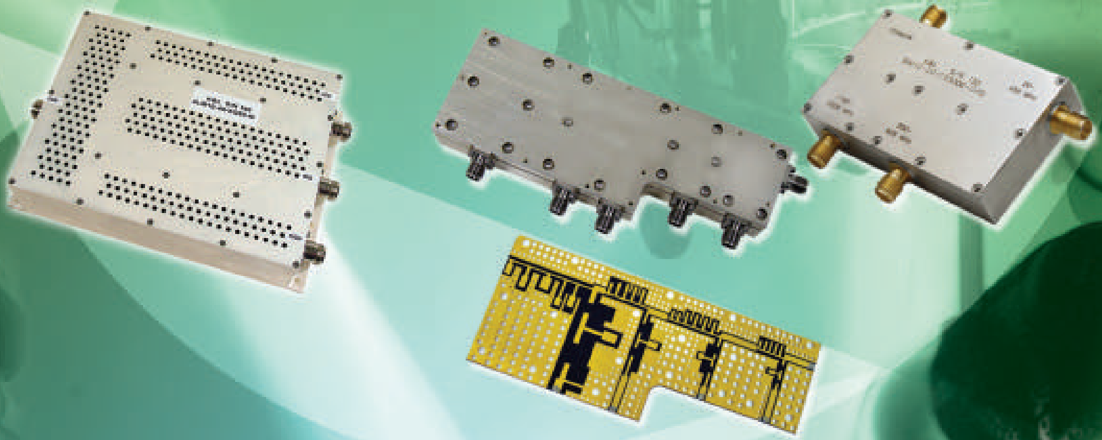

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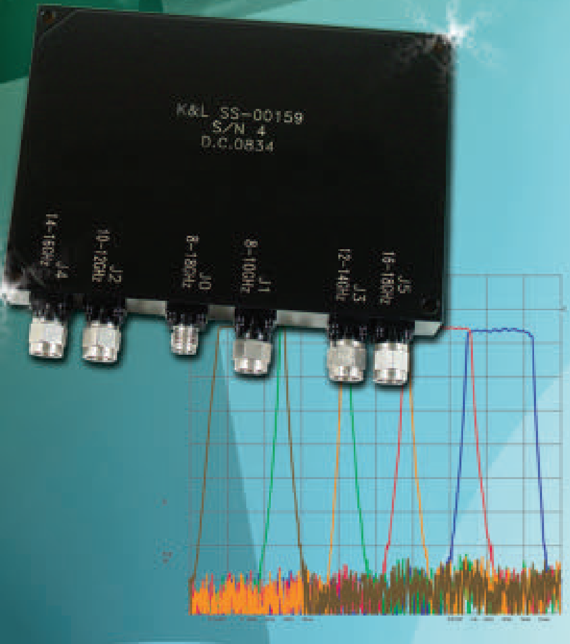

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these activities. As you see and may surmise, there are "way too many cooks" in this Export Control kitchen.

HOW THE SYSTEM IS SUPPOSED TO WORK AND DOES

The idea behind the existing organizational approach to Export Controls was that various agencies with their different agendas and perspectives would create a system of "checks and balances" that would be more difficult to defeat by those trying to game the system. However, it has not worked out that way, and the associated costs of all these redundant activities are very high and are becoming administratively prohibitive. There were several obvious problems with these arrangements and some that are not so obvious. The most obvious one involves overlapping jurisdictions. It is not always clear for example where a specific item falls on one of these "lists" or to which agencies that should possibly be involved in an Export License application.

For example, a company that wants to act ethically may not be clear about where to submit its export license application, or may end up going to one agency to be subsequently told they must now go to a different agency. Yet, no agency has the legal authority (nor will they formally or informally) to actually interpret the Export Control laws and regulations. You are responsible for any action taken, and are criminally liable if you proceed in an illegal fashion. You can see the "Catch 22" situation.

It has been reported that some export license applications can be approved by one agency and denied by another. The flip side is that savvy companies can "shop their applications" by picking the regulator they believe is most likely to say yes. The problem of multiple forms to multiple agencies is made worse by long processing times. These departments have limited funds from which to support staff to review applications, and the State Department is reportedly still mostly paper based. Commerce is only slightly ahead with an IT system that needs to be updated. The net effect for industry is potentially long processing times – four to six months is not unusual for an application. In that time frame it is very possible for the American company to find that the foreign bid competition that it was trying to enter is now closed and the order placed with a competitor.

HAVING A SYSTEM EXPORT LICENSE DOES NOT EQUAL HAVING A LICENSE FOR THE SUM OF ITS PARTS

The next difficulty builds on the others, and is a vexing problem for the microwave industry. The U.S. Export Control system makes more work for itself by requiring approval at the level of individual components. Think about how many parts are in a Fighter with all its avionics and associated equipment. In addition, it has Radar Guided Missiles, Electronic Warfare Suites, and RF Communication Systems, among many other systems. It is absurd to control things at that low a component level.

For example, a foreign country was approved to buy an F-16 Fighter Aircraft from Lockheed Martin without having any apparent difficulty in obtaining the license through appropriately filling out all the required export paperwork. Now, according to U.S. Export Control Policy, that does not mean that suppliers to that weapons platform or system are approved to export anything that they supply to it. In addition, suppliers are not authorized under US Export Control Laws to respond even when asked to bid parts to that foreign country to help maintain that F-16 Fighter Aircraft. And as a supplier, one must apply for a Marketing License before they can even talk with a foreign company representative or they are in violation of the law. For the microwave industry, it is a non-starter to do any business with a foreign F-16 operator that may ask them to bid for a spare radar power amplifier or that EW beamforming network. Or for that matter, even any questions on an RF power transistor requires approval. It is controlled at that level, right down to the performance characteristics of the transistor. We are now letting government regulators into controlling access via the S-parameter data. And, it gets worse. Suppliers are not allowed to transfer parts to another U.S. ally whose F-16s are operating from the same base to support an American-led operation. This makes the problem more complex. Bottom line – component suppliers are not covered by the platform's OEM export license.

PROTECTIONISM AND POLITICS

Export control regulations are even affecting weapons development programs around the world, which is of great concern to many American defense firms. The ITAR processes make it difficult for firms like Raytheon, Northrop Grumman, General Dynamics, Boeing and many others to share information around the world with their own international subsidiaries. This inhibits the inclusion of American technology into bids for foreign contracts in foreign countries or to even explore collaboration with foreign firms in allied nations. And, they cannot talk to their own company employees outside the U.S. without first getting a Marketing or Technical License for the U.S. government to approve the contact. This can shut American firms out of foreign weapons programs at the earliest stages, which is not good. What is even more troubling is that many people outside the U.S. have a perception that the U.S. export policy and regulations are a very high "self-imposed hurdle" to overcome, fueling speculation on motives about the

U.S. government hiding behind "the rules," and acting very protectionist and partisan in defense of U.S. technology and product dealings. In some instances, foreign governments and countries have accused the U.S. of trying to stop foreign business competitors, and this activity has actually encouraged these negative perceptions. The current system encourages multinational companies to move research, development and production offshore, "eroding our defense industrial base" as well as "undermining our control regimes."

THE EXPORT CONTROL/ITAR CONUNDRUM ON THE INDIAN FIGHTER COMPETITION

It was no surprise to some of us that all U.S. Fighter entries in the ongoing Indian Fighter competition were down-selected out of the Tender to supply advanced fighter aircraft to India. It had been reported in the press that the love affair with the Indian Air Force and the Russian Fighter community was becoming a strained relationship at best. And the Indians were requiring that industry in their country participate fully as partners in all technology and hardware manufacture. This implied direct manufacture of critical electronic subsystems, including Advanced Electronic Warfare Self-Protection suites, Electronically Scanned Active Arrays (including all transmit receive modules) and covert RF communications systems. It has been reported in the Defense press that the U.S. government would not approve the license to allow that to happen. So while the U.S. political and Administrative levels of government said they would support the sale, the cold hard facts when it got to the regulators of ITAR/Export Controls was they said absolutely not. There would not be any export on the "jewels of defense electronics" on board these advanced Indian fighters. So the two remaining contenders still in the competition are the Eurofighter and the Rafelle, who have reported "full and complete cooperation" with Indian industry on the local manufacture of their fighter aircraft with the U.S. losing out on a chance to win these large contracts.

THE BASICS OF REFORM

Fundamental reform needs to be carried out in a half dozen government agencies and the final set of updated Export Control rules will need to 1) achieve consistency of purpose and direction, 2) have a well thought-out strategy on the various technologies and approaches to controls that are realistic and 3) put in place specific regulations that will have clear and unambiguous objectives. The government needs to fix all the conflicts and put in place crisp guidance to be followed by everyone. The government's intent on what technology needs to be protected must be crystal clear. And the Export Control Regulations should support those findings. Export Control rules need to be an enabler for national security, not used as a gatekeeper to hold back on everything. And once they have vetted these new rules and effectively challenged themselves that they have done it correctly, they will then need to roll it out and plan to implement it. It now has to stand on its

own as an effective U.S. government policy directive, specifically designed for protecting critical technology for the warfighter. The government must transform this process into a unified business-like methodology. And it has to communicate it clearly to the stakeholders – our citizens, the business and government community and our global allies. Make no bones about this task, it will be arduous, painful and time consuming to upgrade and make common sense of all these disparate agency rules and regulations. Mistakes will be made and lessons will be learned in this effort. But the old system is broken, and needs to be upgraded to today's standards of coalition warfare and global alliances.

GETTING TO THE ECR FINAL OUTCOME — IS IT EVEN POSSIBLE?

To achieve this goal will be a monumental task given how many different entrenched government bureaucracies play in the game of Export Controls, ITAR and the licensing process. Government organizations have a unique ability to "wrap themselves in a warm and fuzzy blanket" of agency and procedural "do's and don'ts" that are derived solely from their own agency's perspective. When operating in this fashion, a specific agency's procedural approach is somehow called upon and used ceremoniously to justify their specific regulatory or decision process. But this logic confounds the average business person who has to deal with the many agencies involved – each seeming to have their own rules, laws and regulations. And business folks have to also fill out application forms and, as such, need to be accountable to their shareholders – who expect lawful behavior tied to good business practices. To deal with a group of government agencies that each have their own point of view, which sometimes are contradictory, at best, and indeed not even understandable, at worst, is not good. The business person is caught in the middle of this, with the added burden that they are legally bound to comply with all regulations under the penalty of law.

HIGHLIGHTS OF THE ADMINISTRATION'S PLANS FOR ECR

Last spring, Defense Secretary Gates set out the Administration's conclusion that fundamental reform is needed. "If the application of controls on key items and technologies is to have any meaning," he said, "we need a system that dispenses with 95 percent of 'easy' cases and lets us concentrate our resources on the remaining five percent. By doing so, we will be better able to monitor and enforce controls on technology transfers with real security implications while helping to speed the provision of equipment to allies and partners who fight alongside us in coalition operations." The President, Secretary of Commerce Locke and others discussed how the end result of addressing these critical questions would be a single control list administered by a single licensing agency operating on a single information technology platform and enforced by a single primary export enforcement coordination agency. The structural reforms require congressional action for a single control list and a single IT

system. This past December, the Departments of State and Commerce issued proposed regulations to achieve two fundamental reform objectives: controlling items based on transparent technical parameters, which translates in export control parlance to "positive lists" that do not overlap; and separating items by tier, to focus controls on the most sensitive items while allowing for more flexible authorizations for relatively mature technologies that are more widely available.

THE U.S. MUNITIONS LIST (USML) AND THE COMMERCE CONTROL LIST (CCL)

The most important aspect of control list reform may be making the USML a "positive" list. Currently, the USML controls many defense articles based on "design intent," in part because, at one time, the majority of items used by the military were produced specifically for the military. Today, however, many technologies used by the military are developed and manufactured by the commercial sector. Moreover, the design-intent nature of the USML is inconsistent with a predictable and transparent regulatory process – one where industry and government alike readily and objectively can determine what is controlled. The existing setup has fueled an increase in commodity jurisdiction disputes. This has resulted in many commercial systems being ruled subject to ITAR control or jurisdictional decisions being delayed, thereby impeding the competitiveness of U.S. items or, even worse, resulting in their being "designed out" of foreign end products.

This "design intent" approach would focus the category's controls on truly significant military items, while moving less significant items – particularly parts and components that do not serve an inherently military function to the Commerce Control List. For many of the low level parts, widely available items will be transferred from the USML to the CCL; Commerce jurisdiction will provide greater flexibility and a simpler structure of controls. First, ITAR registration would be eliminated for many small and medium-sized exporters if their sole ITAR items are minor elements of Defense products. Second, the change in jurisdiction should eliminate many problems associated with the "see through" rule, which make certain items manufactured offshore subject to U.S. re-export control requirements if they incorporate U.S. origin ITAR parts and components, regardless of value or importance. Third, there would be far fewer transactions requiring U.S. exporters to enter into and obtain complex Manufacturing Licensing Agreements or Technical Assistance Agreement to share data and services. Finally, there could be a significant reduction in the time required to determine the jurisdiction of parts and components.

The USML is not the only focus of the Administration's attention. The existing CCL is largely a "positive" list that describes items using objective criteria, but it is not wholly so. The Administration will seek to make it sufficiently positive, clear and precise so that someone who is not an expert on U.S. export controls, but understands the technical characteristics and capabilities of an item, can accurately determine its jurisdictional status and classification.

THE PARALLEL-TIERED CONTROL LISTS

The government's plan involves converting the USML and CCL into parallel constructed, three-tiered lists that allow the U.S. government to focus control on the most sensitive items while establishing cascading controls on more mature and widely available items. The government would then apply licensing policies associated with the tiers. To implement this tiered construct, the U.S. government has developed control list criteria:

1) Tier 1 items are weapons of mass destruction or are almost exclusively available from the U.S. that provide a critical military or intelligence advantage. These are what Secretary Gates has termed our "crown jewels."

2) Tier 2 items are almost exclusively available from regime partners or adherents and provide a substantial military or intelligence advantage, or make a substantial contribution to the indigenous development, production, use, or enhancement of a Tier 1 or Tier 2 item. These are what the U.S. government has termed "precious metals."

3) Tier 3 items are more broadly available and provide a significant military or intelligence advantage or make a significant contribution to the indigenous development, production, use, or enhancement of a Tier 1, 2, or 3 item, or are other items controlled for national security, foreign policy, or human rights reasons.

COMPLIANCE AND ENFORCEMENT

Enforcement activities have a high priority in the Administrations reform program in at least three important respects. The government will establish an Export Enforcement Coordination Center comprising representatives from Department of Commerce/BIS, the Federal Bureau of Investigation, Immigration and Customs Enforcement, the Intelligence Community, and military security agencies. Agencies will share information and leverage their resources to enhance compliance with export control laws and regulations. To enhance coordination among export control enforcement agencies, Commerce/BIS will continue to make use of specific compliance tools to prevent the unauthorized export of technologies to end users of concern. Third, BIS is adjusting how we penalize those who violate U.S. export controls. In the past, BIS typically has imposed penalties on companies involved in export violations. Going forward, where a violation is the deliberate action of an individual, the Administration will consider seeking penalties against that individual including heavy fines, imprisonment and the denial of export privileges – as well as against the company. The same will be true for supervisors who are complicit in deliberate violations by their subordinates.

At the same time, the Administration will recognize that even companies that have good intentions can make mistakes. The Administration promotes the submission of voluntary self-disclosures (VSD) in these and other instances. And the Administration views VSDs, along with robust internal compliance programs, as important mitigating factors. Given the volume of exports and re-exports that are subject to the EAR-BIS (more than 20,000 license applications during 2010), we rely on industry for the bulk of compliance as their knowledge of the products, their end users, and their customers makes them the front line troops in this important effort.

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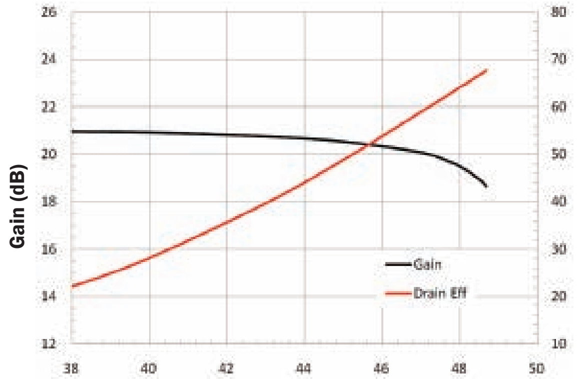

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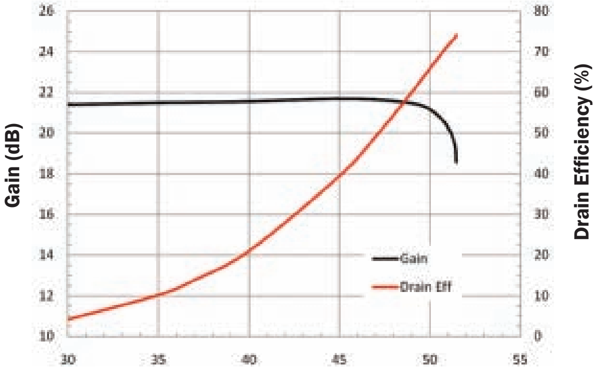

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The government has a plan in place to upgrade its IT systems to make them more user-friendly for exporters and to leverage the resources and information of agencies across the U.S. government. One of the first steps it will take to improve customer service through expansion of IT capabilities is to establish online registration for the export licensing system. This allows an exporter to go online to file and quickly obtain a personal or corporate information number that allows the exporter to file licenses and other requests. This approach also transfers to the exporter the responsibility to manage its account and add or remove persons authorized to have access to the system. This move will eliminate the manual and sometimes untimely processing of more than 6500 annual requests for access to the licensing system.

THE OUTCOME: GETTING IT RIGHT THIS TIME

- When the Administration has implemented these actions, its goal will be what they call the three greater efficiencies. It will control and investigate those items that are the most significant in terms of providing the United States with a military or intelligence advantage, while facilitating exports to coalition partners in order to improve our interoperability.
- Increased education to ensure that everyone subject to our regulations knows of their existence and requirements. The effort also will help exporters understand how the changes will affect their compliance responsibilities. The Administration will also be emphasizing the adoption of internal export management and compliance programs.
- Enhanced enforcement to ensure that exporters, re-exporters and end users comply with our regulations and use U.S.-origin items responsibly. Administration compliance personnel will evaluate exports made under license or license exception to ensure they comply with the Export Regulations. Government agents are increasing their presence domestically and abroad. They will have new export control officers in China and Singapore, and will leverage the resources of the FBI and Immigration, Customs Enforcement (ICE) as participants in the Export Enforcement Coordination Center. ■

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Addressing the Challenges of Wideband Waveform Generation and Analysis

Satellite and radio waveforms can utilize custom/proprietary formats with modulation bandwidths beyond 1 GHz for increased data rates. Generating custom waveforms with wide modulation bandwidths can present challenges, especially when excellent signal fidelity is required and when distortions must be kept to a minimum. Traditional signal generators can provide the required signal purity, but are limited in modulation bandwidths. In addition, wide bandwidth signal analysis requires a new approach for waveform demodulation relative to a traditional RF signal analyzer approach.

These challenges highlight the need for an improved wideband waveform generation and analysis methodology. This article will show a new waveform generation solution, using a wide bandwidth, high precision arbitrary waveform generator (AWG), combined with a vector RF/microwave signal generator with wideband IQ inputs to generate a 16QAM waveform at X-band with a 1.76 GHz symbol rate. Simulation will provide the flexibility needed to create custom/proprietary AWG waveforms. A 32 GHz high performance digital oscilloscope with vector signal analysis (VSA) software will be used to demodulate the waveform to measure the error vector magnitude (EVM).

A PARADIGM SHIFT FOR WIDE BANDWIDTH APPLICATIONS

RF signal generators have traditionally been used for wireless applications. They typically offer good signal purity and performance and the convenience of software applications, which can be used to generate parameterized and pre-configured waveforms, such as Mobile WiMAX™ and LTE. However, RF signal generator AWG modulation bandwidths are typically limited to approximately 100 MHz, which can limit their ability to address emerging applications, such as wide bandwidth satellite and radio communications. In these communication systems, modulation bandwidths may significantly exceed 100 MHz and possibly even approach 1 to 2 GHz of modulation bandwidth. In addition, military radio applications, such as software defined radio (SDR), may require custom waveforms to be generated, such as a custom orthogonal frequency division multiple access (OFDMA) waveforms. Flexibility is needed in the waveform generation process

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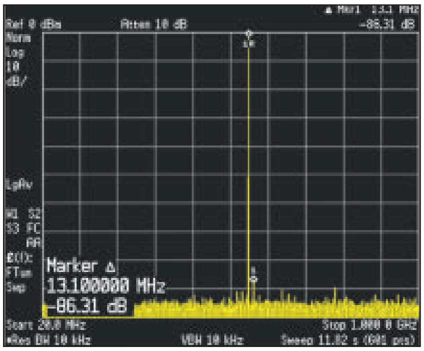


Fig. 1 *Spectral purity of high performance arbitrary waveform generator.*

to facilitate custom proprietary waveform creation, in addition to wide modulation bandwidths.

A similar situation exists for RF signal analysis. Today's RF signal analyzers have IF bandwidths of approximately 140 MHz, which can limit modulation domain analysis, or waveform demodulation, to applications where the modulation bandwidth is within 140 MHz. A new approach is needed for RF/microwave modulation domain signal analysis applications, which exceed 1 to 2 GHz of modulation bandwidth at X-, Ku- and Ka-band carrier frequencies.

High performance commercial-off-the-shelf (COTS) AWGs and digital oscilloscopes are an enabler for wide bandwidth RF/microwave applications. Recent breakthroughs in their performance present a paradigm shift in the way RF engineers think about creating and analyzing wideband satellite and radio waveforms over traditional approaches.

For example, take the spectral purity of a high performance AWG, as shown in ***Figure 1***. The AWG is used to generate a simple single tone at 555 MHz with a sampling rate of 7.2 giga samples per second (GSa/s). The spectral purity is clean, with spurious down to approximately –86 dB. Of course, although this CW case shows the performance that can be achieved with a wideband AWG, it is not representative of the modulated signal formats used for satellite and radio applications.

The next section of this article will show the waveform creation and analysis of a 16QAM waveform at X-band with a 1.76 GHz modulation bandwidth. The residual error vector magnitude (EVM) will be used as the metric, to show the high performance that can be achieved with today's AWG and oscilloscope COTS technology.

A 16QAM EXAMPLE USING A WIDE BANDWIDTH COTS TEST SETUP

Figure 2 shows the high performance wide bandwidth COTS test equipment used to generate and analyze a 16QAM waveform at X-band with a 1.76 GHz modulation bandwidth. The upper left is a precision wide bandwidth AWG with a DAC resolution of 14 bits up to 8 GSa/s, or 12 bits up to 12 GSa/s. The AWG has 2 GSa of arbitrary waveform memory per channel and 5 GHz of analog bandwidth per channel. This is the AWG used to generate the CW tone in Figure 1, but here it is being used to generate a wideband 16QAM waveform. A vector signal generator with wideband IQ inputs is shown on the lower left. This is used to modulate the IQ waveform on an X-band carrier centered at 10 GHz.

A high performance 32 GHz digital oscilloscope, with VSA software, is connected to the signal generator output to demodulate the wideband 16QAM waveform at the RF/microwave carrier frequency. Although oscilloscopes are traditionally used for time-domain measurements, here it is being used for RF/microwave frequency modulation domain analysis.

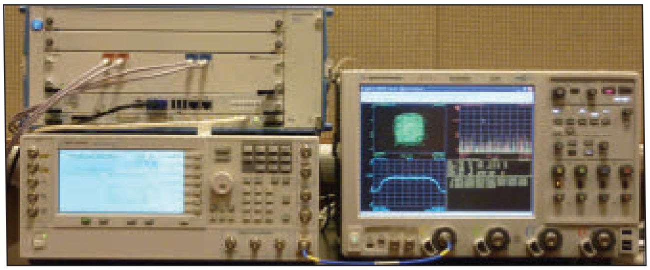


Fig. 2 *COTS test equipment setup to generate and analyze wideband satellite communications and radio waveforms.*

Figure 3 shows the setup diagram of the test equipment shown in Figure 2. Waveform creation software or simulation software, such as MATLAB™, can reside on an external PC and downloaded to the AWG. However, in this example, it is installed in the oscilloscope and downloaded from the oscilloscope to the AWG via LAN.

The differential analog IQ outputs of the AWG are fed into a vector RF/microwave signal generator with external wideband IQ inputs, to modulate the IQ waveforms onto a 10 GHz carrier. The output of the vector signal generator is connected to channel 1 on the high performance digital oscilloscope to demodulate the waveform. However, before generating the 16QAM waveform, a MATLAB utility is first used in the digital oscilloscope to create and download a wideband multi-tone waveform for flatness corrections (see ***Figure 4***). The complex frequency response (magnitude and phase) of the AWG output path, in combination with the I/Q modulator in the vector PSG, are analyzed using the VSA software in the oscilloscope. This information is fed back into the MATLAB script,

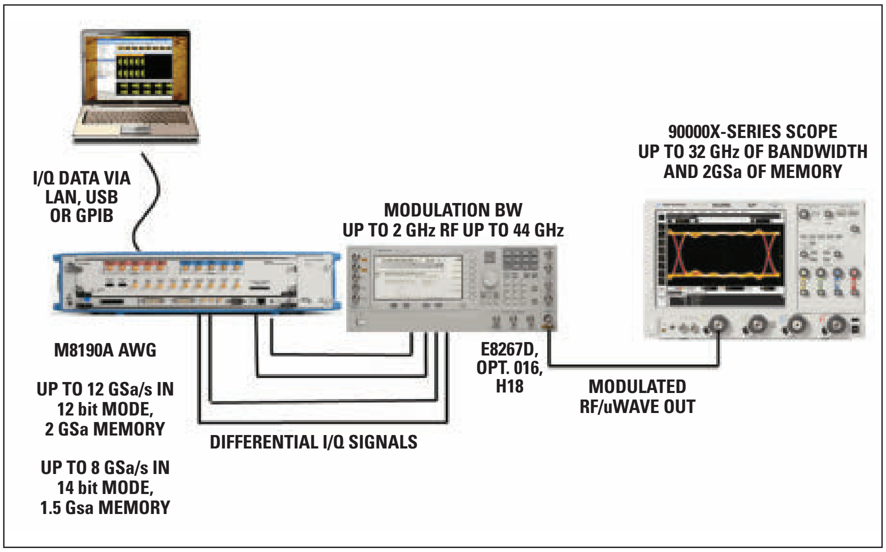
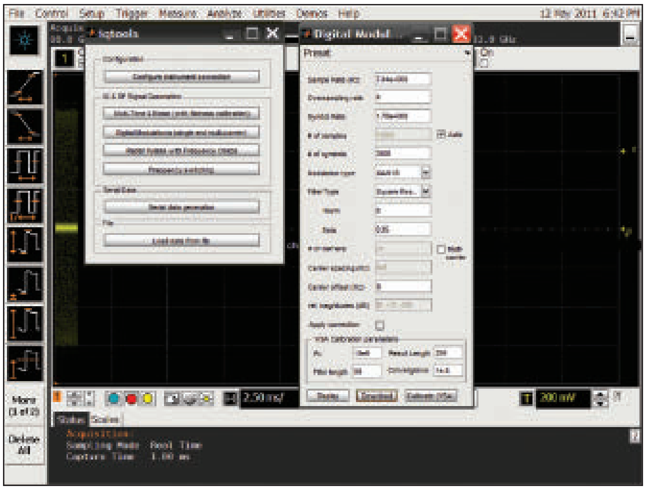


Fig. 3 *Diagram of the test equipment setup.*

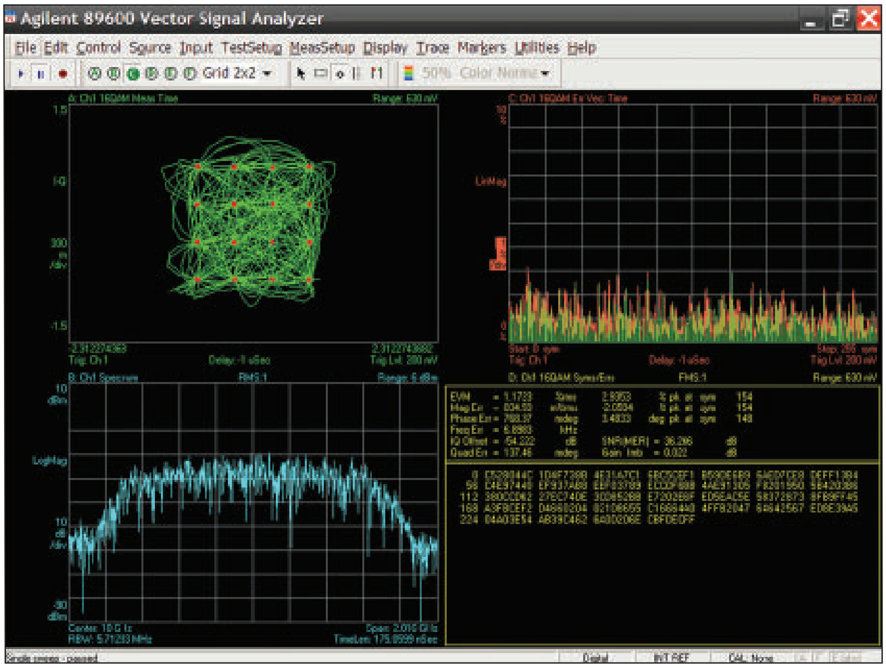
which calculates a pre-distorted waveform and downloads it into the AWG.

Once flatness corrections have been performed, a MATLAB utility is then used to create and download the 16QAM waveform from the oscilloscope to the AWG via LAN. The digital modulation dialog box is configured for a 16QAM waveform with a 1.76 GHz symbol (modulation) rate and 4× oversampling (7.04 GSa/s sample rate). A 0.35 alpha root raised-cosine filter is applied. The high performance digital oscilloscope with VSA software is then used to demodulate the resulting RF/microwave wideband waveform as shown in ***Figure 5***.

The 16QAM constellation is shown on the upper left of the VSA display, the RF modulated spectrum centered at 10 GHz is shown on the lower left, the EVM vs. symbol (time) is shown on the upper right, and the EVM summary table is shown on the lower right. The residual EVM is measured at approximately 1.17 percent, which is quite impressive for a modulation bandwidth of 1.76 GHz at a 10 GHz carrier frequency. Using the VSA software with wide bandwidth high performance digital oscilloscopes enables RF engineers to analyze wide bandwidth modulated waveforms at X-, Ku- and Ka-band (up to 32 GHz) directly, without the need for external down-conversion. In addition, multiple phase coherent inputs enable multiple-input multiple-output (MIMO) OFDMA waveforms to be analyzed and demodulated,[1] using the digital oscilloscope with VSA software. Although not shown in this example, MATLAB can also be used as a custom user defined function (UDF) in digital oscilloscopes.[2]



▲ *Fig. 4 Configuring a MATLAB utility to generate and download a 1.76 GHz 16 QAM waveform to an M8190A AWG.*



▲ *Fig. 5 Measurement results for a 1.76 GHz 16 QAM waveform at 10 GHz.*

SUMMARY

An improved approach for generating and analyzing wide bandwidth waveforms for satellite and radio applications was shown. High performance precision AWGs, combined with RF/microwave vector signal generators with external wideband IQ inputs, enable RF engineers to generate wideband waveforms with excellent signal fidelity. Simulation tools, such as MATLAB, facilitate creating and downloading custom/proprietary waveforms using COTS equipment. High performance digital oscilloscopes, combined with VSA software, enable wide bandwidth RF/microwave waveforms to be analyzed at X-, Ku- and Ka-band, up to 32 GHz, without the need for external down-conversion. Exceptional residual EVM performance was demonstrated with the AWG, vector signal generator and digital oscilloscope on a 10 GHz X-band waveform modulated at a 1.76 GHz symbol rate. ■

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2. "Wideband Radar and Satcom Measurements Using Wide Bandwidth Oscilloscopes to Directly Measure and Analyze X, Ku, and Ka-band Radar and Satcom Transmitter Outputs up to 32 GHz," *Agilent Application Note*, www.agilent.com/find/powerofx.

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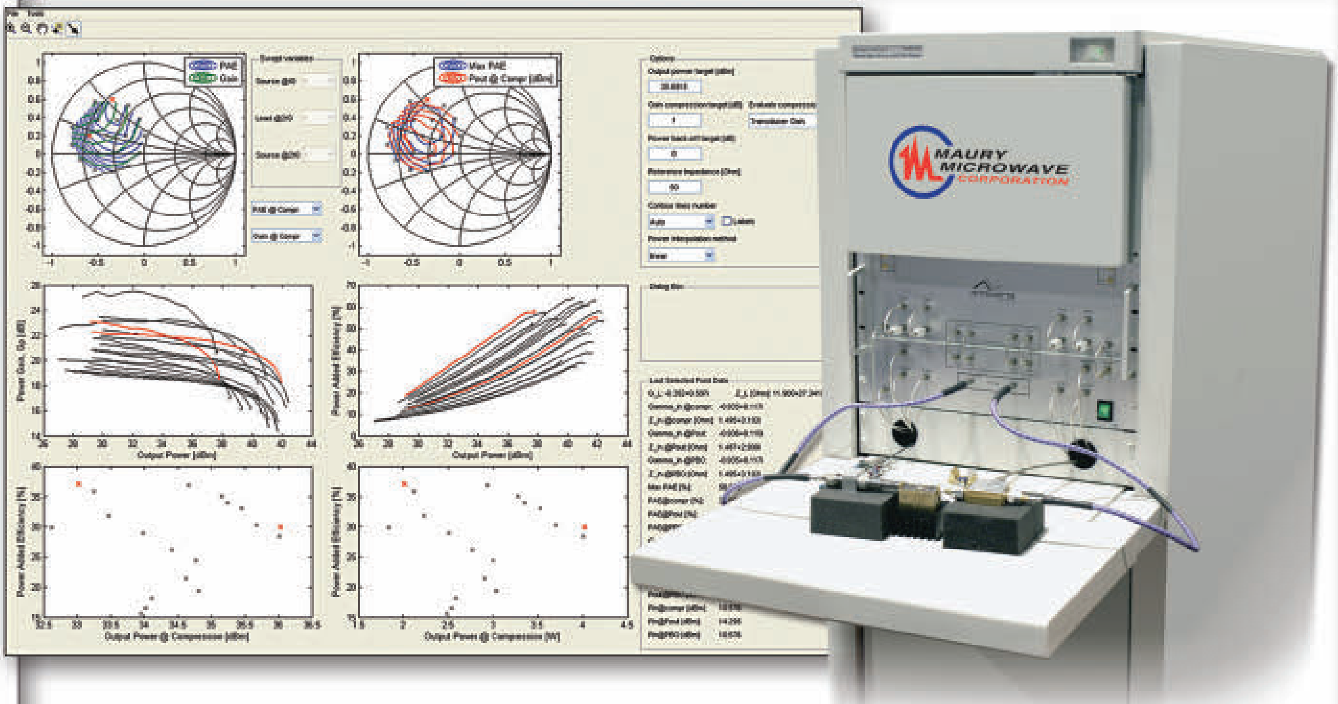

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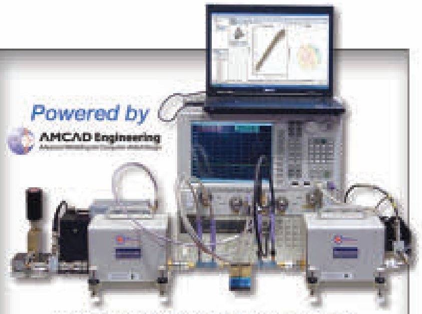

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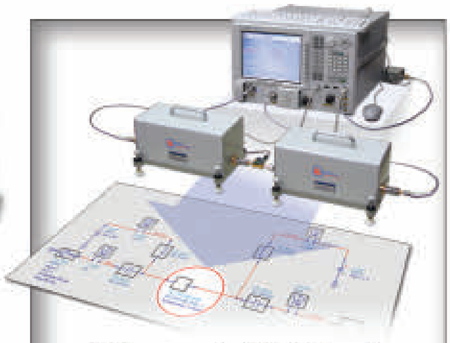

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New Group Delay and Phase Measurement Method for Long Distance Transmission

The demands placed on modern communications systems for transmitting wideband signals at high quality are growing in both the civil and military sectors. The performance of such systems crucially depends on achieving constant magnitude and linear phase versus frequency of the transmission coefficient within the useful band. Measuring the phase linearity and the group delay of such systems is vital. This applies in particular to microwave communications systems that include components such as satellites or satellite base stations. With systems of this kind, a baseband signal of large bandwidth is up-converted to a high frequency signal at the transmitter end, and the high frequency signal is down-converted to the baseband at the receiver end. Applications like this require group delay to be measured even on frequency-converting devices.

Relative group delay can be determined using the reference mixer method. This measurement method, however, requires access to the mixer's local oscillator (LO) or at least to a reference frequency. Given that numerous aerospace and defense applications do not allow access to either, a different approach is needed. In addition, the reference mixer method reaches its limits when used to perform free-space measurements on transmission systems. With this method, a system's input and output are connected to a network analyzer via RF cables. If distances of more than a hundred meters have to be bridged, cable losses will deteriorate the signal-to-noise ratio (SNR) significantly.

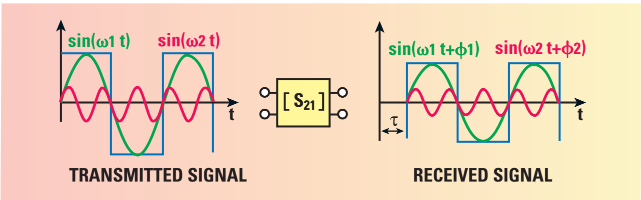

Fig. 1 Example of a transmitted and received signal.

To solve this problem, a new, two-tone method has been developed that allows users to measure relative group delay on converters and mixers with high precision. This method requires no access to the local oscillator or a reference signal, and places only modest requirements on the frequency and phase stability of the local oscillator(s) involved. The method also enables group delay measurements on a transmission system by means of two network analyzers spaced apart from each other. This eliminates the need for RF cable connections, avoiding the typical problems resulting from the use of long cables.

TRANSMISSION QUALITY

For correct information transmission, the signal shape at the transmission system output must be identical to the shape at its input. The amplitudes of the output and the input signal may differ, as the signal may undergo amplification or attenuation to match its amplitude to the conditions prevailing at the receiver end. Also, there is no impact on signal quality if the signal arrives at the receiver with a delay.

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Jochen Wolle
Rohde & Schwarz, Munich, Germany

However, for correct transmission all frequency components within a transmission channel or the transmission bandwidth must undergo identical attenuation or amplification and have an identical delay, relative to the input signal. ***Figure 1*** offers an example of a transmitted and received signal.

For two signals with the frequencies ω1 and ω2 to have an identical delay within a transmission channel, the following must be fulfilled:

$$\varphi = -\omega\tau \qquad (1)$$
$$\varphi_1 = -\omega_1\tau$$
$$\varphi_2 = -\omega_2\tau$$
$$\varphi_2 - \varphi_1 = -\tau(\omega_2 - \omega_1)$$
$$-\frac{\Delta\varphi}{\Delta\omega} = \tau$$

where $\Delta\varphi = \varphi_2 - \varphi_1$ and $\Delta\omega = \omega_2 - \omega_1$

To obtain a constant delay for all frequencies, the phase of the transmission coefficient S_{21} must be a linear function of frequency. Starting from equation (1), changing the unit of Δφ from radians to degrees, substituting Δω with 2πΔf and reducing the step size to infinitesimal values, the following relationship is obtained:

$$\tau = -\frac{1}{360°} \bullet \frac{d\varphi}{df}$$

The delay, τ, is referred to as the group delay, which is defined as the negative derivative of the phase versus frequency.[1] For a transmission channel to be distortion-free, its transmission coefficient, S_{21}, must have constant magnitude and linear phase versus frequency. By contrast, the absolute values of phase and phase slope versus frequency (the latter can be expressed as the group delay) do not impact transmission quality.

S-PARAMETERS

Rather than determining the derivative of the phase (S_{21}) versus frequency, which is based on infinitesimal deltas, vector network analyzers calculate the difference quotient.

$$\tau = -\frac{1}{360°} \bullet \frac{\Delta\varphi}{\Delta f} \qquad (2)$$

This yields a good approximation of the required group delay. Δf is referred to as frequency aperture. From ***Figure 2*** Δφ = φ2 – φ1 and Δf = f2 – f1 are used for calculating group delay.

Determining the group delay based on the phase measurement of S-parameters delivers precise results as the measurement accuracy of the network analyzer is very high and can be increased further by applying suitable calibration methods. This approach is ideal for non-frequency-converting DUTs, such as amplifiers and filters.

However, in the case of frequency-converting DUTs such as satellite base station converters, the phase of the transmission coefficient S_{21} cannot be measured directly because the input and the output signal have different frequencies. Moreover, the phase of the output signal is influenced, not only by the DUT, but also by the frequency and phase drift of its local oscillator.

REFERENCE MIXER METHOD

Phase and group delay measurements on mixers with an accessible LO are performed using the reference mixer method.[2] The reference mixer uses the LO of the mixer under test in order to convert the reference signal from the network analyzer to the frequency of the IF signal output by the mixer under test. Sharing the same LO compensates for the effects of frequency and phase fluctuations of the LO of the mixer under test. ***Figure 3*** shows a test setup for mixer measurements using the reference mixer method.

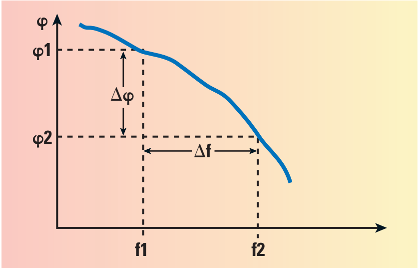

Fig. 2 The terms Δφ = φ2 – φ1 and Δf = f2 – f1 for calculating group delay.

The measurement yields the mixer's phase and group delay relative to a reference mixer that was used in place of the mixer under test in order to calibrate the test setup. The reference mixer is often assumed to have ideal characteristics, so the phase and group delay of the mixer under test are measured relative to the reference mixer. With many mixers, the assumption that they have ideal characteristics is justified, as they exhibit a group delay variation of less than 1 ns, which corresponds to a rather linear phase versus frequency.

As has been mentioned, correct information transmission does not depend on absolute group delay, but on the deviation of the group delay from a constant value within the relevant frequency range. The reference mixer method is, therefore, sufficient in most cases. However, this measurement technique cannot be used with DUTs whose LO cannot be accessed.

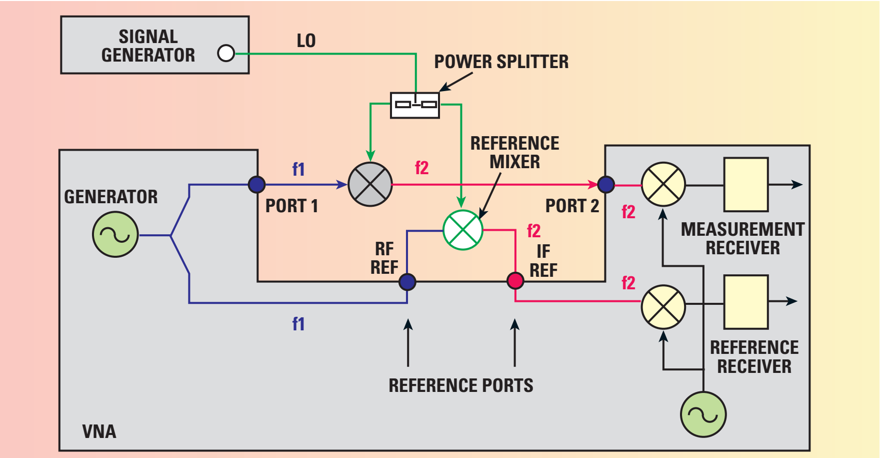

Fig. 3 Test setup for mixer meaurements using the reference mixer method.

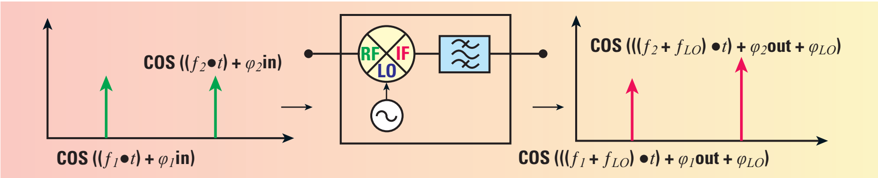

Fig. 4 Group-delay measurement using the two-tone method.


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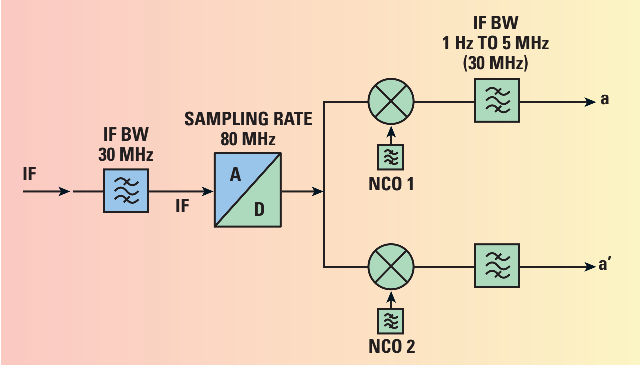
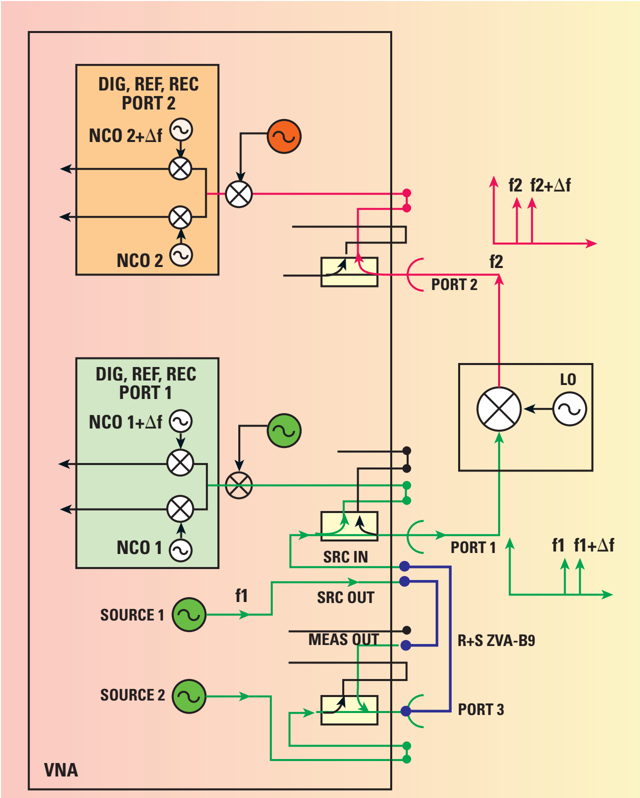
One possible approach in such cases would be to provide the reference mixer LO by means of an external generator, and set the LO's frequency as closely as possible to that of the DUT's internal LO. In most cases, though, this approach does not yield sufficiently stable results. However, the new two-tone method delivers reliable results, regardless of the stability of the DUT's LO.



▲ *Fig. 5 Digital front-end with two digital downconversion stages.*

THE TWO-TONE METHOD

This method stimulates the DUT with a two-tone signal, whereby the network analyzer measures the phase difference between the two carriers, both at the input and the output of the DUT. From the resulting phase differences and the carrier frequency offset, the analyzer calculates the group delay in the same way as in the classic S-parameter measurement.



▲ *Fig. 6 Block diagram of test setup for group delay measurement using the two-tone method.*

Figure 4 illustrates group delay measurement using the two-tone method. The frequency offset, Δf, between the two carriers corresponds to the frequency aperture in S-parameter measurement.

$$\tau = -\frac{1}{360°} \bullet \frac{\Delta\varphi}{\Delta f} \qquad (3)$$

$$\Delta\varphi = \left(\varphi 2out + \varphi LO - \varphi 1out - \varphi LO\right) - \left(\varphi 2in - \varphi 1in\right)$$

$$\Delta f = f2 - f1$$

To measure the phase between two signals with different frequencies, the signal is down-converted to the IF and digitized. In the digital signaling processing (DSP) stage, the signal is down-converted to DC by means of a numerically controlled oscillator (NCO) and filtered. For the two-tone method, each receiver of the network analyzer requires two digital mixer and filter stages with two independent NCOs. This allows the magnitude and phase relationships of two carrier signals to be determined simultaneously in each receiver and used to calculate the group delay. This is shown in ***Figure 5***.

The signal paths within the network analyzer contribute to the measured group delay. This effect can be

removed by a calibration that is based on a mixer with known group delay.

The two-tone method is particularly suitable for measurements on frequency-converting DUTs because the frequency and phase fluctuations of the DUT's internal LO cancel each other out when the phase differences between the carriers are determined. In addition to group delay, the relative phase as well as deviation from linear phase can be calculated by integrating the group delay and the derivative of the group delay by differentiating it. Together with scalar conversion loss, this method delivers all parameters necessary to characterize a DUT to determine transmission quality.

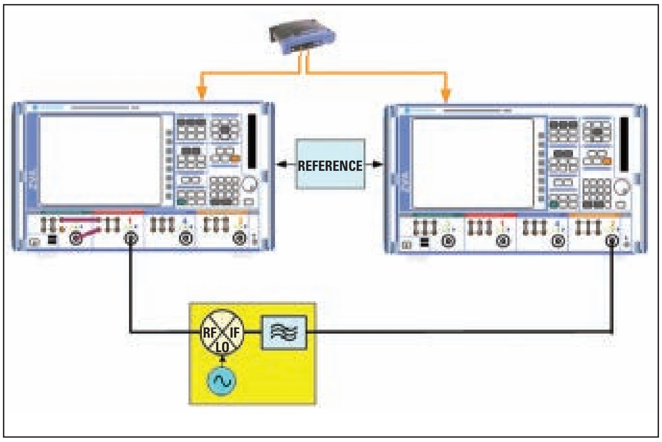
TEST SETUP

To obtain accurate results, the two-tone signal must be generated with a defined frequency offset. The ideal approach is to use the two internal sources of a four-port network analyzer. This ensures an identical frequency offset between the two RF carriers of the two-tone stimulating signal and the two digital oscillators (NCO). Using one of the network analyzer's couplers, the two carriers are combined into a two-tone signal and fed back into the source path. The reference receiver measures the phase difference between the two input signals, which are then applied to the DUT. The DUT output signals are measured by the receivers at port 2 (see ***Figure 6***).

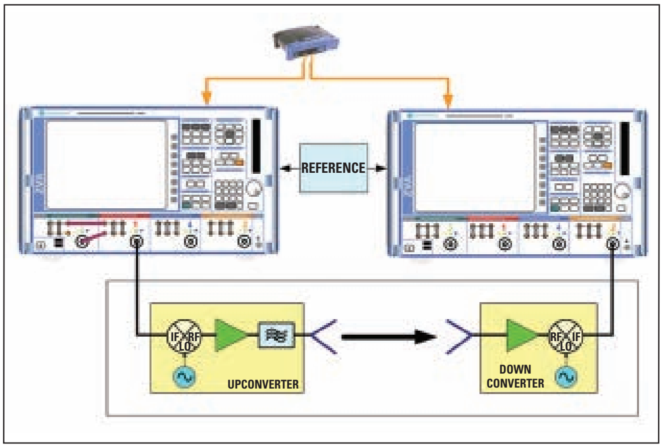
MEASURING USING TWO VNAS AT SEPARATE LOCATIONS

If the input and output of a transmission system are located far apart (as in free-space measurements), the group delay and phase are very difficult to measure. Long cables are required to transport the RF signals from the DUT to the network analyzer, but they can result in significant losses, deteriorating the signal-to-noise ratio. In addition, phase errors will occur when the cables are moved as they have only limited phase stability.

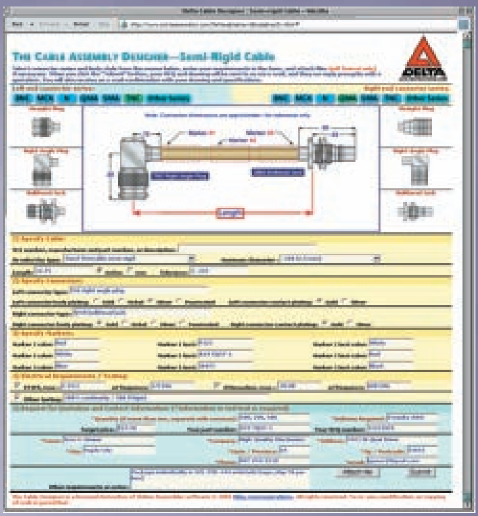
These difficulties are avoided by measuring the group delay and relative phase using the two-tone method with two spatially separated network analyzers, which both need to be aware of the precise frequency offset of the two-tone signal. The frequencies of the two NCOs are then set accordingly and the individual frequency points read synchronously by the two analyzers. This solution makes it possible to measure the magnitude, group delay and phase of the transmission coefficient without a coaxial connection. All that is required is a common reference frequency for the two network analyzers, which can be



▲ *Fig. 7 Test setup with two network analyzers installed at separate locations.*



▲ *Fig. 8 Test setup for measuring group delay and conversion loss on a microwave link.*



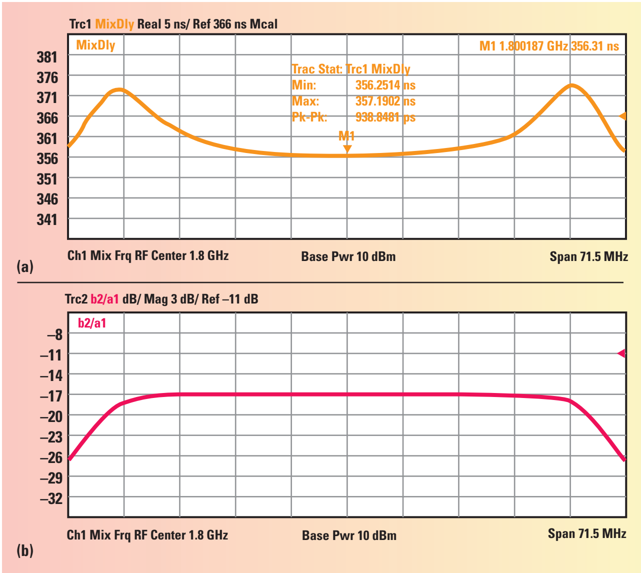
provided by means of radio-based modules, for example.

Figure 7 shows such a test setup where one network analyzer acts as a master, the other one as a slave. The master controls the slave via a LAN connection and processes and displays results. The two analyzers communicate with each other using LAN messages in line with the LXI standard. They are connected to one another via a LAN router with an integrated DHCP server that assigns the IP addresses to the devices. Alternatively, the devices can use fixed IP addresses. The two analyzers can communicate over a distance of 2 × 100 meters. This is the maximum possible length of a LAN segment. For larger distances, a WLAN connection can be used.

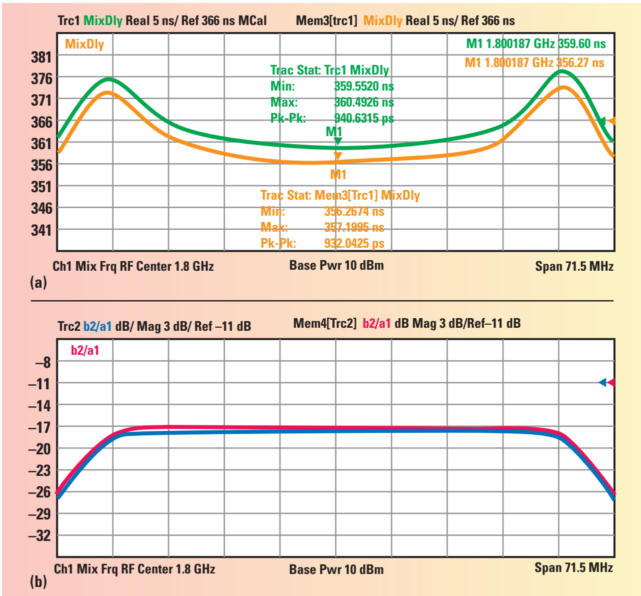
In operation, the master generates the two-tone signal to be applied to the DUT and measures the phase difference between the two signals at the DUT input. It sets the receiver of the slave to the DUT's output frequency. In the case of a frequency-converting DUT, the output frequency differs from the input frequency. The slave measures the phase difference between the two carriers at the DUT output and sends the data to the master, which calculates the conversion loss and the group delay from the data received. This procedure is repeated for each frequency point.

The master sets the two-tone signal and its own receiver to the frequency to be measured, and also sets the slave to the corresponding frequency. This test setup can be used to measure the conversion loss magnitude as well as the absolute and relative group delay.

After installation, the analyzers are connected to the LAN/LXI network and to a common reference frequency. The master displays the magnitude and the relative group delay of the transmission coefficient. If the analyzers are switched off after calibration, the displayed group delay will be shifted by a constant value relative to the actual group delay. If the analyzers remain switched on and connected to the reference frequency between the



▲ *Fig. 9 Relative group delay (a) and conversion loss (b) measured on a microwave link.*



▲ *Fig. 10 Relative group delay (a) and conversion loss (b) after increasing the distance between the transmitter and the receiver by one meter.*

calibration and the measurement, the master will also display the correct absolute group delay.

As has been mentioned, constant magnitude and group delay of the transmission coefficient are crucial to correct information transmission, whereas the absolute values of these quantities are not relevant to transmission quality. It is, therefore, sufficient to calibrate the master and slave together once before they are installed at their respective sites.

MEASURING A MICROWAVE LINK

The following example describes the process of measuring a microwave link based on an up-converter and a down-converter with inaccessible internal LOs. The input frequencies are different from the output frequencies. The magnitude of the conversion loss and the relative group delay are to be measured. ***Figure 8*** shows the test setup.

For this application, it is sufficient to measure relative group delay, or group delay deviation from a constant value, respectively. This means that a mixer with a constant group delay is sufficient for calibration. The LO of the calibration mixer offsets the input frequency relative to the output frequency by the same delta as the DUT does during signal up-conversion and down-conversion. For applications with identical input and output frequencies, a non-frequency-converting through connection is sufficient for calibration. ***Figure 9*** shows the relative group delay and the conversion loss.

In a subsequent measurement, the distance between the transmit and receive antenna is increased by about one meter. ***Figure 10*** shows that the relative group delay, or group delay response, remains the same, which was to be expected. The absolute group delay, however, increases by 3.3 nanoseconds, which corresponds approximately to the electrical length of one meter.

SUMMARY

The two-tone signal method is ideal for measuring group delay on frequency-converting devices that do not allow access to their internal LO. It accommodates measurements on test ports spaced a large distance apart, requiring two vector network analyzers; a coaxial connection between the two analyzers is not needed and the analyzers communicate with each other via a LAN/LXI interface. ■

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2.45 GHz High Gain Self-Oscillating Mixer for Simple Short-Range Doppler Radar

A high gain self-oscillating mixer (SOM) for short-range Doppler radars, which meets the needs of simplicity, low power and low cost, is accomplished using a new optimization technique based on SOM's constant gain curves similar to those of amplifiers. Using the optimization technique, the maximally optimized value for conversion gain and corresponding circuit parameters can be obtained. The measured conversion gain is up to 21.2 dB with one FET, which is the highest value reported to date. For the SOM, a microstrip slotted-square-patch resonator (SSPR) with a high quality factor is adopted. The SSPR-SOM, which emits a low power of –3.64 dBm with a microstrip patch antenna of 3.8 dB gain at 2.45 GHz band, shows good performance as a proximity motion detector.

Modern microwave communication systems have to comply with hard requirements for small size, low cost and reduced power consumption. In order to obtain a final system with such specifications, a commonly used approach is the combination of some functionalities of the system on a single circuit, reducing the number of components and the final cost of the system.[1]

Doppler radars are widely used for various purposes, including near distance motion detections. Examples include vehicle equipment, measurement of water surface velocity, detection of acoustic vibrations, non-contact cardiopulmonary monitoring and proximity motion detection in which the system's microwave front-end consists of several components. Some examples are one or two antennas, a local oscillator, one or two hybrids and/or an isolator, a frequency mixer and bandpass filters.

In order to reduce the number of components, hence to save on the size and cost of the Doppler radar, a self-oscillating mixer (SOM) could be adopted.[2] There are various advantages related to the self-oscillating mixer technique: cost is reduced, due to a lowered component count and thus higher reliability, the more compact solution offers easier integration into monolithic microwave integrated circuits (MMIC) and the total power consumption is lowered.[3]

The performance limits in Doppler radar sensing depend mainly on mixer conversion loss at baseband, and phase noise of the local oscillator signal in the RF band.[4] Hence, in this

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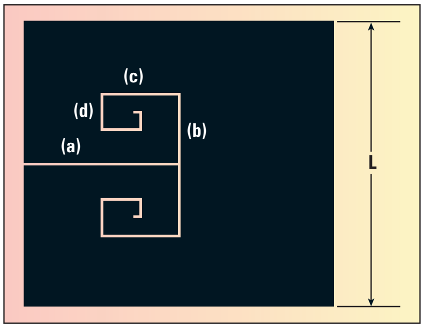


Fig. 1 Layout of the designed SSPR.

work, a Doppler radar is designed, based on SOM, for short-distance motion detections, with simplicity, low cost and low emitting power. For further reducing the cost and complexity with the least degradation of performance related to the SOM's phase noise, dielectric resonator is replaced with a new slotted-square-patch resonator (SSPR), which is easy to fabricate. For maximizing the conversion gain of the SOM, an optimization technique based on constant gain curves is carried out. The high conversion gain is helpful in reducing the emitted power from the Doppler radar.

MICROSTRIP SSPR

Phase noise is one of the most important performance parameters of an oscillator. For a lower phase noise, a dielectric resonator (DR) is most frequently used in microwave frequencies because of its high quality factor. The DR however has higher cost and additional difficulties in properly positioning it on a post with the exact coupling factor.

Figure 1 is the layout of the SSPR, which is a microstrip patch type resonator with the effective wavelength of $n\lambda/2$ and a high Q-factor. The resonator is designed by inserting the successive slot lines of the ratio of r = N/(N1) in the square patch, denoted as (a), (b), (c) and (d) in the figure. Hence, the lengths of (a) to (d) are $L\times r$, $L\times r^2$, $L\times r^3$ and $L\times r^4$, respectively. The slot lines start from the center of one side, L, of the square patch and with the length reduced by the same ratio, r, until it reaches a given slot number or a minimum limited length that can be manufactured.

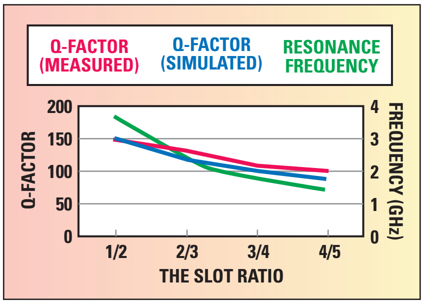


Fig. 2 Resonance frequency and quality factor of the SSPRs, according to the slot ratio $r = \frac{N}{N+1}$.

Here, only four successive slots are used.

According to the chosen integer N, from 1 to 4 for L = λ/5, four resonators with one λ electrical length were designed. ***Figure 2*** depicts the results of simulations and measurements. The total slot length increases and the line microstrip width decreases with N increasing, hence the resonance frequency decreases and the Q-factor decreases. The measured unloaded Q-factor was 154.1 for N = 1, which is approximately a 13.6 percent improved value, compared to that of the conventional hair-pin resonator.[5] The SSPR's improved Q-factor is due to the adoption of a slotted-patch type resonator, which can inherently maximize use of the circuit space and also to use the wider line width of middle part in length of the resonator in which current flow is maximized. The simulations were performed using a commercial 3D electromagnetic simulator, HFSS™. The substrate used is Teflon with a thickness of 0.762 mm, a relative dielectric constant of 3.48 and loss tangent of 0.003.

SOM DESIGN

The RF-layout for the proposed SOM or SOM Doppler radar circuit is shown in ***Figure 3***. A 50 Ω termination at the left end of the gate transmission line, the self-bias circuit and the IF bandpass filter at the drain transmission line are not shown in the figure. The circuit was simulated using a commercial circuit simulator ADS™ with an HB-simulation test bench. A well-known transistor, NE3508M04, was self-biased near the pinch-off region (V_{DD} = 3 V, V_{DS} = 2 V, I_{DS} = 3 mA, V_{GS} = –0.4 V).

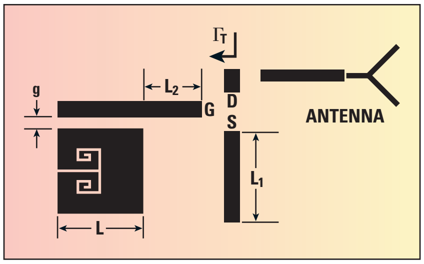


Fig. 3 RF layout of the designed SOM Doppler radar.

A transistor oscillator with a one-port negative-resistance is effectively created by terminating a potentially unstable transistor with an impedance designed to drive the device in an unstable region. In the circuit model for a two-port transistor oscillator of ***Figure 4***, the input and output reflection coefficients are generally given by Equations 1 and 2.[6] Then the input and output stability circles can be drawn as ***Figure 5***, using the conditions of $|\Gamma_{in}| = 1$ and $|\Gamma_{out}| = 1$.[6]

$$\Gamma_{in} = S_{11} + \frac{S_{12}S_{21}\Gamma_T}{1 - S_{22}\Gamma_T} \quad (1)$$

$$\Gamma_{out} = S_{22} + \frac{S_{12}S_{21}\Gamma_L}{1 - S_{11}\Gamma_L} \quad (2)$$

The source transmission line L_1 in Figure 3 was adjusted for a wider unstable region. The unstable region is inside of the input stability circle and outside of the output stability circle, which is region (b) in Figure 5.

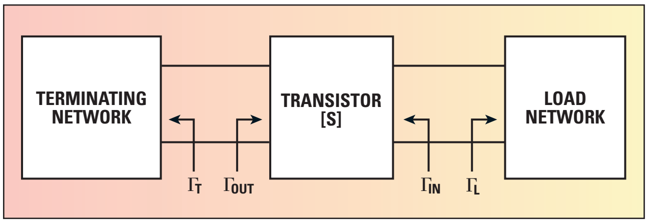


Fig. 4 Circuit model for a two-port transistor oscillator.

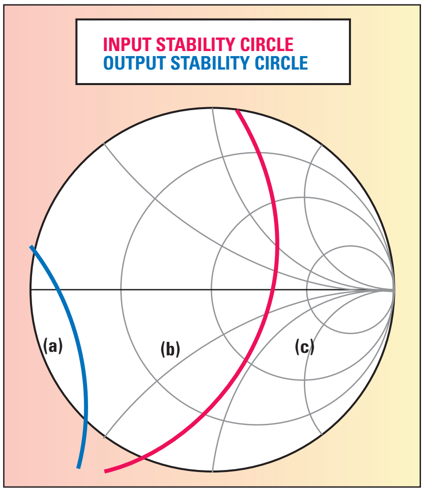
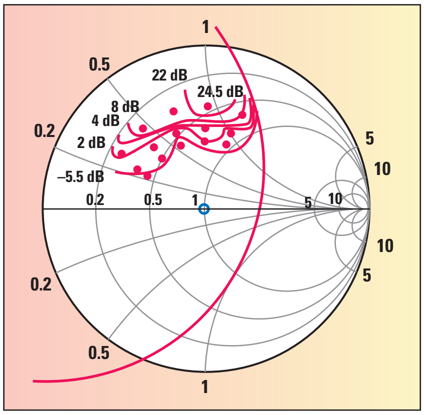


Fig. 5 The input and output stability circles.

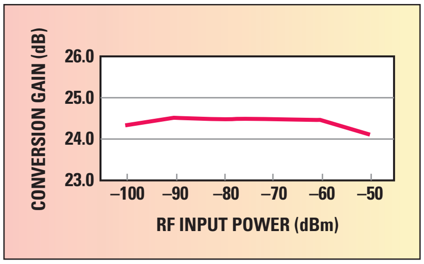


▲ *Fig. 6 Constant conversion gain curves of the designed SOM Doppler radar.*

On the other hand, the conversion gain, G_c, for a mixer is generally defined by Equation 3. Here, P_{RF} and P_{IF} are the powers of the received RF signal and the corresponding IF signal, respectively. In order to obtain the maximally optimized G_c, constant conversion gain circles are drawn, which are similar to those of amplifiers, according to Γ_T.

$$G_c(\text{dB}) = 10\log\frac{P_{IF}}{P_{RF}} \quad (3)$$

The gap, g, between the SSPR and the 50 Ω gate transmission lines, and L_2, were changed so that the Γ_T can be moved within the unstable region (b) of ***Figure 6***. Then a conversion gain point for each change of Γ_T can be obtained. A systematic investigation of 15



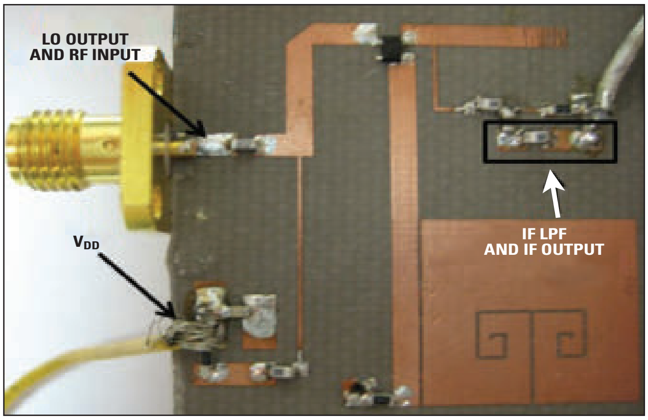
▲ *Fig. 7 Simulated conversion gain as a function of RF input power.*

points for the pairs of Γ_T and conversion gain, G_c, using a circuit simulation with ADS, gives the rough constant conversion gain curves outlined in the figure. For the simulations, the RF input power was assumed to be –50 dBm at the antenna port. The maximum conversion gain can be seen to be approximately 24.5 dB and at this point, the related parameters were g = 0.1 mm and L_2 = 11.0 mm.

The change in the simulated optimum conversion gain of the SOM as a function of the RF input power is shown in ***Figure 7***. The variation of the conversion gain is only 0.9 dB for RF input powers from –50 to –100 dBm, assuming a short distance motion detector.

MEASURED RESULTS

The optimized SOM for Doppler radar with a SSPR was fabricated as shown in ***Figure 8***. The SSPR is 13.8 × 13.8 mm and the total dimensions of the SOM circuit were 32 × 36 mm. The self-oscillated output power of the SOM Doppler radar was measured using a spectrum analyzer (Agilent E4407B). It shows –3.64 dBm LO output power at 2.45 GHz. As shown in ***Figure 9***, the phase noise obtained is –107.86 dBc/Hz at 100 kHz offset, which is comparable to a general

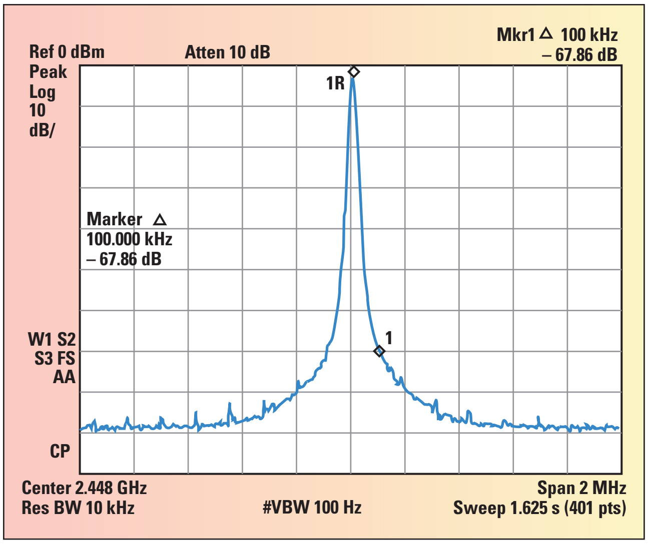


▲ *Fig. 8 Photograph of the fabricated SOM Doppler radar.*

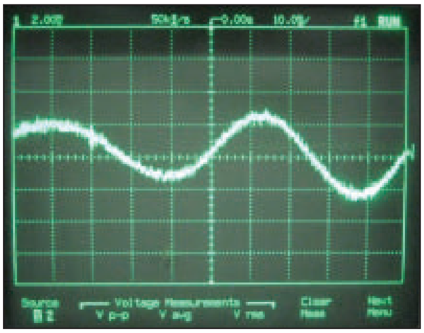
TABLE I

COMPARISON OF CONVERSION GAINS

Ref.	Frequency (GHz)	IF Frequency	Conversion Gain (dB)
[7]	2.5	about 50 MHz	8 to 13
[8]	5 to 6 9.8 to 11.8	about 200 MHz	5 to 12
This work	2.45	about 120 kHz	21.15



▲ *Fig. 9 Measured phase noise of the fabricated SOM Doppler radar.*



▲ *Fig. 10 IF waveform of the proposed SSPR-SOM Doppler radar used as a motion detector.*

oscillator. To measure the conversion gain accurately, –50 dBm RF power was driven, using a signal generator, and an IF power of -28.85 dBm was obtained at the IF port, which means that a 21.15 dB conversion gain was obtained. The measured conversion gain of 21.2 dB of the proposed SSPR-SOM for Doppler radar shows an excellent performance, compared to other high gain SOMs,[7-8] as summarized in ***Table 1***.

To observe the operation of the SOM Doppler radar working as a proximity motion detector, a simple aluminum metal plate target of 30 × 30 cm, moving at a distance of approximately 2.0 m with a velocity of approximately 1.2 m/sec, was used. The detected IF shows a peak-to-peak voltage of approximately 5.0 mV and a Doppler frequency of approximately 19.0 Hz. ***Figure 10*** shows an oscilloscope waveform at the IF port of the SOM Doppler radar when the motion is detected. The antenna used is a microstrip patch antenna with a gain of 3.8 dBi.

CONCLUSION

A simple, low cost and low power SSPR-SOM for Doppler radar is proposed. The proposed SSPR and a very high gain self-oscillating mixer (SOM) can replace the entire DR resonator, LO, mixer and hybrids in a conventional Doppler radar for the purpose of circuit simplicity, low power and low cost. The proposed constant gain curves, according to the Γ_S, give an extremely high constant gain of 21.2 dB, compared to other works that have been reported. The SSPR-SOM of 32 × 36 mm, with a microstrip patch antenna is very simple, but works very well as a Doppler radar for short-distance motion detection. ■

ACKNOWLEDGMENT

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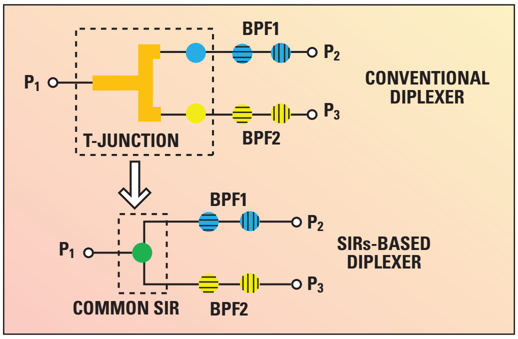
Packaged Microstrip Line Diplexer Using SIRs

A compact microstrip line diplexer is reported, which is integrated into a commercial off-the-shelf package for frequency-division duplex wireless communication systems. This diplexer is designed based on the concept of stepped-impedance resonators (SIR), offering twofold advantages. First, by making use of the first two resonant modes of an SIR, the first resonator in two bandpass filtering channels of the diplexer can be shared, so that the circuit size can be reduced greatly compared to the conventional design. Second, by adjusting the impedance and length ratios of different SIRs, high out-of-band suppression can be achieved over a wide frequency range. The proposed diplexer is then assembled into a commercial package and measured with a customized test fixture. Both simulation and experiment show good results.

A diplexer is an essential component in frequency-division duplex (FDD) wireless communication systems. Typical requirements of modern diplexers are compact size, good return loss, low insertion loss and high isolation between two passbands. Packaged diplexers are usually preferred because they can easily be integrated into transceiver subsystems. Therefore, the aim of this work is to present a complete design procedure of packaged microstrip diplexers suitable for commercial off-the-shelf utilization.

In the proposed diplexer, two passbands are centered at 10 and 15 GHz, respectively, and they have an identical bandwidth of 700 MHz. Some trade-offs have to be made between the circuit size and the electrical performance (such as isolation). The circuit size, however, has high priority in this work due to the limited area of the selected package. In the conventional design of diplexers, the two channels of bandpass filters (BPF) are designed independently and subsequently combined at the common input port for achieving the desired duplexing function through iterative optimization. This design scheme would have two shortcomings if the transmitting and receiving passbands have a large frequency separation: one is the large circuit size occupied by two BPFs and the other one is design complexity due to the T-junction at the common input port P_1. Its transmission response is frequency-dependent, especially over a wide frequency range, so the T-junction would have to be optimized with great effort so that it would not affect the performance of two channel filters.



▲ *Fig. 1 Topology simplification from conventional diplexer to SIR-based diplexer.*

The concept of stepped-impedance resonator (SIR) was proposed to specially arrange the harmonic frequencies of a transmission line resonator by adjusting its impedance and length ratios.[1] Based on this concept, the T-junction and the first resonators in two filtering channels can be replaced by one common SIR,[2] of which the fundamental resonance and first harmonic are allocated at two passbands, respectively. This topology simplification is illustrated in ***Figure 1***. As a result, the T-junction is removed and circuit size is greatly reduced. Furthermore, by using dissimilar resonators with staggered harmonic frequency allocations, it is possible to achieve a high rejection of spurious passbands over a wide frequency range.[3] In the figure, blue and yellow solid nodes represent resonators of lower and upper bands, respectively, while different patterns indicate dissimilar resonators. Therefore, this work will take full advantage of these special features of

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SIR in order to develop a compact packaged diplexer with wideband harmonic suppression.

DESIGN OF THE MICROSTRIP LINE DIPLEXER

Figure 2 shows the proposed diplexer combining two BPFs with a common resonator R1. The substrate of choice is RT/duroid® 6010.2LM with a substrate thickness of 0.635 mm and a copper thickness of 17 μm. Half-wavelength SIRs are chosen for all the resonators in order to avoid the use of grounding vias. A three-pole Chebyshev response is selected for both BPFs in order to reach 20 dB attenuation at 10±2 GHz and 15±2 GHz. The 10 GHz BPF is composed of SIRs R_1, R_2 and R_3, while the 15 GHz BPF consists of SIRs R_1, R_4 and R_5.

In order to enlarge the stopband, the following frequency allocation scheme is adopted for designing the proposed diplexer. All the results in ***Table 1*** are obtained from full-wave simulations.[4] From the table, it is evident that, on one hand, by introducing an impedance ratio larger than 1, the first two resonances of the common resonator R_1 are allocated at 10 and 15 GHz, respectively. On the other hand, for all the other resonators (R_2 to R_5), their first harmonic frequencies are set higher than twice of the fundamental resonant frequency by adjusting their impedance ratios less than 1. Moreover, their harmonic frequencies are staggered, and as a result, spurious passbands can be suppressed over a wide frequency range. However, it should be noted that even when the impedance ratios are the same for R_2 and R_3 as well as R_4 and R_5, their first harmonic frequencies are different due to different length ratios of SIRs, as well as different parasitic effects of the microstrip bend or step discontinuities.

According to the design specifications, the following coupling matrices are synthesized for two passbands, respectively.

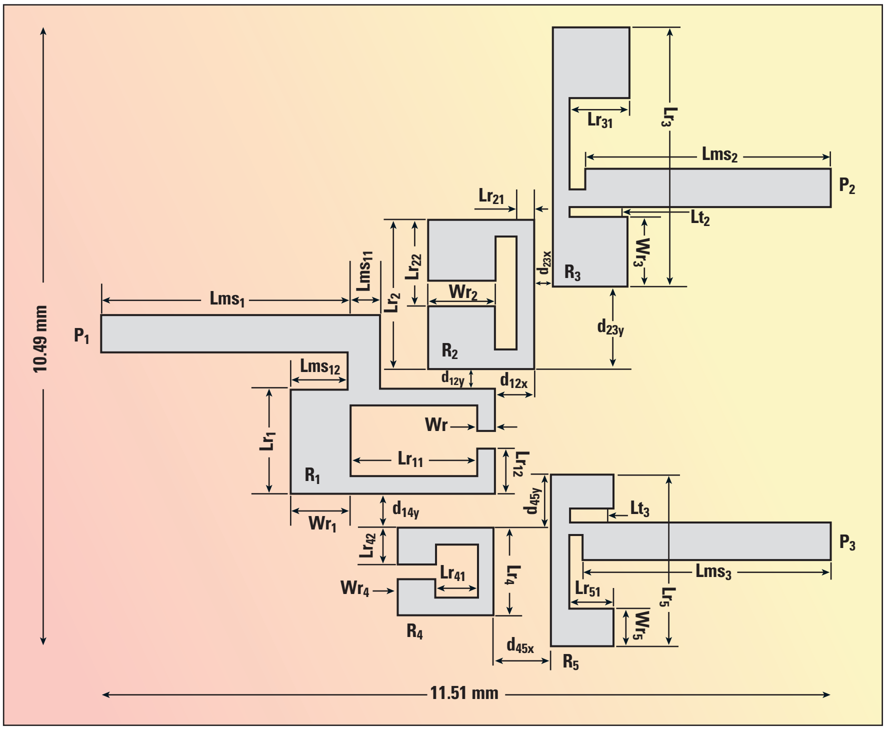
$$[M]\big|_{10\text{GHz}} = \begin{bmatrix} & S & 1 & 2 & 3 & L \\ S & 0 & 0.0758 & 0 & 0 & 0 \\ 1 & 0.0758 & 0 & 0.0722 & 0 & 0 \\ 2 & 0 & 0.0722 & 0 & 0.0722 & 0 \\ 3 & 0 & 0 & 0.0722 & 0 & 0.0758 \\ L & 0 & 0 & 0 & 0.0758 & 0 \end{bmatrix}$$

$$[M]\big|_{15\text{GHz}} = \begin{bmatrix} & S & 1 & 2 & 3 & L \\ S & 0 & 0.0505 & 0 & 0 & 0 \\ 1 & 0.0505 & 0 & 0.0481 & 0 & 0 \\ 2 & 0 & 0.0481 & 0 & 0.0481 & 0 \\ 3 & 0 & 0 & 0.0481 & 0 & 0.0505 \\ L & 0 & 0 & 0 & 0.0505 & 0 \end{bmatrix}$$

TABLE I

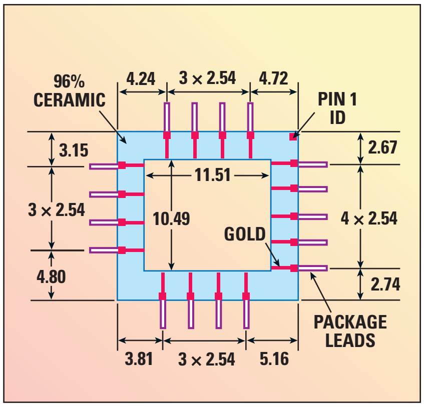
FREQUENCY ALLOCATION SCHEME OF THE SIRs

	R_1	R_2	R_3	R_4	R_5
Impedance Ratio	1.52	0.53	0.53	0.76	0.76
Fundamental f_0 (GHz)	10.0	10.0	10.0	15.0	15.0
Fundamental f_{h1} (GHz)	15.0	28.0	24.5	>30	>30



▲ *Fig. 2 Diagram of the microstrip line diplexer.*

The external quality factor and the coupling coefficients between resonators are subsequently extracted according to the synthesized coupling matrices using the method of Hong and Lancaster.[5] In this procedure, attention must be paid to the following two aspects. The first one is that the diplexer should fit into the available area of the selected commercial package.[6] ***Figure 3*** shows an illustration of the package. It can be seen that the total dimension of the usable area in the package is only 11.51 × 10.49 mm, or 1.02 λ_g × 0.93 λ_g, where λ_g is the guided wavelength of the 50 Ω line at 10 GHz. The second aspect is the input/output of the diplexer should be located at the exact position of the package leads in order to reduce the parasitic effects of the ribbon bond-



▲ *Fig. 3 Illustration of the commercial package.*

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TABLE II

DIMENSIONS OF THE MICROSTRIP DIPLEXER

Parameter	Value (mm)	Parameter	Value (mm)	Parameter	Value (mm)
Lms_1	3.59	Wr_2	1.00	Lr_{41}	0.57
Lms_{11}	0.51	d_{12x}	0.53	Lr_{42}	0.53
Lms_{12}	0.72	d_{12y}	0.24	Wr_4	0.52
Lr_1	1.52	d_{23x}	1.21	d_{14y}	0.38
Wr_1	0.77	d_{23y}	0.18	d_{45x}	0.64
Lr_{11}	1.79	Lr_{31}	0.81	d_{45y}	0.64
Lr_{12}	0.64	Lr_3	3.76	Lr_5	2.41
Wr	0.25	Wr_3	1.02	Lr_{51}	0.60
Lr_2	2.13	Lms_2	3.63	Wr_5	0.51
Lr_{21}	0.23	Lt_2	0.15	Lms_3	3.71
Lr_{22}	0.89	Lr_4	1.27	Lt_3	0.18

ing. A slight optimization was carried out, based on the initial geometrical dimension, in order to satisfy the design specifications and the final dimensions of the designed diplexer as listed in ***Table 2*** for reference.

PROTOTYPING AND RESULTS

Figure 4 shows a perspective view of the packaged diplexer together with the test fixture that is designed using the same substrate. The diplexer is assembled inside the commercial ceramic package with the support of two bonding ribbons on each lead.

A back-to-back transition between the 50 Ω microstrip line and the package is designed and optimized to achieve a good match between the two passbands. Two stages of impedance transformers are utilized with the second stage meandered for reducing the circuit size. ***Figure 5*** plots the simulated performance of the back-to-back transition, and it shows that the return loss is better than 20 dB for the 10 GHz passband and better than 17 dB for the 15 GHz passband.

After being analyzed in a full-wave simulator, the packaged diplexer together with the test fixture was prototyped and measured with three subminiature version A (SMA) connectors, using a vector network analyzer (Anritsu 37397C). A photograph of the fabricated prototype is given in ***Figure 6***.

The measured scattering parameters are compared with the simulated ones in ***Figure 7***. Good agreement is observed except for the increased insertion loss at the high edge of the 15 GHz passband,

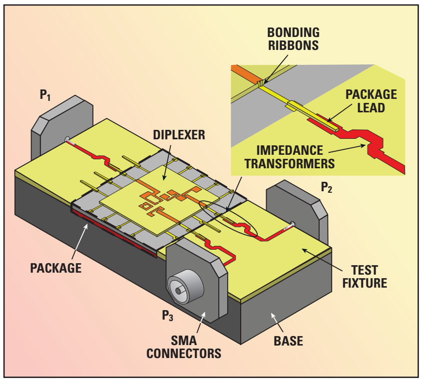


Fig. 4 *Packaged microstrip line diplexer.*

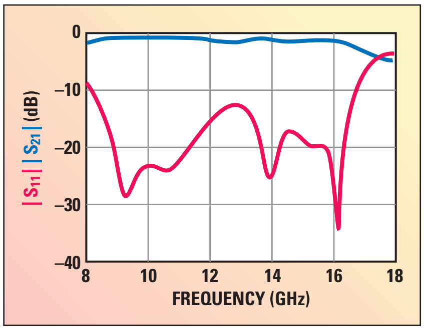


Fig. 5 *Simulation results of the back-to-back transition.*

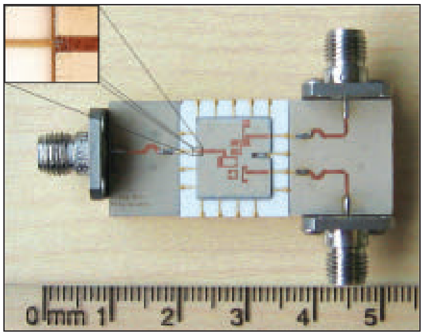


Fig. 6 *Photograph of the fabricated prototype.*

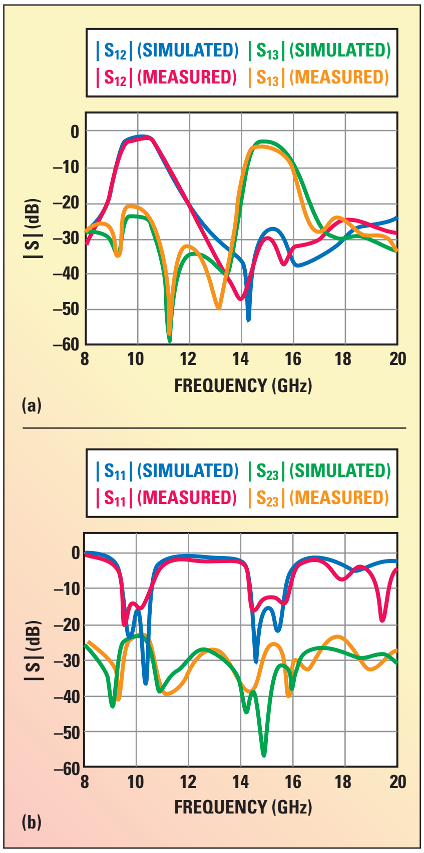
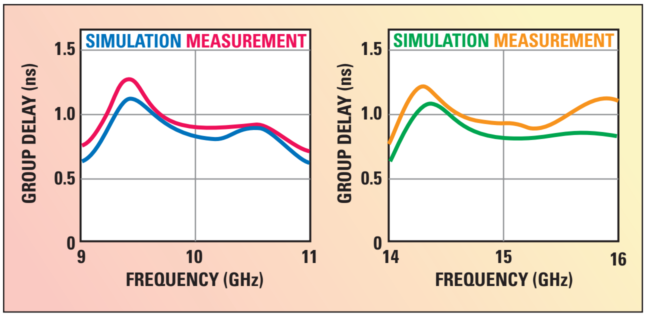


Fig. 7 *Comparison between simulated and measured S-parameters of the packaged diplexer: (a) S_{12} and S_{13} (b) S_{11} and S_{23}.*



▲ *Fig. 8 Comparison of group delay between simulation and measurement.*

which will be discussed below.

From figure 7a, it can be seen that in the simulation, the maximum in-band insertion losses are 2.0 and 3.4 dB in the 10 and 15 GHz passbands, respectively. However, the measured maximum insertion losses are 2.5 and 4.8 dB in the 10 and 15 GHz passbands, respectively. The additional loss can be partially ascribed to the insertion loss of the SMA connectors, which is not included in the simulations. Furthermore, if the diplexer is encased, the measured maximum insertion loss in the 15 GHz passband is 4.4 dB, which means there is 0.4 dB radiation loss from the circuit itself.

It is shown in figure 7b that the simulated return loss of the common port P1 is better than 15 dB for both passbands while the measured return loss is better than 14.5 dB in the 10 GHz passband and better than 12.5 dB in the 15 GHz passband. In addition, the simulated isolation is higher than 23.5 dB over the entire frequency band of interest with a measured one better than 22 dB. The isolation can be further improved by allocating transmission zeros in the passband of the other filter.

Finally, the measured group delay, shown in ***Figure 8***, tallies well with the simulated one. Both of them present small in-band variation.

CONCLUSION

A compact packaged microstrip line diplexer is reported and good results are obtained in both simulation and measurement. This packaged diplexer is very compact and it can be directly and easily applied to wireless communication systems with frequency-division duplex mode. ■

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Defense Market Trends for Microwave Applications in AEW&C

Airborne Early Warning & Control (AEW&C) is a broad term used to describe the airborne capability to detect air, land or water threats and direct a response, typically from a large distance. The radar, control and aircraft platforms are diverse but high performance semiconductor devices and electronic technologies enable them. The rationale behind airborne surveillance is simple: the more you see, the more you know. High altitude aircraft and powerful radars achieve the "more-you-see" capability and sophisticated sensor, onboard processing and communications capabilities satisfy the "more-you-know" dimension.

Earlier versions of these capabilities were called Airborne Warning and Control System (AWACS) or Airborne Early Warning (AEW). In fact, one of the most widely deployed platforms, the E-3 Sentry, has become commonly known as "AWACS." These systems play a major role on the modern battlefield by providing real-time intelligence and the control needed to maintain air superiority over the combat area. These platforms are not solely for wartime use. Several nations devote resources exclusively to enable surveillance of borders in peacetime.

Current airborne surveillance includes, not only detection, tracking and identification of targets, but also execution of actions that result from data derived from its suite of sensors. These actions may be offensive, like the control of other aerial assets (mainly interceptors), or defensive, like initiation of electronic countermeasures. As the processing capabilities on these aircraft have increased, their control capabilities have also improved and expanded to the point where the mission is now exclusively AEW&C.

Airborne Early Warning and Control capabilities provide a fundamental building block of a national defense or combat strategy. Until recently, design and development of AEW&C platforms had been the near-exclusive domain of U.S. military OEMs, but as countries acknowledge the importance of the mission, more

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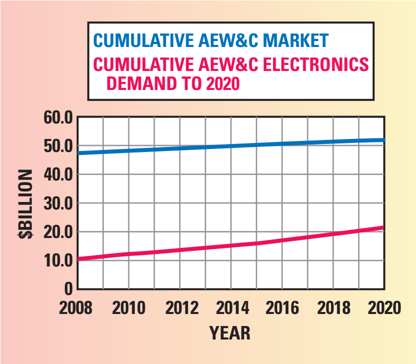
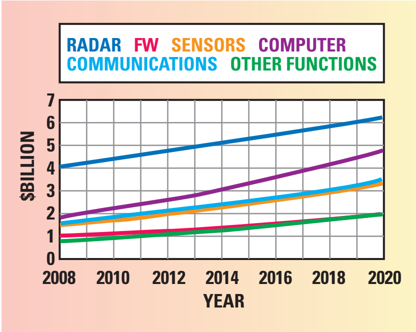


▲ *Fig. 1 Cumulative AEW&C platform market to 2020.*



▲ *Fig. 2 Cumulative AEW&C electronics segmentation.*

AEW&C development effort is being undertaken in other regions and countries, including Europe, Israel, China, India and Russia.

The market is thus growing along two paths: countries with mature capabilities will seek to upgrade to the latest technology to outpace threats, and countries with rudimentary or no capability will purchase new AEW&C platforms. As existing users expand or upgrade their coverage and new countries implement services, Strategy Analytics believes the number of planes in service will see a steady increase with upgrades and retrofits.

Strategy Analytics forecasts a market growing to more than $52 B by 2020 (see ***Figure 1***). The total electronics content for radar, communications, computers, sensors and other related systems will increase over time as technology is upgraded, growing to $22 B.

All AEW&C platforms make extensive use of advanced electronics and component technology for radar, communications, EW, computer, sensor and other related systems. The diversity of AEW&C platforms incorporates a range of technologies including tubes, silicon/GaAs/GaN/other microelectronics and optoelectronics. The basic subsystems found onboard a typical AEW&C platform are as follows:

- Radar
- Data processing
- Displays
- Identification Friend and Foe (IFF)
- Radio & Data Communications
- Navigation
- Electronic Support Measures (ESM)
- Electronic Counter Measures (ECM)

These subsystems require a control system to ensure that all are functioning correctly at the right time. AEW&C aircraft also have individual electronic units for other systems, notably the flight controls and engines. Collectively these represent a substantial opportunity for electronic components and associated hardware.

From an electronics perspective, even though the yearly increase in platforms is relatively small, the deployed base is very large. The attractive aspect of this market is the development time, longevity and expense of the airframe platform, which makes it uniquely suited to the upgrade market (see ***Figure 2***). The most important system aboard the AEW&C platform is the main radar sensor. A typical AEW&C will have at least two radar systems: the main radar for the early warning functions and a smaller nose-mounted unit for general use in situations such as adverse weather alerts. New platform developments and upgrades are typically utilizing some form of phased array radar to perform these functions. There are two basic designations for electronically scanned arrays: passive and active. The phased array concepts are identical for both types, but the implementation is different, with the main difference being the transmit power source. Older AEW&C platforms predominantly use passive arrays utilizing TWT-based power sources with radars in rotating rotodomes, while new platforms are increasingly making use of GaAs-based T/R modules in active arrays.

As an example, the E-3D Sentry, best known as the AWACS, uses an older Passive Electronically Scanned Array (PESA) radar that continues to provide several major air forces with a system well matched to their needs. The main radar antenna is located

inside a rotating rotodome mounted above the spine of the aircraft. This rotodome contains several systems, primarily the Northrop Grumman AN/APY-1/2 search radar on one side of a 30-foot long beam structure and, on the other, a set of aerials for the IFF AN/APX-103 interrogator, supplied by the Telephonics Corp., and data-link fighter-control (TADIL-C) antennas. A dual klystron-based amplifier system inside the fuselage generates the RF power that is sent to the antenna array via waveguides.

There have been several upgrades to this program, but there is no plan to replace the PESA radar with a solid-state Active Electronically Scanned Array (AESA) radar. One of the biggest upgrades for the AWACS was the Radar System Improvement Program (RSIP) that has been referred to as "Sharpening the Eye of the Eagle" and replaces aging original equipment. RSIP was a joint U.S./NATO development program involving major hardware and software-intensive modification and costing $1.2 B for the 32 U.S., 17 NATO and seven UK E-3 aircraft.

At the other end of the spectrum is the U.S. Navy E-2 platform, the most popular AEW&C plane in the world. The U.S. Navy has added incremental improvements, the most recent implemented in the Hawkeye 2000. The Navy is also performing a major platform upgrade with the E-2D Advanced Hawkeye. This variant will revamp the radar and include the Northrop Grumman APY-9 AESA based radar. Its new rotodome, developed by L-3 Communications Randtron Antenna Systems, will provide 360-degree scanning capability in a hybrid mechanical/electrical scanning arrangement.

In an AESA implementation, each element is driven by a transmit/receive (T/R) module. These T/R modules contain solid-state MMICs, typically GaAs for the transmit/receive paths and silicon for the control functions with future trends pointing toward GaN technologies being used in conjunction with SiGe.

Development time, cost, mission and radar performance are just a few of the trade-off characteristics that make platform upgrade such a multi-layered decision process. As described, most of the earliest, most popular aircraft platforms were modified to incorporate rotating rotodomes. A discussion of modifications and trade-offs must often be viewed in the context of the entire AEW&C platform and whether the improved performance and capability of an AESA radar does not offset the cost of retrofitting the rest of the platform.

Changing focus to communications, information must be disseminated quickly and efficiently to all assigned agencies working with the AEW&C aircraft. The users of this information generally fall into two categories: onboard and external staff. In practice, the AEW&C platform is at the center of a three-dimensional network of forces ranging from relay satellites and ground stations to strike aircraft and other assets. Other onboard communications capabilities include secure voice and data communication systems.

- The Erieye has a secure voice and data link communications suite with HF and VHF/UHF links. The VHF/UHF data link operates at 4800 bps.
- The Boeing Wedgetail has a communications suite that includes three HF and eight VHF/UHF communications systems together with Link 4A and Link 11 systems.

AEW&C platforms must ensure that all communications are secure from enemy eavesdropping. To address this issue, the Joint Tactical Information Distribution System (JTIDS) was developed and is now common to most airborne assets. An additional avenue to address this issue is AWACS systems providing anti-jam communication for information distribution, position location and identification capabilities.

As far back as 1989, an improved communication system named HAVE QUICK A-NETS was deployed to address secure communications. This system provides secure, anti-jam contact with other AWACS platforms, friendly aircraft and ground stations. It is also included in French and RAF systems. The AN/ARC-164 HAVE QUICK II radios are used for air-to-air, air-to-ground and ground-to-air communications and are deployed on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all Army rotary wing aircraft. By 2007, nearly all U.S. military aircraft had adopted HAVE QUICK. Improvements include HAVE QUICK II Phase 2, and a "Second generation Anti-Jam Tactical UHF Radio for NATO" called SATURN. The latter features more complex frequency hopping.

Another system called enhanced TADIL-A Link-11 ensures high speed exchange of radar information. Also known as TADIL-J, or Link-16, it requires additional computer memory to anticipate new ESM and future enhancements. The Class 2H JTIDS terminal is a secure digital communications system that allows E-3 crew members to communicate with other participants such as fighter aircraft, Navy units and ground-based units during air battle. It has a capability to identify units using common points of reference.

Looking at the communications systems in general, common trends across the board include a move toward higher frequencies and wideband performance, driven by a need to have multi-mode, multi-band capabilities that will enable these radios to act as nodes in the total battle space. This is coupled with an increasing emphasis on data and efficient spectrum use that will drive linearity requirements as well as the continued development of SDR and cognitive radio capabilities. While Si-based power amplifiers are the incumbent technology, these factors will provide opportunities for other RF technologies that can couple high power outputs with wideband performance, linearity and higher efficiencies.

Electronic Support Measures (ESM) provide for a passive detection, electronic surveillance capability to detect and identify air and surface-based emitters. The ESM system passively detects signals from hostile, neutral, friendly, and unknown emitters and identifies targets, augmenting present on-board sensors. ESM equipment consists of sensitive direction finding radar-warning receivers coupled to an extensive software threat library to permit the calculation of bearing and type tracks. These are made available in a format readable by the data processing software, allowing the operators to passively identify sources of transmission, oftentimes at ranges nearly double those of active radar and with useful receive sensitivity.

Electronic Counter Measures (ECM) are now considered essential for all military and even some chartered civil aircraft. There may be times when high-value platforms, such as AEW&C, will have to rely on self-defense when enemy fighters or missiles get too close. Lacking offensive armament, the AEW&C relies on special ECM and electronic counter-countermeasures (ECCM) to confuse and deflect incoming threats. The concept of Smart Jamming, for example, involves detecting the oncoming missile, classifying it by identifying its seeker signature and then sending a jamming signal in a particular band to break its lock. These types of concepts are leading to what may be described as a "no-channel" concept in which the systems are tasked with looking at a complete frequency

range resulting in multiple channels being handled by one receiver. For jamming applications, this has to be coupled with high power capabilities across the frequency range and this has opened the door for GaN-based systems in this area.

The enabling RF technologies, of which there is a wide range, include Si, SiGe, GaAs, GaN as well as TWTs. Each technology offers specific advantages.

- Si LDMOS/MOSFET technologies provide good saturated power capabilities, but have a relative limited frequency range. While operating along the same frequency ranges, SiC offers higher power.
- SiGe offers broader frequency capabilities, but is limited in power. However, the integration capabilities will see SiGe used in the receive function while SiGe-based ADC and DAC components will see increasing penetration of the radar, EW and communications systems as phased array capabilities are coupled with digital receivers.
- GaAs offers a strong mix of power, frequency and linearity capabilities that have driven the use of this technology but still has limitations compared to TWT capabilities.
- TWTs offer the broadest frequency operation, very high efficiencies and reliability coupled with high power but scaling can be an issue, depending on the platform.
- GaN appears to offer the best solution in terms of power, efficiency, wide frequency operation and reliability though linearity can be an issue.

The AEW&C platform is a good example of the trends in the defense industry that will drive demand for RF technologies. For communications, electronic warfare and radar systems, both in AEW&C as well as in the broader defense sector, capabilities are expanding around specific parameters such as broadband performance, power, linearity and digitization. No one semiconductor technology solution will singularly satisfy every system requirement, and we will see different technologies used side-by-side depending on the requirements of the system and platform. While global economics have forced governments to rethink defense priorities, the desire for technology differentiation will lead to continued opportunities for electronic systems and the enabling of semiconductors in both emerging platforms as well as through upgrade/retrofit channels. ■

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Extending Millimeter-wave Measurement Systems with Harmonic Mixer Technology

Emerging applications in the millimeter-wave (mm-wave) band, which occupies the 30 to 300 GHz spectrum (wavelengths from 10 to 1 mm), now span radio astronomy, communication, imaging, space research and homeland security. Market forecast and limited available spectrum suggest that attractive growth is just over the horizon. Most engineers extend their existing test equipment into this mm-wave spectrum with frequency extension accessories based on harmonic mixer technology.[1] The purpose of this article is to provide an overview of the low cost harmonic mixer technology (retail pricing is currently between $2,000 and $6,000 USD) and to present practical tips on how to apply this commercially available down conversion technology to spectrum analysis.

HARMONIC MIXER PRIMER

To overcome frequency limitations in available instrumentation, frequency extension accessories based on harmonic mixer technology are used to down convert the mm-wave spectrum into the signal analyzer's bandwidth for analysis. In a typical external mixer setup, the harmonic mixer bridges the gap between the mm-wave output from the DUT and the lower frequency spectrum analyzer input (see ***Figure 1***). In this way, the harmonic mixer provides the enabling technology for mm-wave measurements. This setup functionally relies on an external mixer option in the spectrum analyzer for the necessary LO and IF interconnects to the harmonic mixer and automatically displays the desired signal parameters. Once connected, the nth harmonic of the LO frequency mixes with the mm-wave frequency (RF) to produce the predefined IF frequency. The conversion loss of the harmonic mixer is proportional to the multiplier factor, n. This popular setup depends on a diplexer for signal separation, which can be either external or internal to the spectrum analyzer.

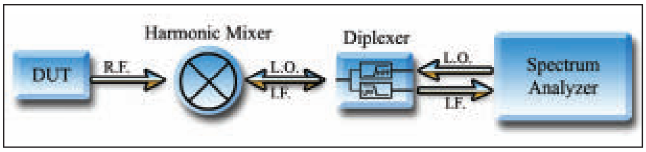

Fig. 1 The harmonic mixer converts the DUT mm-wave (RF) to a predefined IF frequency.

With an external mixer option, the harmonic mixer operation with the spectrum analyzer is transparent to the user. The harmonic mixer with waveguide interface can conveniently connect to the mm-wave output of the DUT or to a waveguide antenna. On the opposite side of the harmonic mixer, a reasonable length coaxial cable (such as 1 meter) offers efficient access to the spectrum analyzer, including the diplexer. After selecting the corresponding waveguide band on the spectrum analyzer, engineers can use their familiar instrument to conduct mm-wave measurements on their DUT. For accurate amplitude measurements, additional offset features are available in the spectrum

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- Designed for harsh environments

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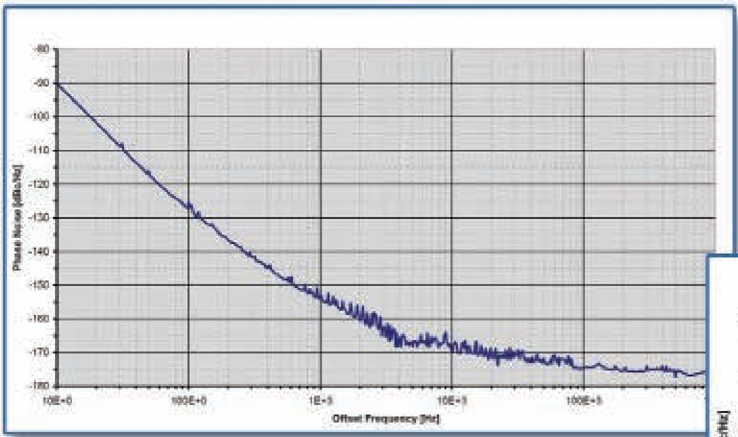
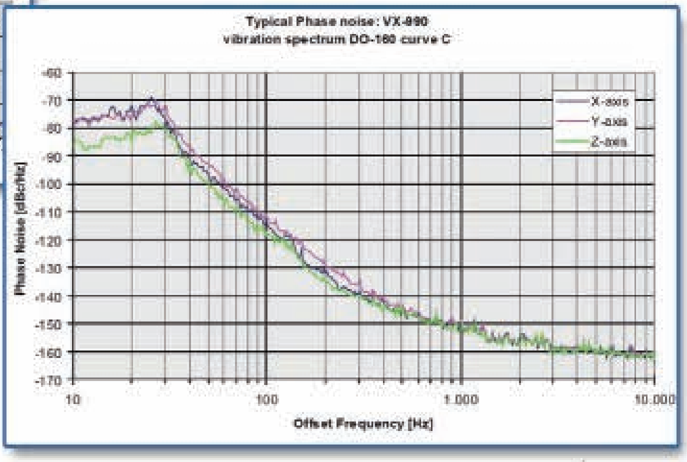


Phase Noise Under Vibration

Frequency: 120 MHz



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- Land based radar

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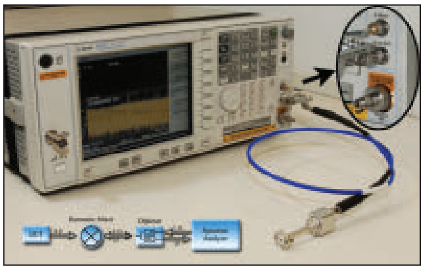
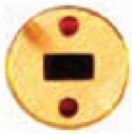
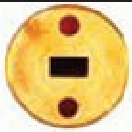
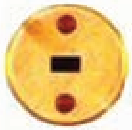
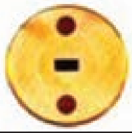
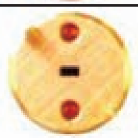
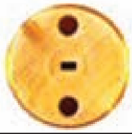
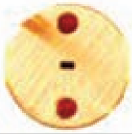
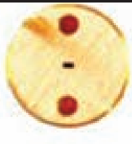


▲ *Fig. 2 A typical mm-wave measurement set-up.*

analyzer to manually compensate for the conversion loss of the harmonic mixer. In this way, this frequency extension accessory offers an attractive value proposition to engineers with mm-wave requirements.

A typical mm-wave measurement setup includes the microwave spectrum analyzer, harmonic mixer and diplexer (see ***Figure 2***). Cabling is efficient and unobtrusive. The inlay shows the close-up interconnects between the diplexer and the IF and LO inputs provided with the external mixer option.

As background, the spectrum analyzer's external mixer option enables substitution of the harmonic mixer for its own RF front-end design to overcome the mm-wave measurement limitation. After substitution, the later stages in the spectrum analyzer's receiver chain are still utilized for the remaining signal analysis capabilities. Harmonic mixer suppliers use spectrum analyzer manufacturer's designated LO, IF, and multiplier factor

WAVEGUIDE SPECTRUM	TE$_{10}$ CUTOFF FREQUENCY (GHz)	RECTANGULAR WAVEGUIDE INTERFACE VIEW	INTERNAL DIMENSIONS (mils)	AGILENT PSA MULTIPLIER FACTOR, n
50 – 75 GHz WR-15 V-BAND	39.9 GHz		148.0 × 74.0	14
60 – 90 GHz WR-12 E-BAND	48.4 GHz		122.0 × 61.0	16
75 – 110 GHz WR-10 W-BAND	59 GHz		100.0 × 50.0	18
90 – 140 GHz WR-08 F-BAND	73.8 GHz		80.0 × 40.0	22
110 – 170 GHz WR-06 D-BAND	90.8 GHz		65.0 × 32.5	26
140 – 220 GHz WR-05 G-BAND	115.7 GHz		51.0 × 25.5	32
170 – 260 GHz WR-04 Y-BAND	137.2 GHz		43.0 × 21.5	38
220 – 325 GHz WR-03 H (J)-BAND	173.6 GHz		34.0 × 17.0	48

▲ *Fig. 3 Popular 50 to 325 GHz mm-wave spectrum by waveguide bands.*

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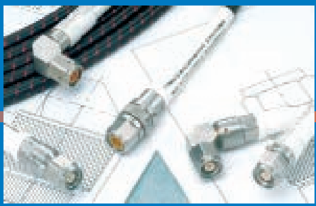

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to characterize their harmonic mixers (with bias, if available).[2] The correction process is easy to implement using the supplier's final test data.

Once connected, the harmonic mixer design down converts the RF signal by mixing the nth harmonic of the LO to generate the predefined IF of the existing instrument. The RF input and the harmonics from the LO drive the mixer to produce the IF that satisfies the equation n(LO) – (RF). As an example, the high performance spectrum analyzer with predefined IF of 321.4 MHz has multiplier values that can range from n = 14 for WR-15 to n = 48 for WR-03 (see ***Figure 3***).[3] Typically, firmware automatically handles the multiplier factor so the displayed start and stop frequencies are the desired mm-wave RF spectrum. In addition, offset compensation is possible so displayed amplitude corrects the conversion loss of the harmonic mixer. In a typical measurement scenario, the display readout offers actual results with real-time updates when using the harmonic mixer technology with the spectrum analyzer.

RECTANGULAR WAVEGUIDES

Below 50 GHz, commercially available instrumentation using coaxial connections are available for convenient and affordable signal analysis, as well as reasonable cable losses. Over the 50 GHz threshold, rectangular waveguide is often implemented for its low-loss transmission of mm-wave frequencies. In particular, popular waveguide band segmentation allows engineers to translate their application into the proper frequency extension accessory that is based on these same industry standard waveguide terminologies.

Figure 3 also contains the key rectangular waveguide information for the TE_{10} propagation mode, including the aperture size, both dimensionally and visually, for relative comparisons. The cutoff frequency indicates the frequency above which electromagnetic energy will propagate in the corresponding waveguide. The dimensions are proportional to the wavelengths, which decrease with higher frequencies. The multiplier factor (n) is a harmonic mixer value chosen by the analyzer manufacturer that down converts the millimeter to the microwave spectrum for easier analysis in modern spectrum analyzers.

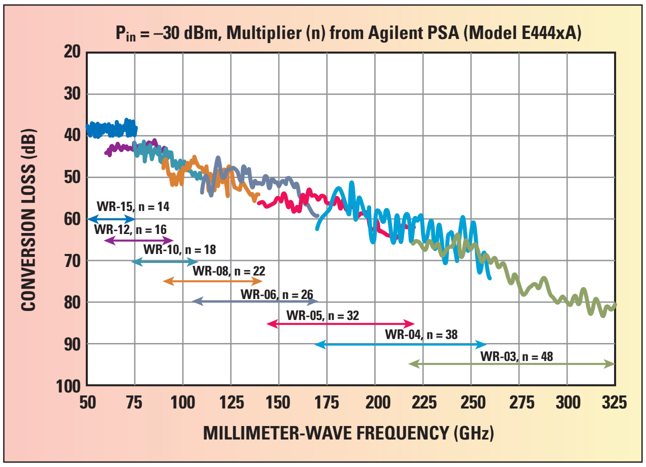

Fig. 4 Representative conversion loss of a single unbalanced harmonic mixer.

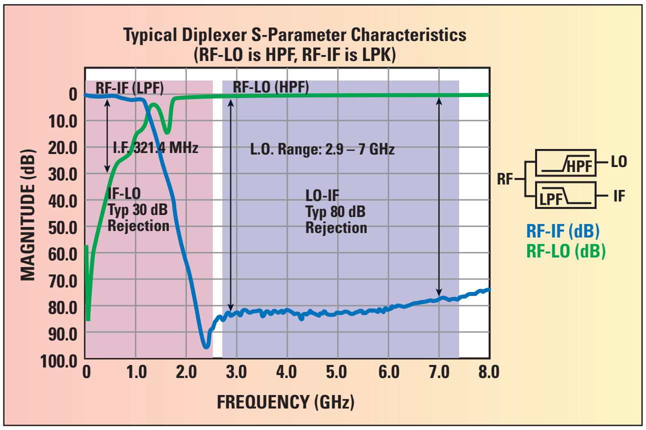

Fig. 5 Diplexer design for external mixing.

MEASUREMENT EXAMPLE

For most convenient readouts, modern spectrum analyzer features can compensate for the external harmonic mixer attributes, so amplitude and frequency readouts are accurate. For amplitude readouts, the harmonic mixer manufacturer supplies the typical amplitude correction factor (that is conversion loss) value, which is largely influenced by the nth harmonic of the LO signal needed to down convert the RF to the predefined IF for signal analysis. As one might expect, the conversion loss


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increases with higher multiplier values. ***Figure 4*** shows the representative conversion loss of a single diode, unbalanced harmonic mixer versus the mm-wave frequency range for the Agilent PSA Signal Analyzer (model E444xA). As predicted, the multiplier factors are overlaid with the typical conversion loss values to show how conversion loss increases with the multiplier value. These results are typical for the predefined LO, IF capabilities of the PSA. Results may vary when using other spectrum analyzers, due to different settings for LO, IF, and multiplier factors. For simplified frequency readouts, the spectrum analyzer contains preset settings, selectable by waveguide band, to compensate for the multiplication factor so the frequency scale reads RF instead of LO or IF.

Independently verifying the operation of the harmonic mixer requires a mm-wave source with a known power level. Simply set the RF source to a value in the harmonic mixer's linear range avoiding input compression. Using Figure 1, apply this "reference" RF signal to the input of the harmonic mixer and complete the LO and IF connections to the spectrum analyzer (an external diplexer may be necessary). After properly configuring the spectrum analyzer for external mixer operation, the readout will display a measured value that includes the reference signal level and the harmonic mixer's conversion loss. By entering the conversion loss as an offset, the spectrum analyzer will display the corrected power level.

MEASUREMENT CONSIDERATIONS

The following factors should be considered by test engineers when using harmonic mixers to extend their measurement system into mm-wave frequencies:

Damage Level: The maximum input power is typically 20 dBm, where nominally +15 dBm is allocated to the LO signal. Maintaining composite power levels below +20 dBm ensures damage will not occur to the harmonic mixer diode(s).

Linearity: Mixers are inherently nonlinear devices, so careful selection of power levels will help optimize the results. Position measurements in the linear input range, which, practically speaking, mean to avoid applying input signals within 10 dB of the 1 dB compression point. Below -30 dBm input power, single diode unbalanced harmonic mixers typically provide both accurate and repeatable measurements when using high performance spectrum analyzers.

Mixer Topology: Balanced mixers are popular for their increased linearity performance. However, they also fundamentally limit harmonic mixing to only even products due to the balanced properties in this topology. This may be a good selection as long as the spectrum analyzer utilizes even harmonic multipliers in their external mixer option. In contrast, the single diode mixer offers more versatility to use both even and odd products with less LO power, which are the reasons for their popularity in mm-wave applications. The single diode topology also requires bias, which can be useful to "peak" responses and further optimize results.

Image Rejection: There will be numerous mathematical intersections occurring where these harmonic cur-

rents, m + n, combine to produce responses within the spectrum analyzer's IF bandwidth. Furthermore, the strongest of these IF responses can, in turn, be combined with other m + n products to produce additional IF responses. Do not be alarmed that the results on a spectral display look like a "picket fence." Instead, most high performance spectrum analyzers offer "image rejection" features to eliminate "false" from the "desired" results, thereby simplifying the signal analysis task.

Conversion Loss and Dynamic Range: Frequency extension using harmonic mixer technology is a valuable tool for measuring fundamental characteristics of mm-wave signals, but not without some trade-offs. As a general observation, the higher conversion loss versus higher frequency behavior reduces measurement dynamic range and might be an obstacle when measuring low-level signals (such as intermodulation distortion products, discrete spurious or noise figure). As a tip, it is important to analyze after external mixing (taking into account the conversion loss) whether sufficient dynamic range (that is signal-to-noise ratio) exists in the spectrum analyzer for accurate measurements. Generally speaking, accurate measurements require greater than 10 dB signal-to-noise ratio.

Diplexer Characteristics: The diplexer is essential to the successful operation of the harmonic mixer, especially in single diode harmonic mixers. Although it is more convenient when the diplexer is integrated into the spectrum analyzer, this is not always the case. For example, the Agilent PSA (model E488xA) requires an external diplexer as part of its external mixer setup. In this case, the predefined IF is 321.4 MHz and the available LO range is 2.9 to 7 GHz. The diplexer design for external mixing is optimized for signal separation and harmonic mixing performance at the predesigned IF and available LO range of 2.9 to 7 GHz and will ensure these frequencies will flow unimpeded and with adequate signal separation to optimize performance for mm-wave spectrum analysis (see ***Figure 5***). The diplexer characteristics are occasionally worthwhile to consider in the setup because they constitute hardware constraints.

SUMMARY

The harmonic mixer technology enables the practical measurement of millimeter-wave signals. This primer describes harmonic mixer technology, including the typical conversion loss versus the millimeter waveguide bands for single diode harmonic mixers. This primer and tips will ensure that engineers can explore the mm-wave frontier using the terminologies and frequency extension accessories as practical tools. This technology is also the foundation for additional frequency extension accessories deployed in mm-wave signal generation, scalar, and vector network analysis. ■

References

1. M. Sayed, "Millimeter Wave Tests and Instrumentation," *65th ARFTG Conference Digest*, June 2005, pp. 28-37.
2. "Using a Millimeter Wave Harmonic Mixer to Extend the Frequency Coverage of a Spectrum Analyzer," OML Inc. Application Note, 42-010124, January, 2001.
3. "External Waveguide Mixing and Millimeter Wave Measurements with Agilent PSA Spectrum Analyzers," Agilent Technologies Application Note #1485, 5988-9414EN, October, 2007.

Spectrally Compliant Waveforms for Wideband Radar

Modern radars often require the use of wideband waveforms to perform high resolution target imaging. In microwave systems, the bandwidth can be on the order of 1.5 GHz, while in UHF systems that typically operate between 200 and 500 MHz, the waveform bandwidth might exceed 200 MHz. A major issue in the operation of such systems is that they often overlap the spectrum used by other radars, and even the spectrum allocated for other types of systems, such as communications and navigation devices.

Thus for the radar to operate using a wideband waveform, spectral notches must be included that suppress the radiated signal by 30 dB or more at frequencies allocated to other systems. One method, for a radar to generate such notches, is to interrupt the sweep of a linear FM (that is a CHIRP) pulse. While this method can be effective, it often results in a significant loss in radiated power as the transmitter is turned off during the notching. The action of turning the transmitter on and off can also cause significant VSWR problems. Additionally, there are systems for which a modulation, such as a phase coded or noise-like modulation, is required.

To address these challenges, Technology Service Corp. (TSC) has developed software for the U.S. Army to generate constant envelope amplitude, spectrally compliant, wideband waveforms. The waveform generation approach is based on constrained optimization theory. Such waveforms are currently being used in a state-of-the-art wideband UHF synthetic aperture radar (SAR). Among the capabilities of the software are the abilities to:

- Generate either constant amplitude pulses, or pulses with controlled leading edge rise times, trailing edge fall times and pulse envelope tapers.

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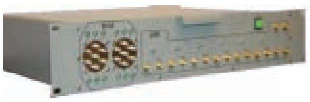

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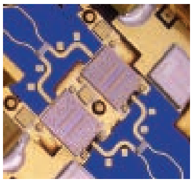

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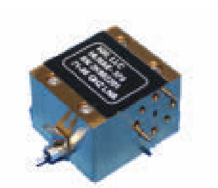

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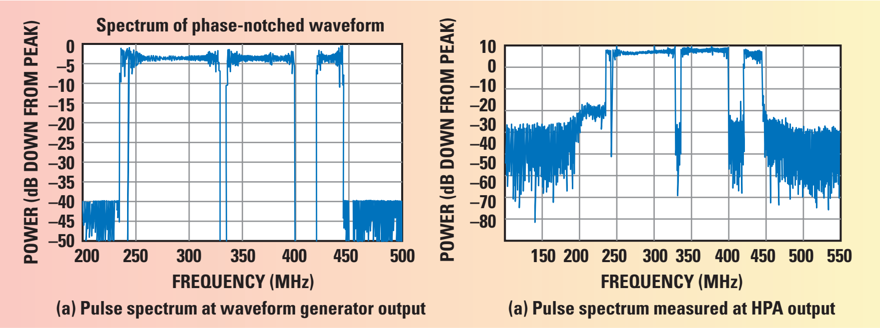


▲ *Fig. 1 TRACER waveform.*

- Create multiple, narrow and wide spectral notches, both within and outside the radar waveform bandwidth (notching in excess of 15 percent of the signal bandwidth has been demonstrated).
- Pre-distort the signal that is input to the radar's high power amplifier (HPA) to ensure that the requisite notches are preserved in the transmitted signal.
- Generate mismatched pulse compression filters that suppress (typically by 15 dB) the high range sidelobes created by the spectral notching.

The software produces the digital waveform coefficients (currently done offline) that are stored in the radar's digital arbitrary waveform generator within nominally one minute. (This time could be shortened by many orders of magnitude by re-hosting the code in a language such as C++ on an FPGA processor.)

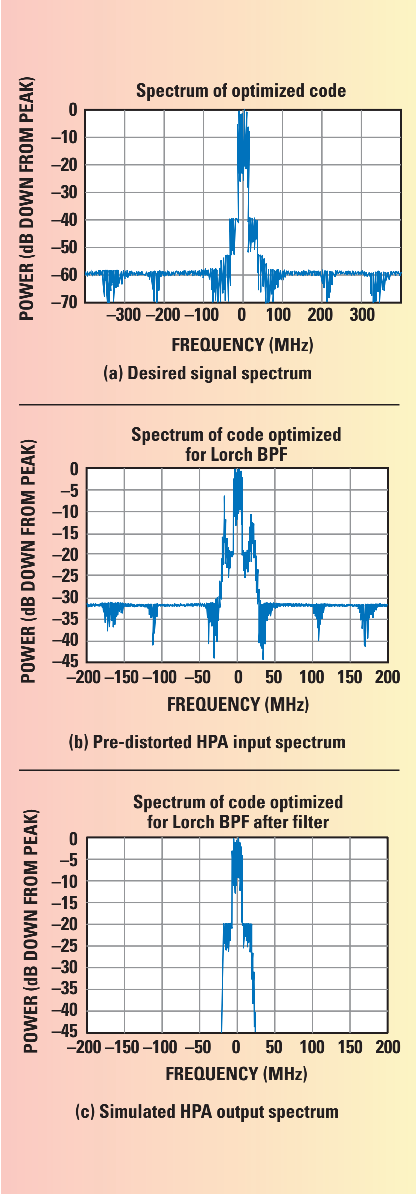
SAR WAVEFORM EXAMPLE

The Tactical Reconnaissance and Counter-concealment Enabled Radar (TRACER) is a UHF SAR that is being developed by Lockheed Martin in Phoenix, AZ, for the U.S. Army CERDEC. For a waveform designed specifically for domestic testing purposes, TRACER was required to incorporate four spectrum notches. There are three in-band notches centered at 243, 332 and 410 MHz with widths of 0.5, 6.8 and 20 MHz, respectively, and one out-of-band notch centered at 452.5 MHz with a width of 5 MHz. ***Figure 1*** shows the notched spectrum of the resulting TRACER domestic testing waveform. The Lockheed measurements have thus confirmed that all of the spectral notches had depths of at least 40 dB when measured at the HPA output. (Note: The pre-distortion techniques described below were not applied to this waveform.)

WAVEFORM PRE-DISTORTION

In some radar systems, the transmitter amplitude and phase characteristics can degrade the spectral notch characteristics. To prevent this from occurring, waveform pre-distortion techniques that compensate for transmitter effects have been developed. The waveform generation software uses the measured transmitter characteristics to pre-distort the signal at the HPA input in a manner that preserves the desired characteristics at the output.

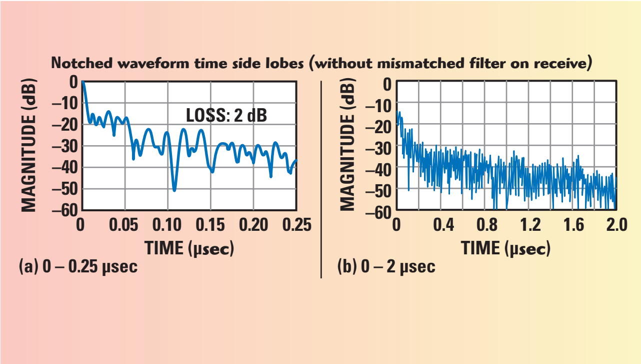
For example, ***Figure 2*** is a simulated case where a transmitter having a steep spectral roll-off and a nonlinear phase characteristic was modeled. Figure 2a shows the spectrum of a desired constant amplitude transmit pulse. Figure 2b shows the spectrum on the pre-distorted signal that was input to the simulated transmitter. Figure 2c shows the resulting spectrum at the HPA output. As can be seen, the spectrum at the simulated transmitter output very closely resembles the ideal spectrum. The output pulse's envelope amplitude ripple was less than 0.1 dB. Thus, the pre-distortion techniques should be effective in preserving the desired pulse amplitude and spectral characteristics. (Note: Although there are no spectral notches in this example, simulated notched waveforms show similar performance.)



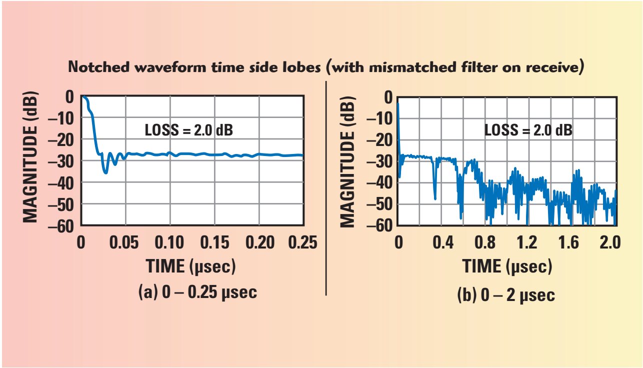
▲ *Fig. 2 Spectrum of desired signal.*

MISMATCHED FILTERING

When a significant fraction of the waveform is notched, high pulse compression sidelobes result. This is shown in ***Figure 3*** for the notched TRACER waveform presented in Figure 1. To reduce the sidelobes, the software also provides a mismatched pulse compression filter (MMF). As shown in ***Figure 4***, the MMF suppresses the high range sidelobes



▲ *Fig. 3 Matched pulse compression filter response for the notched TRACER waveform.*



▲ *Fig. 4 Mismatched pulse compression filter response for the notched TRACER waveforms.*

by nominally 15 dB. The cost for achieving this sidelobe suppression is a 58 percent broadening of the 3 dB compressed pulse width and a 2.0 dB SNR loss. These values are comparable to a weighting function (that is Hamming) that would typically be applied to a radar signal.

SUMMARY

The Spectrally Compliant Waveform Generation Software, which is a licensed TSC product currently being used by the Army's TRACER program, has been used to support several other radar development efforts. The waveform generation software can provide the capability of a wideband system to operate in complex RF environments and to address the requirements of both U.S. and host nation spectrum management organizations.

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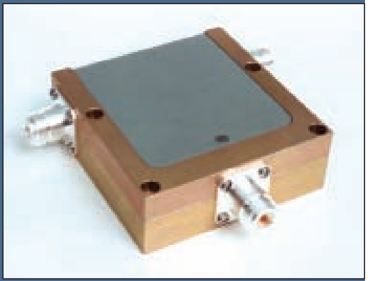

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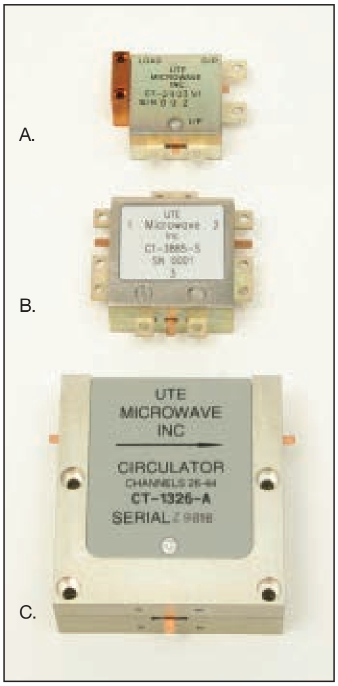

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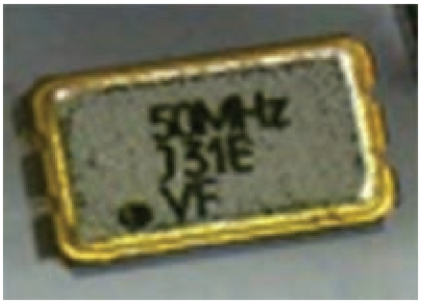


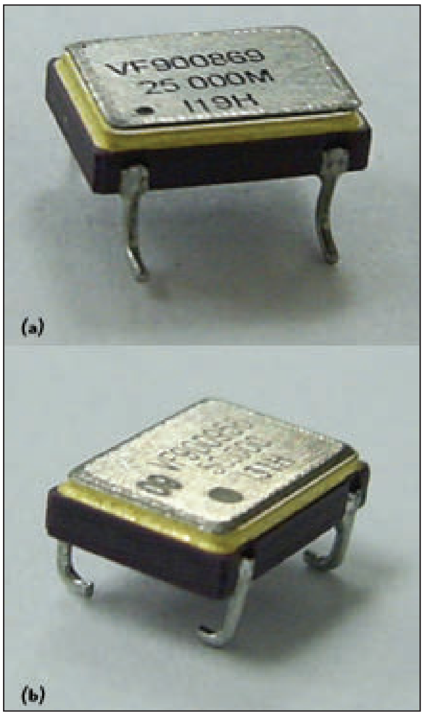
Smaller is Better in Military Applications

In many electronic assemblies today, thermal mismatch between the printed circuit board (PCB) and the ceramic components causes micro cracks in the solder joints. Several factors contribute to these cracks, notably component size, temperature variation, PCB material and solder material. A common result of these cracks is intermittent failures during use. The failures are easy to detect, but hard to repeat. In commercial applications, we have all experienced this when a cell phone call is dropped, there is a skip in a YouTube video, or an Internet application is temporarily interrupted. The impacts of these interruptions are usually trivial. In military applications, a missile loses its location or target, a soldier's tracking device fails (leaving him temporarily "lost" or worse, not identified as "friendly") or radio communication stops. In these applications, intermittent failures can be life threatening.

In the electronic components market, the standard package for an oscillator device is a ceramic surface-mount (SMT) 7 × 5 mm, 4 or 6 pin package. There are tens of millions of these devices sold every year. In the commercial market, where temperature variations are limited to –40° to 85°C, these oscillators are used in every type of application from SONET to LTE to test equipment. Their universal availability and small size make them ideal for most applications.

In military applications, where temperature extremes are much more demanding (–55° to 125°C), the 7 × 5 mm package is "too big." It seems crazy to think a part the size of the word "big" on this page is actually too big for an application. The calculations are complicated, but the reason is simple; over these temperatures, the PCB flexes more than the ceramic package. The weakest part of the assembly is the solder joint. To relieve the pressure of the stress, micro cracks form on the joint. If there is enough flex and enough cracking, the electrical connection in the joint is "opened" and, for a moment or longer, the device stops functioning. Once the temperature is reduced, the

VALPEY FISHER CORP.
Hopkinton, MA

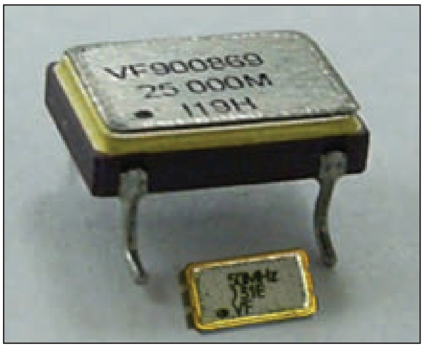


▲ *Fig. 1 Gull wing package (a) and J-lead package (b).*

PCB returns to a normal state, the micro cracks fill in and the device begins working again.

Designers of military-grade systems are well aware of this phenomenon and choose to design using larger packages (14 × 9 mm or greater) with leads on them. The leads "flex," allowing the PCB to move while the more rigid package remains stiff. In applications where a smaller component size is required, manufacturers have been challenged to create new package solutions. Since 7 × 5 mm packages are not available with leads, one accepted solution is to braze or weld leads onto the package. The parts are manufactured using the standard 7 × 5 mm assembly process and then have the leads attached using a brazing process (see ***Figure 1***). The leads are added one at a time and the process is time consuming and tedious. It is also expensive, adding significant cost to the devices. However, it works to relieve the thermal "mismatch" between the PCB and ceramic package.

The Valpey Fisher VFH3225 miniature hi-rel/COTS oscillator represents a significant change for designers of military systems. It takes advantage of the latest package technology, a ceramic SMT 3.2 × 2.5 mm 4 pin package (see ***Figure 2***). At just one



▲ *Fig. 2 Valpey Fisher VFH3225 package compared to traditional 7 × 5 mm package.*

quarter the size of the 7 × 5 mm package, or the size of the "b" in the word big, it is small enough that the thermal mismatch between PCB and ceramic is not significant. In other words, the PCB does not flex enough to cause significant stress on the solder joints to crack them. There is no need to add costly leads and designers are no longer restricted to using the larger packages with leads on them.

In addition to solving the thermal mismatch problem, the VFH3225 is the only military temperature range oscillator available that operates up to 160 MHz while maintaining a temperature stability of 50 ppm. With supply voltages of 3.3, 2.5 and 1.8 V, a low power consumption of 12 mW and available Group A, B or C testing, the VFH3225 is a good fit for applications where the environmental conditions are demanding and the choices are limited.

The VFH3225 represents the latest technology achievement from Valpey Fisher. With more than eight decades of innovation in oscillators (including special recognition in 1945 from General Eisenhower for the company's contribution to the war effort), the company continues to design and deliver hi-rel/COTS products that enable a wide range of applications for military communications, munitions and guidance systems.

VENDORVIEW

Valpey Fisher Corp.,
Hopkinton, MA
(800) 982-5737,
www.valpeyfisher.com.

Broadband Combiner Provides Input Failure Protection

Werlatone provides Non-Coherent RF Combiner designs with proven heat dissipation techniques for broadband Non-Coherent Combining applications, such as combining two or more signals of differing power, frequency and/or phase onto a single output. Model D9048 provides a four-way combining solution capable of handling 500 W CW output power while covering a full 20 to 1000 MHz bandwidth. While providing exceptional port-to-port unbalance protection, this unit operates with only 0.65 dB of insertion loss. Measuring just 5" × 4.7" × 1.4", the model D9048 is more efficient and smaller than most 20 to 500 MHz combiners in the marketplace today.

Designed for military and commercial applications, this unit will tolerate a full input failure at rated power and operates over a temperature range of –55° to +85°C. Input failure tolerance insures that remaining transmitter(s) may continue to operate until the amplifier system can be properly shut down for maintenance. This small package size weighs 2.5 pounds and can be supplied with several connector options including: N Female, 7/16 Female and SMA connectors. The model D9048 is also available as a RoHS compliant design.

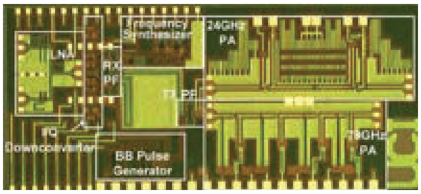
The company offers extensive experience as a supplier to military platforms worldwide, with 0° combiners/dividers, dual directional couplers, 90° hybrid couplers and 180° hybrid combiners/dividers. These components can be used in military communications and EW applications, such as HF, VHF, UHF, S-band ground based, shipboard, aircraft radar as well as commercial communications, such as AM, FM, VHF, UHF, digital UHF and satellite radio.

VENDORVIEW

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

Third-Gen SiGe Reduces Noise and Power Consumption

TowerJazz recently announced the company's third-generation 0.18 µm SiGe technology, SBC18H3, offering transistors with 240 GHz Ft and 260 GHz Fmax in a cost-effective and analog-friendly 0.18 µm node. The technology is built on the same mature integration platform used for the company's prior two SiGe processes, which are currently in high volume production (SBC18H2 at 200 GHz and SBC18HX at 155 GHz). The technology addresses next-generation needs for high speed interfaces in communication protocols, such as optical fiber, and high data rate wireless, by improving performance with reduced noise and power consumption of key building blocks. SBC18H3 also targets applications



such as automotive collision avoidance systems, millimeter-wave radar and GHz imaging.

Power consumption is dramatically reduced. For example, a 77 GHz amplifier can be made to consume three times less DC power than was possible with older technology. At the same time, noise is improved to levels exceeding those of prior SiGe technologies as well as the results typically reported for III-V materials (minimum noise figure at 20 GHz is measured at less than 1 dB and at 40 GHz at only 2 dB).

For design support, SBC18H3 Process Design Kits (PDK) include mm-wave components such as a transmission-line toolbox, PIN diodes for RF switching, and support for small size MIM capacitors. PDKs are available for Cadence Virtuoso and Agilent ADS. TowerJazz offers a monthly MPW for quick and cost-effective prototyping of designs, and leading customers have already built initial SBC18H3 prototype designs through this MPW service. The IP of high speed components from H2 and HX can be readily ported to the new H3 process since they are all in the same 0.18 µm node.

**TowerJazz,
Newport Beach, CA
(949) 435-8000,
www.towerjazz.com.**

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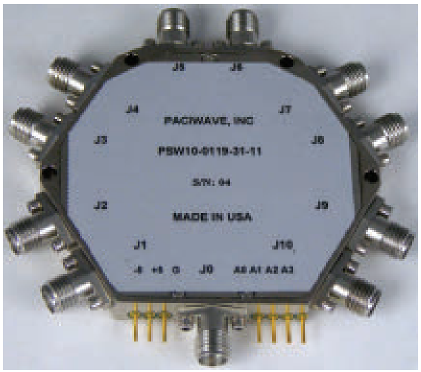
Ultra Low Loss PIN Diode RF Switches

Paciwave has developed a new family of ultra low loss PIN diode RF switches for military and instrumentation applications that feature high switching speed, high isolation and excellent VSWR. The model PSW10-0119-31-11 is a SP10T switch that covers the RF band from 1.5 to 18.5 GHz, is TTL controlled by Paciwave designed integral driver, has insertion loss of 4.0 dB maximum (3.6 dB typical), isolation of 80 dB minimum (85 dB typical), is reflective and has a switching speed of 30 ns typical. Power handling is on the order of +30 dBm CW, +33 dBm peak. Port return loss is 10 dB maximum, 15 dB typical.

The unit is powered by ±5 VDC. Options include absorptive operation, higher power handling and low video transients. The unit is housed in a compact radial package measuring roughly 2.4 inches in diameter by 0.28 inches thick, which allows for optimally short internal transmission line lengths to optimize port to port phase and amplitude matching. Matching is within ±0.5 dB port to port on amplitude and ±10° on the phase at the high end of the band. Operating temperature range is –40° to +85°C and the unit can be hermetically sealed.

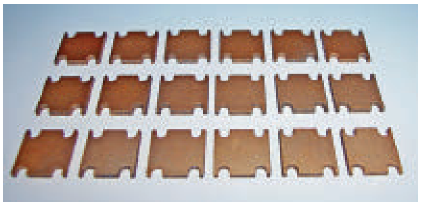


Paciwave has spent the last 16 years optimizing and refining its circuits, materials and processes and now is able to offer customers some of the best-performing switches on the market. Paciwave's ultra low loss switch technology is available throughout the entire line of switches from SP1T to SPNT, covering all the common frequency bands up to 40 GHz. Paciwave's switch-related products, such as matrices, filter banks, calibration modules and integrated microwave assemblies, also feature ultra low loss switch technology.

Paciwave Inc., Sunnyvale, CA (408) 745-0385, sales@paciwave.com, www.paciwave.com.

Aluminum Diamond Heat Spreader Material for GaN Devices

Nano Materials International has introduced aluminum diamond metal matrix composites (MMC) for use as heat spreaders that can reduce GaN junction temperatures by up to 25 percent, has a coefficient of thermal expansion (CTE) close to that of SiC and metallization well suited for die attach. They also have excellent dimensional tolerances and material stability. In addition, they can be economically produced in large quantities while adding a minimal cost to each GaN device.



Polycrystalline diamond has the highest thermal conductivity of any material, ranging from 1200 to 2000 W/mK. When used in an aluminum diamond MMC, the effective conductivity remains over 500 W/mK, far higher than common heat spreader materials such as copper tungsten (200 W/mK), copper molybdenum (250 W/mK) and copper-molybdenum-copper (350 W/mK). The MMC material with nickel-gold electrolytic or electroless plating can be made in the thicknesses required for use as a heat spreader and in virtually any shape and size typical of GaN HEMT or MMIC devices. It is available as a MMC material alone or incorporated within a package, allowing it to accommodate the specific needs of device manufacturers and package suppliers.

The aluminum diamond MMC products have been tested with a variety of GaN devices and are proving well suited for solving the problems created by GaN's extremely high power density. They are likely to be an essential part of the solution for removing heat at the device level from high power RF and microwave amplifiers that will be employed in future generations of military electronic warfare, radar, and communications systems.

Nano Materials International, Tucson, AZ, www.nanomaterials-intl.com.

Multichannel Coax Rotary Joint / Slip Ring Assembly

Up to 30 channels.
Use MDL's rotary joint to transfer 3 RF signals and a 30-channel slip ring for flawless DC transmission. We make and assemble both components, so you'll save labor and testing costs. And you're assured of the highest quality and reliability from the leader in high quality cast components and waveguide packages.

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Slip Ring Assembly

Isolated Contacts:	*30*
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Current:	*.1 - 5 Amps*

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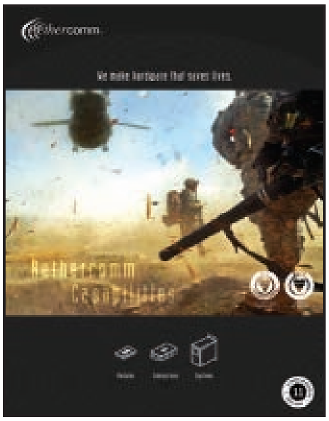
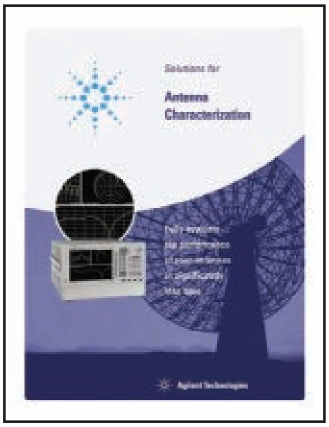


Capabilities Brochure

This capabilities brochure features Aethercomm's three major product lines: RF amplifier modules, RF subsystems and RF systems. The major classes of RF amplifier modules are broadband high power, linear high power and high power pulsed amplifiers. The products are employed in electronic warfare, radar and communication systems and other applications that require high power RF energy. Aethercomm offers automated assembly and test capabilities, hybrid and MIC capabilities, custom product design and is ISO 9001:2008 and AS 9100 certified.

Aethercomm Inc.,
Carlsbad, CA (760) 208-6002, www.aethercomm.com.

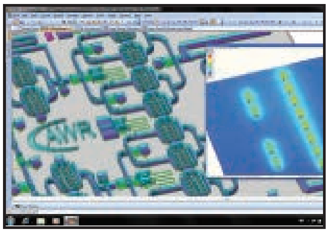


Antenna Test Solutions Brochure

VENDORVIEW

See how to lower antenna test times by as much as 80 percent, significantly improve measurement sensitivity or replace existing 8530A-based solutions with higher performance and code emulation.

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

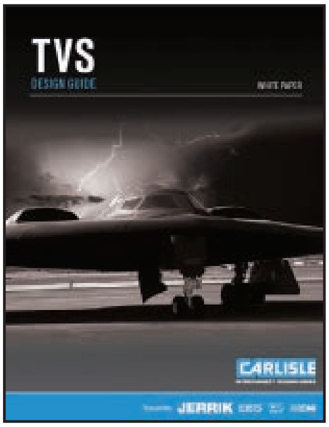


Product Portfolio

VENDORVIEW

AWR Corp. dramatically reduces development time and cost for products employed in wireless, high speed wired, broadband, aerospace and defense, and electro-optical applications. The 2011 version of its product portfolio – Microwave Office™, Visual System Simulator™, AXIEM® and Analog Office® – features electrical-thermal MMIC co-simulation design flow, simulation-state management technology, yield analysis/optimization via a graphical shape-based manipulation approach, envelope simulator and asynchronous electromagnetic (EM) simulation support.

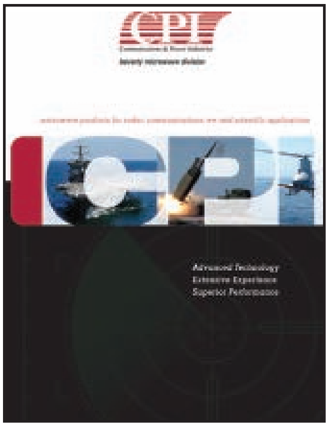
AWR Corp.,
El Segundo, CA (310) 726-3000, www.awrcorp.com.



TVS Design Guide

Lightning strikes aircraft, helicopters, UAVs and ships with a higher frequency than most people would believe. There also is the potential of a nuclear event that would propagate an Electro Magnetic Pulse (EMP) to consider. By using Transient Voltage Suppression (TVS) devices, the company can guard against the destructive energy spikes generated by lightning and EMPs. This guide will explain many of the considerations needed to select the proper device to prevent EMP issues.

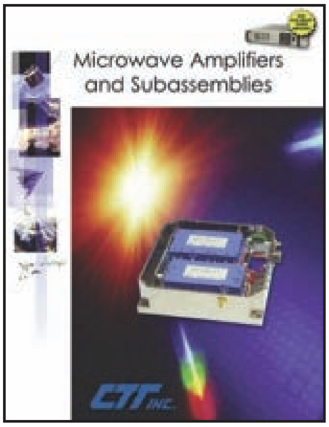
Carlisle Interconnect Technlogies,
St. Augustine, FL (904) 829-5600, www.carlisleit.com.



Product Catalog

CPI's Beverly Microwave Division (BMD) designs and manufactures a broad range of RF and microwave products for radar, communications, electronic warfare and scientific applications. CPI/BMD is the world's largest manufacturer of receiver protectors and related products. Other product lines include magnetrons, TWTs, CFAs, transmitter assemblies, scientific systems, high power solid-state switches and switch assemblies, pressure windows and a wide variety of multifunction components and integrated microwave assemblies.

Communications & Power Industries (CPI),
Beverly Microwave Division, Beverly, MA (978) 922-6004,
www.cpii.com/bmd.



Amplifiers and Subassemblies

This 36-page catalog features more than 175 new amplifier products, including lightweight LNAs with drop-in or connectorized options. CTT's expanded product offerings include gallium-nitride (GaN) monolithic-microwave-integrated-circuit (MMIC) device technology power amplifiers for wideband jammer applications and narrowband radar applications. A new line of rack-mount power amplifiers operates from 0.5 to 31 GHz for wide or narrowband linear applications covering UHF through Ka-Band. Additional solid-state amplifier products have been introduced for use in a wide range of applications.

CTT Inc.,
Sunnyvale, CA (408) 541-0596, www.cttinc.com.

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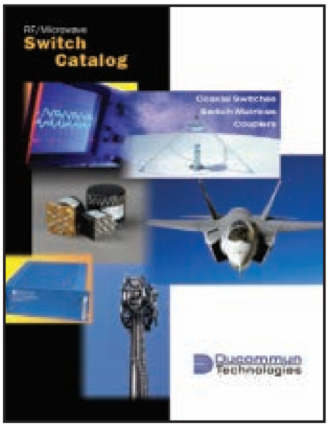
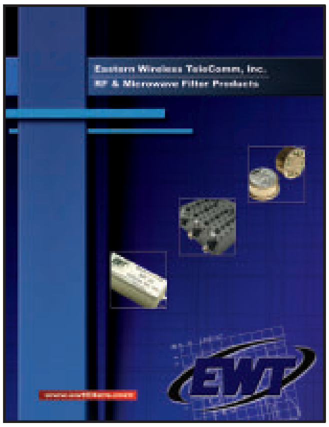


Switch Catalog

Ducommun LaBarge Technologies has served the aerospace, defense, industrial and telecommunications markets for more than 40 years by providing RF components and sub assemblies. Ducommun is a design and manufacturing company specializing in RF products, including coaxial switches. Its heritage includes industry stalwarts as Dynatech (DMT) and DBP Microwave (DBP). It designs and manufactures RF coaxial switches covering the frequency range of DC to 50 GHz. In addition to RF coaxial switches, Ducommun designs switch matrices, millimeter-wave components and integrated subassemblies.

Ducommun LaBarge Inc.,
Carson, CA (310) 513-7256, www.ducommun.com.



Filter Catalog

VENDORVIEW

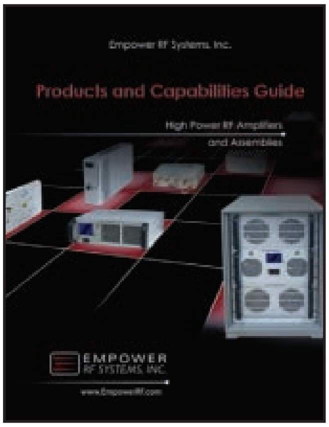
This new short form catalog features a sampling of the company's RF and microwave filter products to 40 GHz utilized in military, commercial and wireless applications. The catalog also highlights some of the company's diverse filter design and manufacturing capabilities.

Eastern Wireless TeleComm Inc.,
Salisbury, MD (410) 749-3800, www.ewtfilters.com.

Connectors Product Catalog

Emerson Connectivity Solutions is a global manufacturer of connectivity products, specifically microwave components and cable assemblies, which support wireline & wireless communications, networking, RF/microwave, test & measurement, broadcast, medical, military and industrial applications. The new kwiQMAte™ branded Johnson® product line catalog of QMA connectors features a push-pull interface allowing for more connectors per application.

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



High Power Broadband RF Amplifiers

VENDORVIEW

Empower's Products and Capabilities Guide is a comprehensive overview of the company's capabilities and a listing of its most popular amplifier products. With products that cover from 150 kHz to 6 GHz and an extensive library of building block designs, there is an array of catalog standard and semi-custom solutions available. This brochure will be especially useful for buyers, sales representatives and engineers.

Empower RF Systems Inc.,
Inglewood, CA (310) 412-8100, www.empowerrf.com.

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10 MHz to 67 GHz Components Catalog

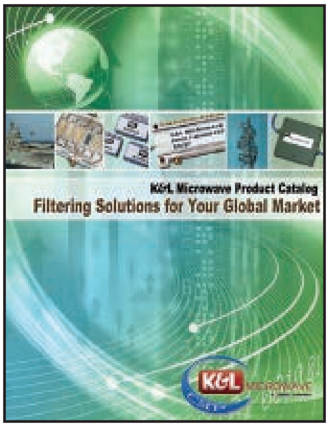
ET Industries is a high technology, leading edge company specializing in the design, development and manufacture of the state-of-the-art radio and microwave frequency, narrowband and wideband subsystems and components. The company was created with the sole purpose of assisting customers to investigate and solve problems that are technologically advanced, and may require critical schedules for completion. ET Industries, therefore, welcomes such programs. The company provides application-specific designs to meet special requirements of its customers. Please contact ET at sales@etiworld.com.

ET Industries,
Boonton, NJ (973) 394-1719, www.etiworld.com.

Microwave Cable Catalog

This short form catalog features the SUCOFLEX 400 microwave cable family that has been specifically developed for high performance electronic warfare applications. Anywhere low insertion loss, best phase stability versus temperature and bending, excellent return loss and mechanical stability are of particular importance, the SUCOFLEX 400 is claimed to be a fitting solution.

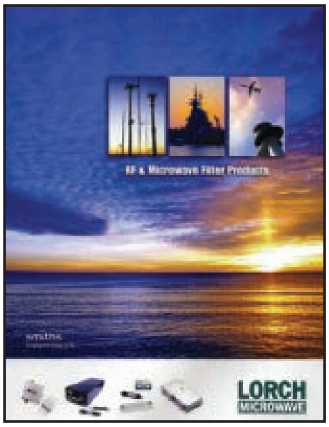
HUBER + SUHNER,
Herisau, Switzerland, info@hubersuhner.com, www.hubersuhner.com.



Product Catalog

K&L Microwave's 128-page catalog can be used as a desktop reference guide that offers details and specifications to help designers and engineers choose products quickly. Integrated assemblies and a wide assortment of lumped component, cavity, ceramic and suspended substrate filters are among the many types of products featured in this catalog.

K&L Microwave,
Salisbury, MD (410) 749-2424, www.klmicrowave.com, www.klfilterwizard.com.



Short Form Product Guide

VENDORVIEW

The Lorch Microwave short form product guide presents the complete product range in a clear and concise format. The products featured are used in a wide range of military and commercial applications. Also included are frequency range of operation, photographs and specific application information, charts and tables.

Lorch Microwave,
Salisbury, MD (410) 860-5100, www.lorch.com.

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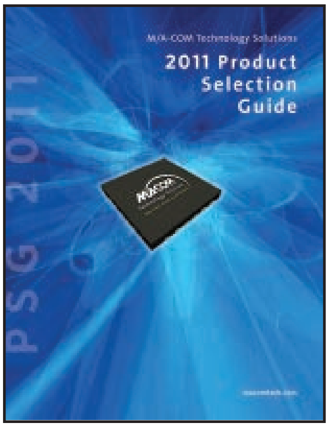
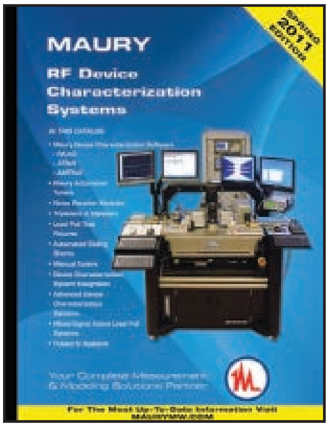


Product Guide

VENDORVIEW

The Product Selection Guide is designed to help engineers select products for commercial, aerospace and defense markets. It contains a listing of products, in addition to packages available, wavelength and frequency information, Decibels-Volts-Watts Conversion Table, Telecommunications Standards, Part Number index, and application block diagrams. Download a copy by going to macomtech.com.

M/A-COM Technology Solutions, Lowell, MA (978) 656-2546, www.macomtech.com.



Device Characterization Systems Catalog

This catalog covers Maury Microwave's full line of device characterization solutions, including IVCAD software, ATSv5 software, load pull and pulsed IV systems, automated tuners, controllers, manual tuners and test bench accessories. It has everything needed to make Device Characterization measurements with confidence. Get the 84-page PDF download from http://maurymw.com/pdf/1G-003b_sprg2011.pdf.

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

Components Catalog

VENDORVIEW

Celebrating its 50th anniversary, MECA (Microwave Electronic Components of America) designs and manufactures an array of RF/microwave components with industry leading performance. MECA is recognized worldwide as a primary source of supply for rugged and reliable components to commercial and military OEMs, service providers and installers by only providing products made in the USA.

MECA Electronics Inc., Denville, NJ (866) 444-6322, www.e-meca.com.

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IF/RF Microwave Signal Processing Components Guide

VENDORVIEW

Mini-Circuits' new 164-page catalog includes more than 750 new products and the industry's most comprehensive listing of RF/IF and microwave components and subsystems with more than 4100 products and more than 25 product lines, including state-of-the-art amplifiers, mixers, VCOs, synthesizers, filters, test accessories and USB Power Sensors. Mini-Circuits' website provides additional data, application notes, design tools and its powerful YONI search engine, which searches actual test data on thousands of units.

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

Analyzing Antenna Performance

VENDORVIEW

Successful integration of an antenna onto a vehicle platform poses many challenges, from vehicle features and motion impacting antenna performance to environmental factors, and radiation hazards. This paper provides a variety of examples on how modeling and simulation can be used to analyze antenna performance, identify problems and evaluate potential solutions. Download at www.remcom.com/antenna-platform-integration/.

Remcom,
State College, PA (814) 861-1299, www.remcom.com.

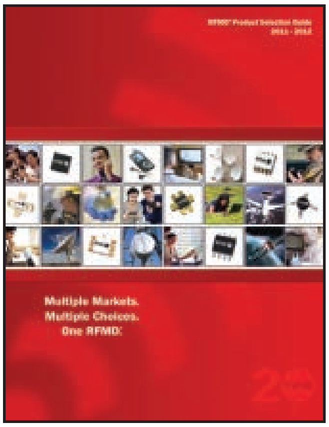
Filters, Multiplexers and Multi-function Assemblies

VENDORVIEW

This catalog features RF and microwave filters, multiplexers and multi-function assemblies. The catalog contains RF and microwave filters, multiplexers and multi-function assemblies for the military, industrial and commercial industries. To request a copy, please e-mail reactel@reactel.com, or visit www.reactel.com.

Reactel Inc.,
Gaithersburg, MD (301) 519-3660, www.reactel.com.

MILITARY MICROWAVES SUPPLEMENT
LITERATURE SHOWCASE



2011 Product Selection Guide

The 2011 Product Selection Guide provides specifications for more than 900 products, including more than 90 recently released products targeting multiple end-market applications. The 64-page guide allows customers to cross-reference and search products using end-market application diagrams. RFMD's Product Selection Guide lists products servicing more than 20 end-market segments, including cellular, Point-to-Point Microwave Radio, WiFi, WiMAX, Smart Energy AMI, Zigbee®, wireless infrastructure, aerospace & defense, broadband transmission, consumer, and others. To download, visit www.rfmd.com/SelectionGuide/default.aspx.

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

Product Catalog

RLC Electronics is a leader in the design and manufacturing of RF and microwave components. The company's product range includes coaxial switches up to 65 GHz, power dividers, couplers, variable attenuators, filters and detector diodes up to 40 GHz. Many components are available in surface-mount construction, designed to meet specific customer requests electrically and mechanically. Those products include filters, switches, couplers and power dividers. New products include programmable attenuators, high power broadband couplers, high frequency broadband power dividers and delay lines up to 40 GHz.

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

Secure Communications Catalog 2011

VENDORVIEW

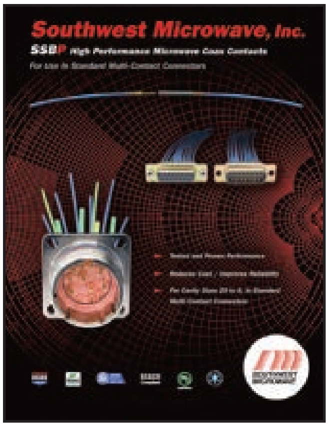
For air force missions, the key to success is the reliability, security, flexibility and future-readiness of communications equipment. This catalog addresses this issue and documents the company's secure communications solutions: mobile and highly mobile airborne radiocommunications, secure information transmission, stationary and mobile ground communications, and test and measurement equipment for radio communications.

Rohde & Schwarz GmbH,
Munich, Germany (Europe): +49 89 4129 12345,
(USA): +1 888 837 8772, www.rohde-schwarz.com.

Product Brochure

RT Logic's product overview brochure summarizes the company's broad line of innovative channel simulation, signal, data and network processing systems for the space and aerospace communications industry. Since RT Logic's founding in 1977, thousands of RT Logic systems have been fielded, with 90 percent of America's space missions utilizing RT's products during their test, launch, or on-orbit phase.

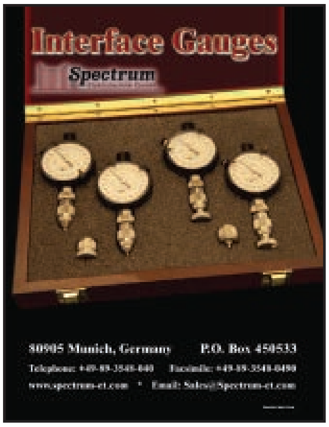
RT Logic,
Colorado Springs, CO (719) 598-2801, www.rtlogic.com.



SSBP Product Catalog

Southwest Microwave's new SSBP product catalog describes a family of microwave contact sizes designed to fit into standard (non-coax) cavities in MIL-DTL-38999 circular, MIL-DTL-24308 D-Sub, and special MIL-DTL-83513 Micro-D connectors. It includes RF/microwave testing to 65 GHz, plus 5000 cycle mating durability plus shock and vibration. SSBP coaxes allow applications to mix microwave signals with DC/digital and fiber optics in one connector. The catalog is available for download online or a printed copy can be requested.

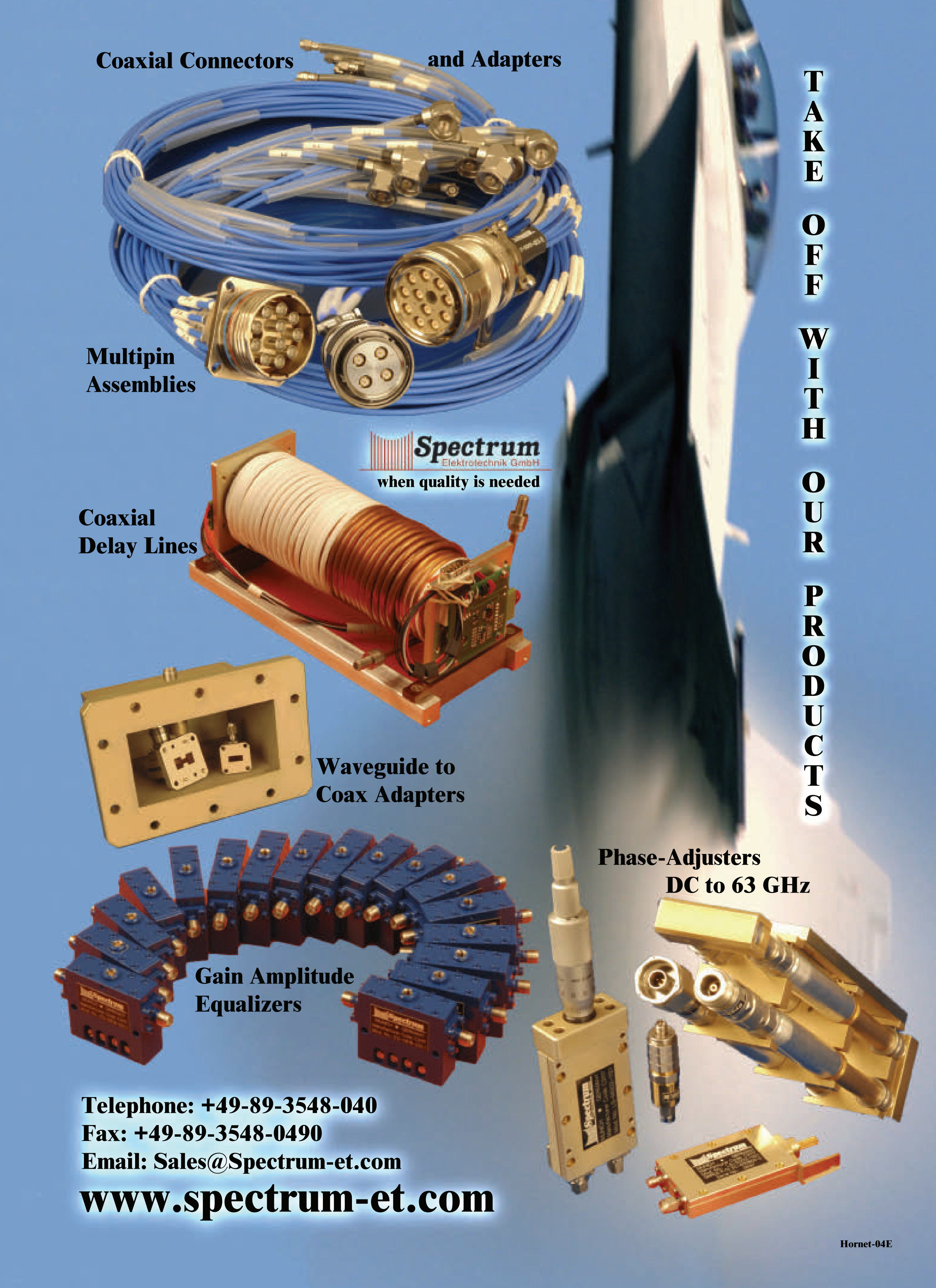
Southwest Microwave Inc.,
Tempe, AZ (480) 783-0201, www.southwestmicrowave.com.



Interface Gauge Catalog

The new short form catalog showcases the manufacturer's full line of connector gauges for checking the critical interface dimensions of most standard coaxial connectors. The sets are supplied in pristine wooden boxes. The catalog outlines the importance of checking the interface dimensions of connectors and adapters as those interfaces not meeting specification will not only lead to the possible degradation of components, but also may damage the connectors of mating components or mating connectors of associated equipment.

Spectrum Elektrotechnik GmbH,
Munich, Germany +49 89 3548 040, www.spectrum-et.org.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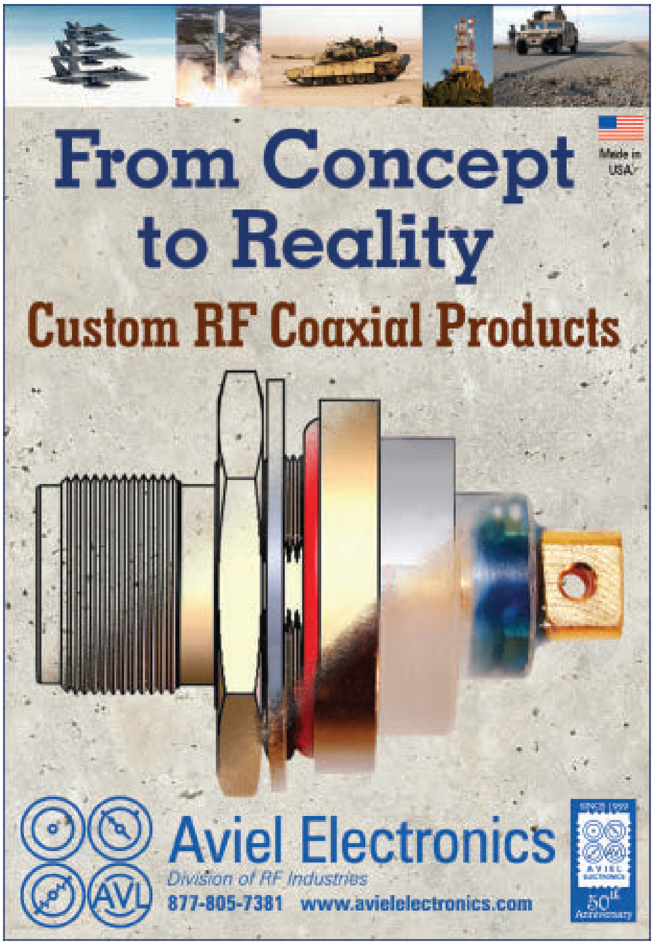

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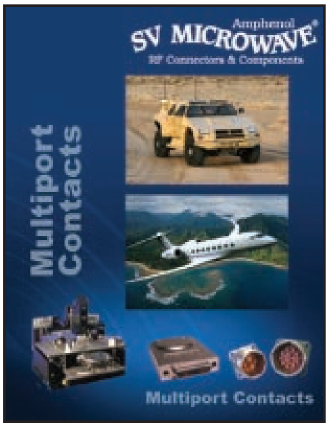
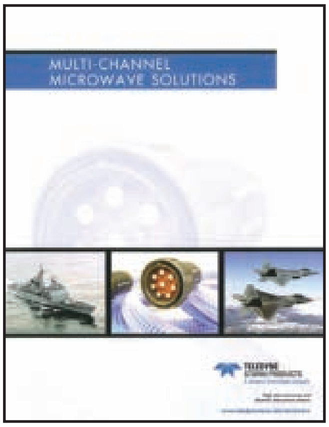


Multiport Contacts Catalog

SV Microwave has released its new Multiport Contacts catalog featuring information on Size 8, 12 and 16 contacts operating to 18 GHz and fitting into M38999, ARINC, Micro-D and SIM connector cavities. These new contacts have enabled SV to combine RF/microwave and DC signals in hybrid harnesses, providing simplified interconnection and smaller package size to aid both designers and operators in the field.

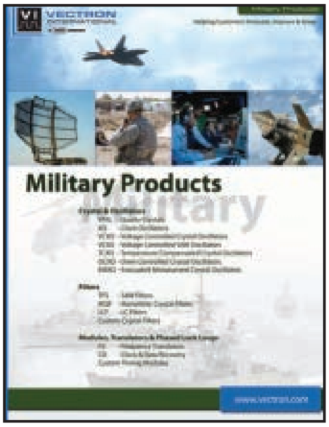
SV Microwave,
West Palm Beach, FL (561) 840-1800, www.svmicro.com.



Harness Capabilities Brochure

Teledyne Storm Products' new Multi-Channel Microwave Solutions brochure details the company's capabilities in the design and manufacture of both standard and custom multi-channel microwave harness assemblies. The harnesses, found in a wide range of airborne, ground and sea-based military and commercial applications, are backed by Teledyne Storm's more than 30 years of microwave cable design and manufacturing expertise. It includes a case study.

Teledyne Storm Products,
Woodridge, IL (630) 754-3300, www.teledynestorm.com.



Military Products Brochure

With more than 50 years experience, Vectron is the leader in providing frequency control and hybrid solutions to customers around the world. Vectron claims its innovative approach to design and manufacture has resulted in the most advanced product offering of any frequency control supplier in the world.

Vectron International,
Hudson, NH (603) 598-0070, www.vectron.com.

The 2011 Defence and Security Forum

At European Microwave Week, Manchester, UK
Wednesday, October 12th

The 2011 EuMW Defence and Security Forum will feature:

MORNING SESSIONS

Safety and Security - Several presentations consider the application of the microwave technology that is being developed to increase security and address safety issues.

LUNCH AND LEARN

Provided to all attendees, courtesy of **Strategy Analytics**, who will present market data and analysis on the global defence market.

AFTERNOON SESSIONS

Radar Challenges for the 21st Century

Keynote: Technological Convergence Between Radar, EW and Communications Against a Reducing Budget Background. Presented by Barry Trimmer of Thales

Through-wall Radar Design for Covert Surveillance. Presented by Cambridge Consultants

Featured Panel Session: **Radar Challenges and Solutions: an Industry Perspective**

EXECUTIVE FORUM

Executives from government defence agencies and leading defence/security contractors will consider how their organizations view future threats to global safety, security and defence and the role of technology in addressing these risks. A Q&A session follows.

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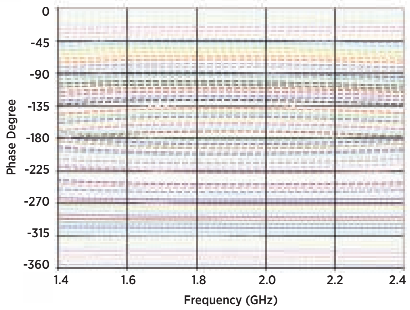
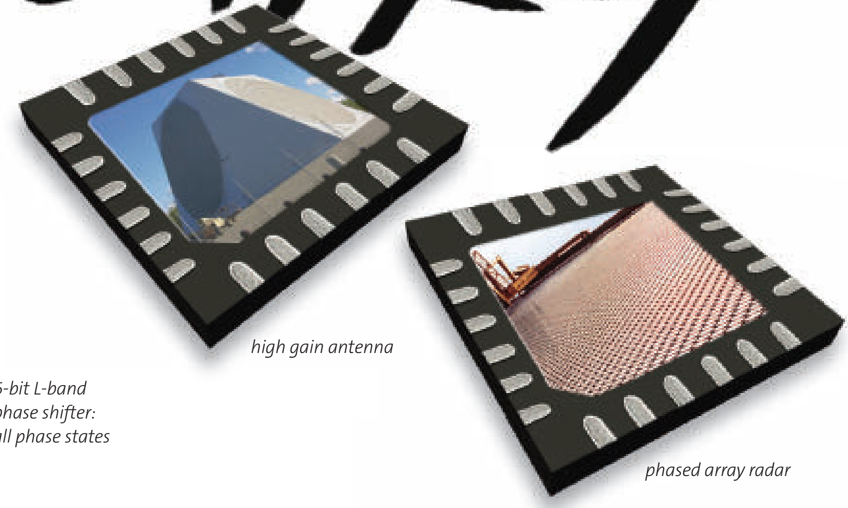
More Accuracy



6-bit L-band phase shifter: all phase states



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M/A-COM Tech Phase Shifters

Extending our leadership in high accuracy semiconductors

Part Number	Frequency (GHz)	Function (dB)	Phase Range (degree)	Insertion Loss (dB)	RMS Phase Error (degree)	Gain Vibration (dB)
MAPS-010143	1.4 - 2.4	4-bit	22.5 - 360	3.2	2	± 0.5
MAPS-010144	2.3 - 3.8	4-bit	22.5 - 360	3.5	3	± 0.6
MAPS-010145	3.5 - 6.0	4-bit	22.5 - 360	4.5	3	± 0.7
MAPS-010146	8.0 - 12.0	4-bit	22.5 - 360	4.5	3	± 0.8
MAPS-010163	1.4 - 2.4	6-bit	5.625 - 360	5.0	5.2	± 0.8
MAPS-010164	2.3 - 3.8	6-bit	5.625 - 360	5.0	3	± 0.8
MAPS-010165	3.5 - 6.0	6-bit	5.625 - 360	5.5	3	± 0.8
MAPS-010166	8.0 - 12.0	6-bit	5.625 - 360	5.0	3	± 0.8

M/A-COM Technology Solutions digital phase shifters are fabricated using GaAs pHEMT technology. Our phase shifters provide a comprehensive set of solutions for active antennas, such as phased array for communications and radar.

M/A-COM Tech phase shifters feature:

- Integral CMOS driver
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- Low DC power consumption
- Minimal attenuation variation over phase shift range
- 50 ohms impedance
- RoHS compliant 4 mm PQFN package

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- Rack Mount, Drawer Mount, Radial Type
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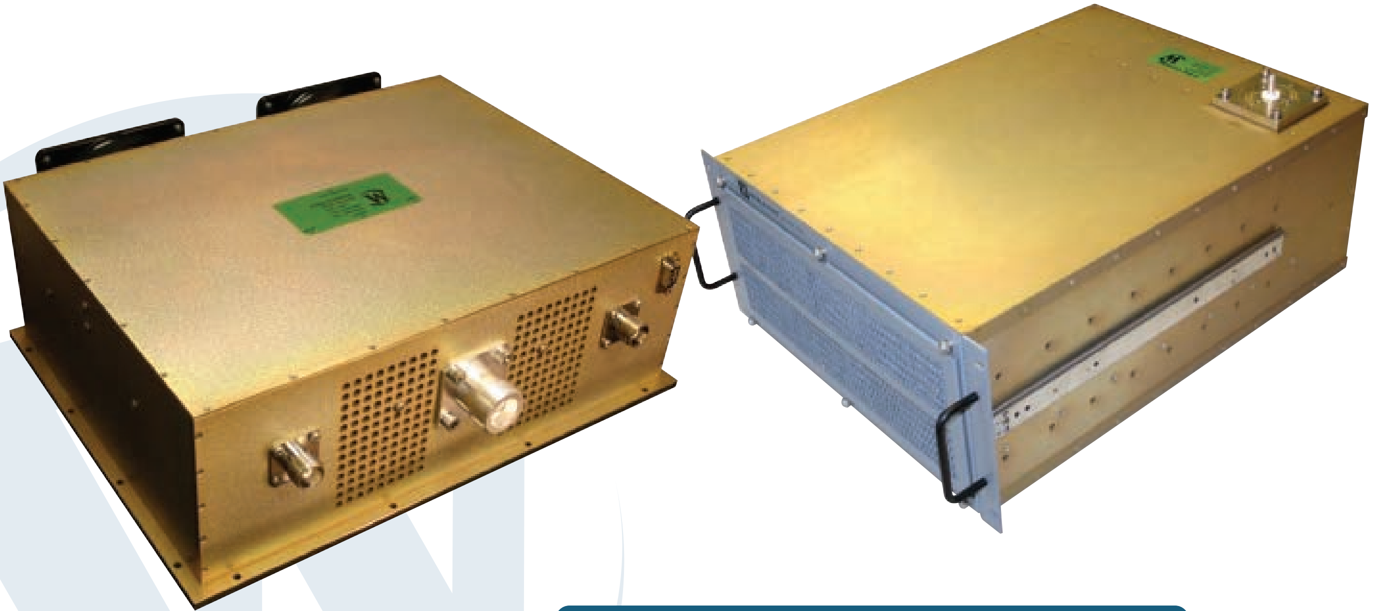

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Model	Type	Frequency (MHz)	Power (W CW)	Insertion Loss (dB)	VSWR	Isolation (dB)	Size (Inches)
D8265	2-Way	1-50	5,000	0.3	1.25	20	15.5 x 15 x 5.25
D2075	2-Way	1.5-30	6,000	0.2	1.25	20	15.5 x 11.75 x 5.25
D8969	2-Way	1.5-30	12,500	0.2	1.25	20	17 x 17 x 8
D6139	4-Way	1.5-32	5,000	0.25	1.25	20	13 x 11 x 5
D6774	4-Way	1.5-32	20,000	0.3	1.20	20	21 x 17.25 x 11
D6846	6-Way	1.5-30	4,000	0.35	1.35	20	3 U, 19" Rack
D8421	8-Way	1.5-30	12,000	0.3	1.30	20	22.5 x 19.5 x 8.75
D7685	4-Way	2-100	2,500	0.5	1.30	20	14.75 x 13 x 7
D2786	4-Way	20-150	4,000	0.5	1.35	20	18 x 17 x 5
D6078	2-Way	100-500	2,000	0.25	1.20	20	13 x 7 x 2.25
H7521	2-Way (180°)	200-400	2,500	0.3	1.30	20	15 x 10 x 2
D7502	2-Way	400-1000	2,500	0.25	1.20	NI*	9.38 x 3.5 x 1.25

*NI = No Isolating Terminations

Our Patented, Low Loss Combiner designs tolerate high unbalanced input powers, while operating into severe Load Mismatch conditions.

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