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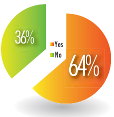

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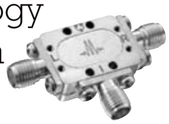

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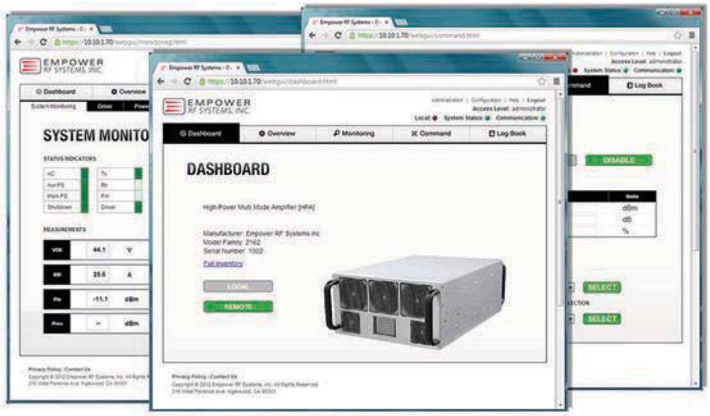

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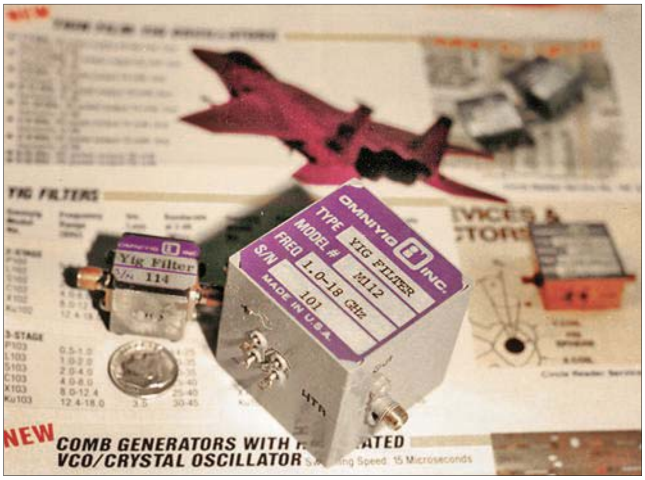

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The bulk of Omniyig's sales are Yig components and Yig subsystems built to MIL STD programs with very stringent MIL STD QA guidelines. Some of the programs that Omniyig has manufactured Yig devices for are the ALQ-99, ALQ-117, ALR-172, ALR-56C, ALR-62, ALR-64, ALR-67, ALR-69, WLR-8, EF111, B1 and L-130… and the list goes on.

R&D activities at Omniyig occur continually, with a dedicated R&D team fleshing out any particulars related to novel custom designs or requests on the client's part. They relish continuously developing new and improved Yig products in providing a deliverable product performing under all environmental conditions.

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Editorial

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The Secret to Success

Welcome to our second annual *Leaders in Electronic Design* issue. This issue gives us the opportunity to partner with some of our sponsors to profile today's brightest movers and shakers. Although all good leaders inspire and motivate their teams and companies, those heading the charge in the design-engineering universe must do so in an extremely dynamic environment. Here, constant change is normal. Technology is ever-more-rapidly changing before our eyes. As it does, design practices, product requirements, materials, and more must adapt to each fresh wave of changes.

Rather than tout their remarkable gifts, however, the leaders profiled here are a largely humble bunch. Repeatedly, they point to the hard work of everyone in the organization and credit them for their success. They recognize that the success of an organization depends not just on its leadership, but on the people who help to build and maintain a creative and effective environment.

The success of an idea also depends on the level of support and openness within the organization. It sounds simple, but such successes require that employees be invested in their jobs. They have to care enough about solving customer and other problems to be inspired to brainstorm ideas. Beyond this motivation, career coaches everywhere underscore the need for autonomy. In other words, employees have to feel that they can reasonably make decisions and take responsibility for driving something forward without being micromanaged.

Finally, we come to the crucial concept of teamwork. The design engineer must have the trust and support of his or her employer, team members, and other contributors to bring it to fruition. For design engineers and their team members, a new project requires countless extra hours that are often added to the regular workload—meetings and coordination with anyone taking part in the process, searching and procuring parts, running simulations, and more. A positive environment in which everyone feels valued and appreciated will inspire all team members to put their best efforts forward and make time as needed.

A great leader is inspiring, motivating, trusting of his or her employees, and committed to building an effective environment. By taking this type of approach, such a leader builds a company environment in which teamwork and brainstorming are supported and happen quite naturally. Yet as many of the leaders in these pages emphasize, those at the top can only carry their message so far. It is then up to the employees in the company to truly bring design-engineering projects and the company to continued success. mw

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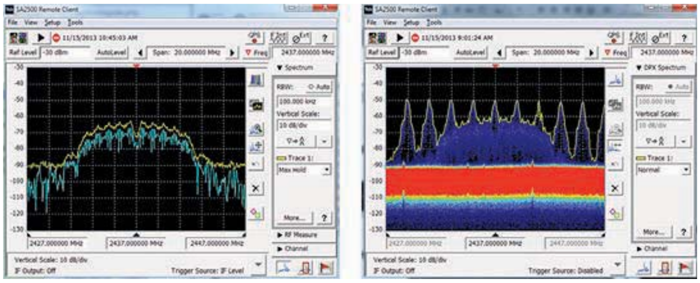

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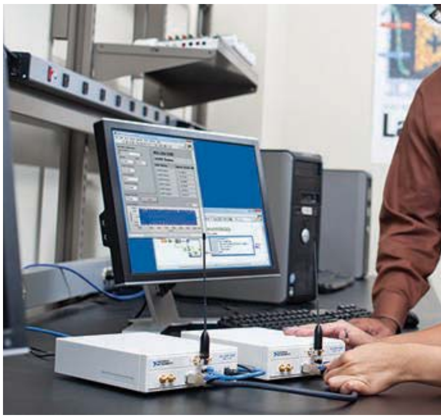

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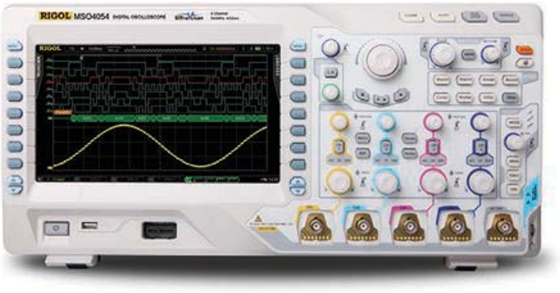

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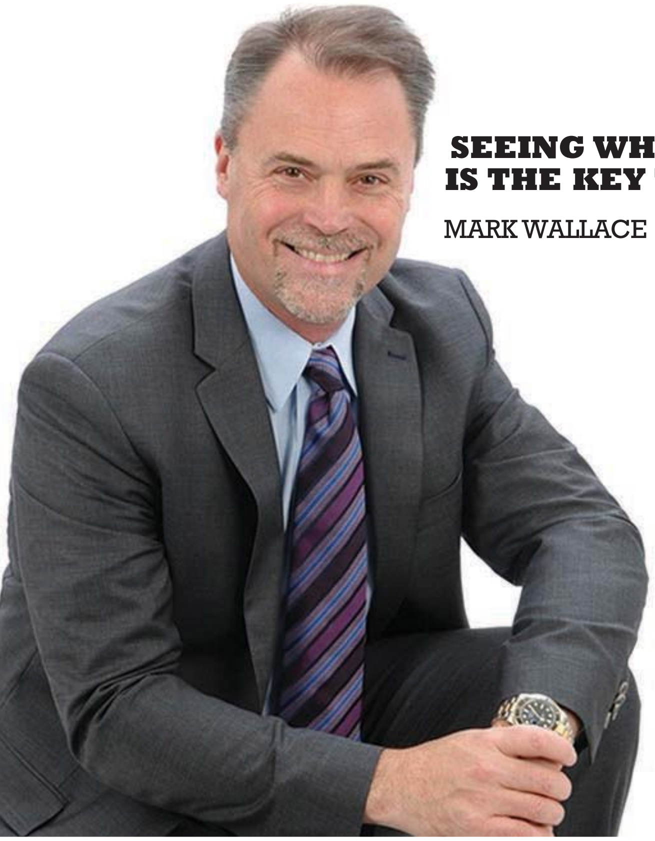

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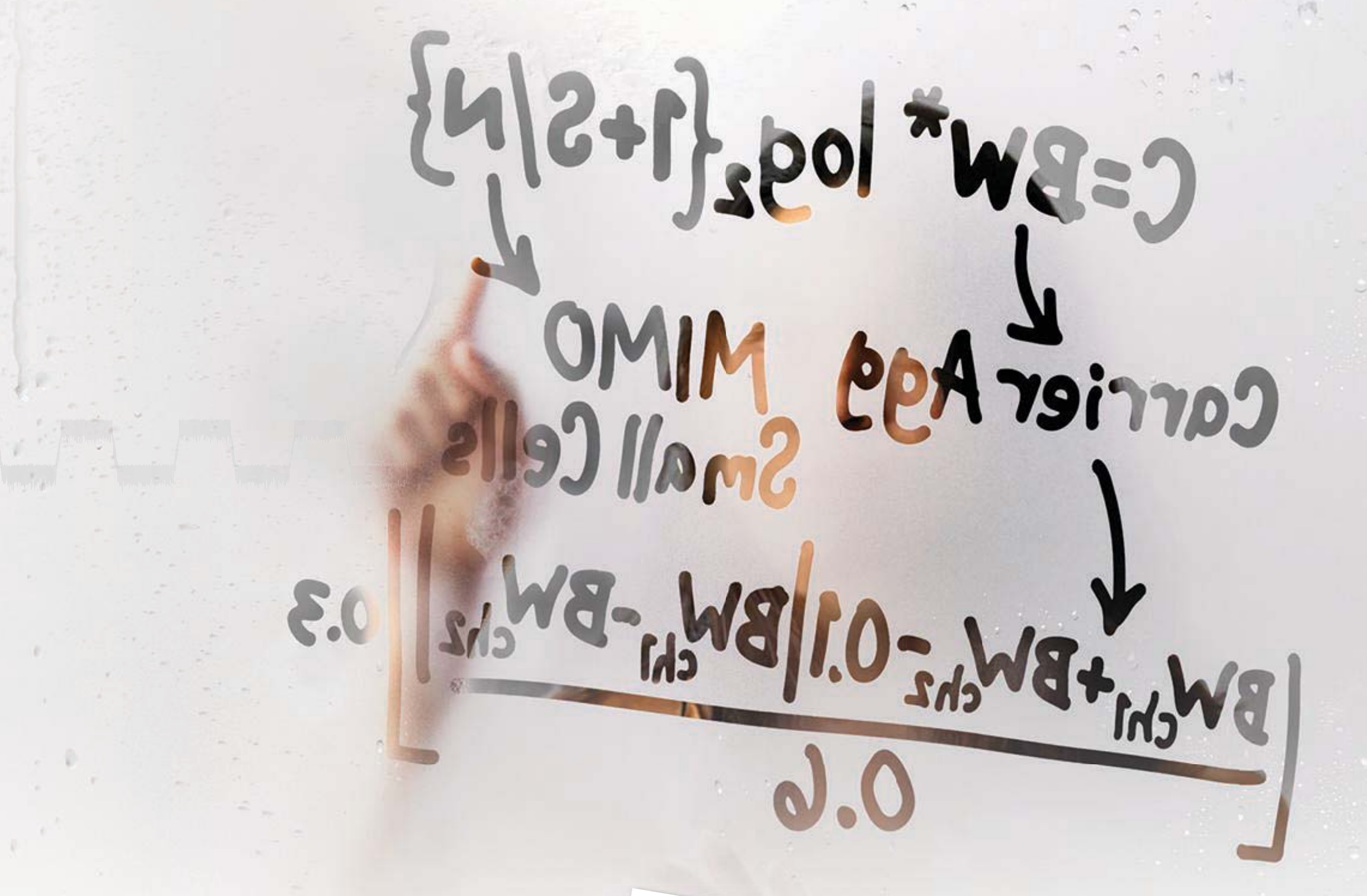

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Founded in 1855, Crane is an established global company dedicated to integrity and honesty; an experience you can trust. With more than 11,000 employees worldwide, Crane has over 120 locations in 25 countries. In the Aerospace & Electronics segment, you will recognize brands that have provided customers with reliable, trustworthy service for many decades: Merrimac®, Polyflon®, Keltec®, Signal Technology, ELDEC®, Interpoint®, Lear Romac®, Hydro-Aire®, and P.L. Porter®.

CRANE MICROWAVE AND POWER SOLUTIONS

Crane Aerospace & Electronics designs and manufactures high-density, high-reliability electronics and is a major supplier of microwave components and power systems found in commercial, military (radar, electronic warfare, missiles, intelligence and guidance systems), and space applications. Our product offerings include power supplies, transmitters, converters, filters, couplers, quads, mixers, high-power amplifier modules, antenna feed networks, beamformers, integrated T/R modules, phased arrays, switch matrices, IFMs, and phase detectors. Products are manufactured under the brand names Merrimac®, Signal Technology, ELDEC®, Interpoint®, and Keltec®.

Microwave Solutions designs and manufactures high-performance millimeter-wave, microwave, RF and IF components, subsystems, and systems for military, satellite, and commercial end-use customers. Patented Multi-Mix® technology allows for highly integrated custom solutions. Complete capabilities include electronic manufacturing services, engineering support services, product development, and production.

Integrated Microwave Assemblies (IMAs) represents the current and future area for product focus. Bringing a strong background in component design and combining the advanced use of Multi-Mix® technology allows exceptionally dense and high-performance assemblies to be designed and built. Recent integrated devices implemented have been in the area of low-noise signal sources, high-performance frequency converters, beamforming networks, and Radiating Element fabrication. Crane Aerospace & Electronics continues to advance the technology needed to meet today's and future system needs.

Recently promoted to Senior Director of Microwave Solutions, Mike Clark is responsible for all microwave operations of the Electronics Group. He has been with Crane for over 11 successful years in all of his roles and is seen as a key leader in the microwave business.

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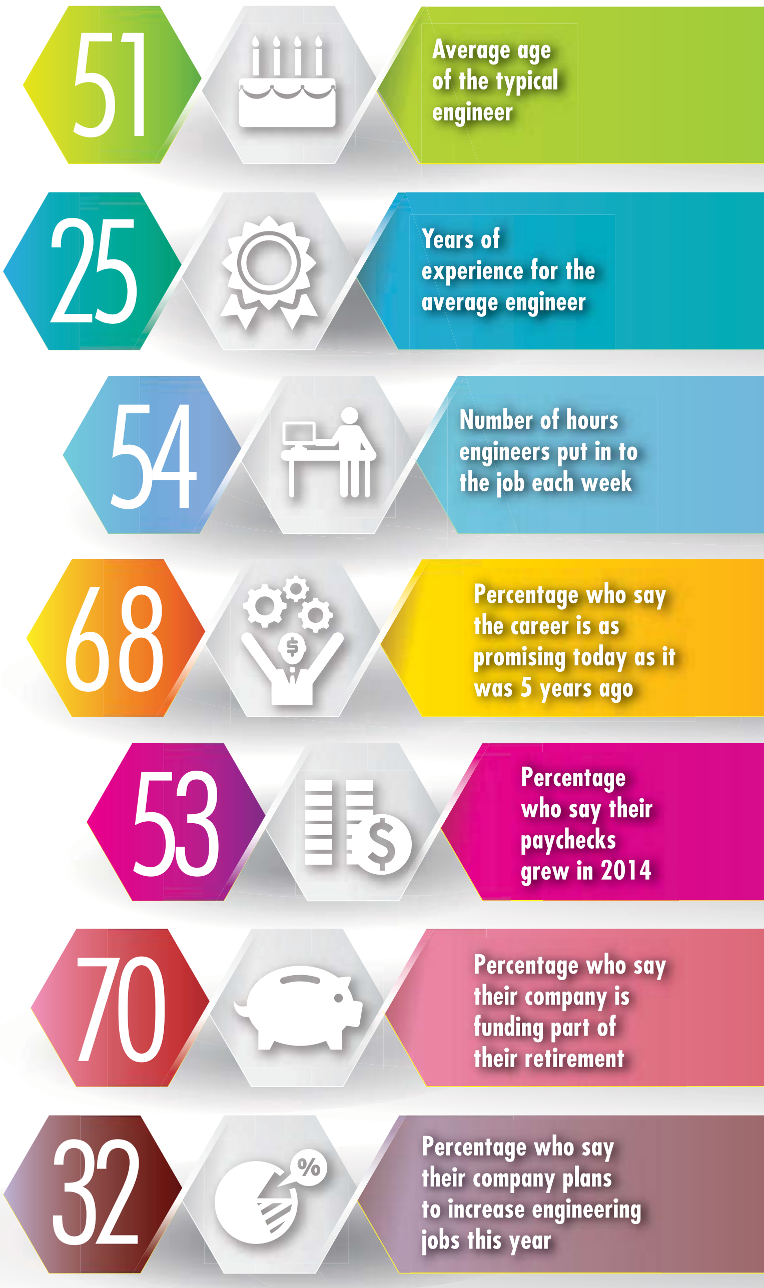
JEAN-JACQUES DELISLE | Technical Editor

2014 RF ENGINEERING SALARY

With economies, industries, education, and technology constantly changing, engineering is quite an exciting profession. RF engineers lead some of today's most cutting-edge technology developments, increasing our knowledge and connection with our world and each other. *Microwaves & RF* recently polled our community to find out what really makes RF engineers tick, how they are compensated, and what they think of the industry surrounding us.

This is the first year that *Microwaves & RF* has performed a Salary & Opinion Survey, giving us a chance to share in the realities of a community that is one of the biggest contributors and least-known of modern technology movers.



HOW SECURE IS AN RF ENGINEER?

In an economy where many have been concerned about layoffs, downsizing, restructuring, and pink-slip frenzy, it seems that the RF engineer stood relatively immune to such fluctuations. The vast majority—more than 86% of RF engineers—are employed with the same job title as the previous year. The main factors for switching job positions were promotion, reassignment, job-switching, and retirement. This makes sense, as the majority of RF engineers are working for full-time employers and have for some time.

The average length of employment with the same employer is almost 13 years (though this figure may have been skewed by the large number of RF engineers who have been working for an employer longer than 20 years). Fully a quarter of all RF engineers reported a stay of such length with their present employers. But the data indicates that another quarter of RF engineers may have swapped jobs between 2009 and 2013.

All and all, RF engineers are paid very well compared to other, more traditional engineering disciplines. The average total compensation for an RF engineer is close to $112,000 a year, with over a quarter of RF engineers reporting six-figure salaries. Most RF engineers don't receive bonuses or additional compensation. Yet those who do appear to be very well compensated, with most reporting an additional $10,000 in income from either bonuses, stock options, or other sources.

SURVEY ENGINEERING BY THE Numbers

Average total compensation in 2014 in dollars: **111,616**

Number of years they've worked at their present company: **13**

Percentage who say they've been contacted by a headhunter this year: **44**

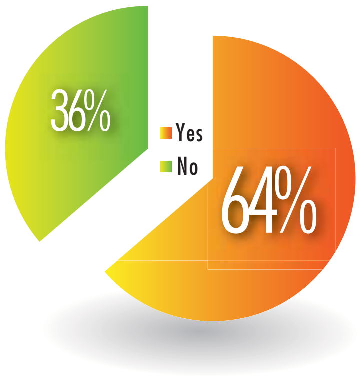
Percentage who express satisfaction in their current positions: **88**

Percentage who feel adequately compensated for the work they do: **64**

Percentage who say their company outsources engineering work: **54**

Percentage who say their company is less focused on employee retention this year: **66**

DO RF ENGINEERS FEEL ADEQUATELY COMPENSATED?



Additionally, the majority of RF engineers reported an increase in salary in 2014—an eighth with a greater than 10% increase. Over a third did report that their salary didn't receive an increase, but less than 10% reported a decrease in salary.

Most RF engineers also indicate that they are equally or better compensated than their peers, with only a third of RF engineers reporting that they may be compensated less. In addition, almost two-thirds of RF engineers feel adequately compensated, with a third feeling they may deserve more. These RF engineers don't appear to be greedy, though, as those who claimed they should be compensated more only requested about a 20% increase in compensation.

The RF engineers who are offered bonuses receive them based upon personal and company/division performance. Additional sources of income are derived from patent awards, project milestone completions, and company profit sharing. An interesting note is that many RF engineers seem to feel the strain of changing health insurance laws. Many companies don't appear to be offering health benefits comparable to past years.

HOW DO RF ENGINEERS FEEL ABOUT JOBS?

Either way, RF engineers appear to be a rather satisfied bunch in terms of their employment. Almost 88% of all RF engineers report feeling at least satisfied where they work. It can be construed that the quarter of RF engineers who decided to change employers must have found a company or position with which they are happier. Close to two-thirds of RF engineers are also of the opinion that there is a reasonable potential for salary advancement compared to the past five years.

In answer to a question regarding the outlook of salary increases, a respondent stated, "Technology still needs engineers. Capable engineers are in demand and well-compensated. The key is to have expertise in the key areas of demand. Outside of that, I would have answered no."

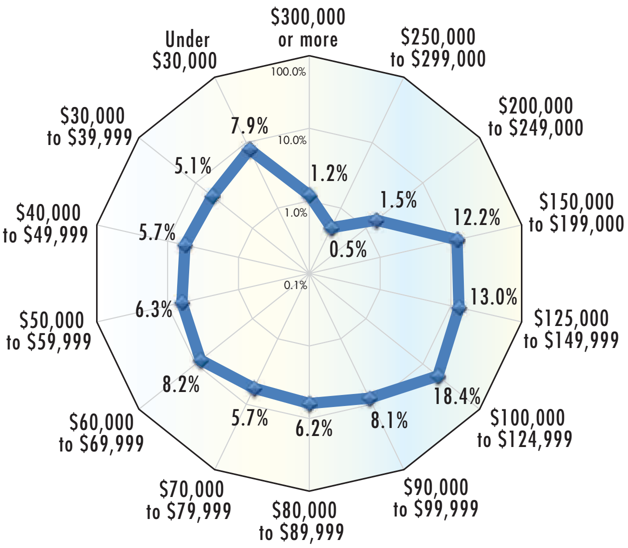
Yet another shared, "It is all about adding value. Engineering today has great opportunities to add value as long as we think not only about the product, but the people building the product and using it."

Not all RF engineers have such a rosy opinion, as some claimed that government funding cuts and corporate stinginess were providing less opportunities for promising engineers. This contrasts significantly with many other respondents, who claim that they are not able to staff enough skilled engineers. Some concern was voiced, in regard to potential salary increases, surrounding the use of work visas, and the growing use of computer tools in the engineering environment.

Regardless of any negative trends and views, just over two-thirds of RF engineers said they wouldn't even consider leaving the engineering profession. Those who shared that they may be interested in phasing out of engineering seemed to be looking for a change of pace, less stress, and more free time to explore other avenues of interest. Also, almost 90% of RF engineers would recommend engineering as a profession to the next generation. This being said, it appears that RF engineers are very passionate about engineering and are very willing to recommend the challenging work environment brought about by a career in engineering.

And challenging it is: More than 90% of RF engineers responded that they feel challenged in their positions. Over two-thirds of respondents said that the challenges associated with design represent one of the most important factors influencing job satisfaction. RF engineers seem to enjoy exploration and researching new technology solutions while working in a team environment. The biggest hold-ups in this process, which seem to add a lot of frustration, are shrinking project deadlines. RF engineers like to stay current and feel that such deadlines limit their ability to stay on the cutting edge.

HOW MUCH ARE RF ENGINEERS MAKING? [%]



HOW IS YOUR COMPANY?

While many industries are cutting back and attempting to "go lean" with staffing, it seems that most RF engineers don't have to be too concerned with this trend. Only about an eighth of RF engineers report that their companies are considering scaling back their engineering staff. Over half of RF engineers report that their companies will maintain their present staff, with almost a third indicating that their companies are looking to expand their engineering staffs.

From these responses, it seems that the majority of companies are having trouble finding qualified candidates for their engineering positions. Most RF engineers report that RF engineering is the engineering discipline with the highest demand. Given the audience surveyed, this opinion may at first seem rather biased.

Yet when compared to the Salary & Opinion Surveys of our sister brands, *Electronic Design* and *Machine Design*, it appears that most engineers actually agreed on this point. A few of the those commenting shared what is in the greatest demand: "microwave/electromagnetic engineers with experience," "microwave and millimeter-wave hardware design," and "electromagnetic interference, electromagnetic compliance, and RF interference engineers."

Interestingly enough, over two-thirds of RF engineers reported that their companies aren't focused on employee retention. This could just be a function of what the prior data indicated—that RF engineers are generally happy with their current employers and don't need extra incentive to stick around. Yet some respondents said, "With the difficulty in finding good, experienced help, it underlines the need to retain current experienced staff." Another respondent stated, "Although it should be, the company isn't doing anything different than last year. We have low turnover in our company. But we can't afford to lose anyone right now, so retention should be a hot topic."

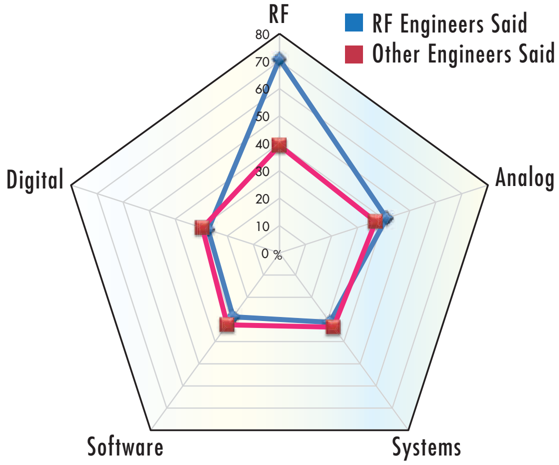
When asked about headhunting or recruitment specialists contacting our respondents with offers, over two-thirds of RF engineers claimed that they had no such contact. This also coincides with a full third of RF engineers sharing that they have no interest in changing jobs in the foreseeable future. Another third said that they would only consider new employment if they were personally approached with an opportunity that was much more interesting than their current situation. Only a tenth of the RF engineers claimed to be actively looking for other employment.

Regarding the industries and markets on which they focus, almost a quarter of RF engineers report working at a location where the dominant focus of the end product is communications systems/equipment. In size, that focus is followed by R&D, government/military, avionics/marine/space, semiconductors/ICs, and test and measurement equipment. Another core group works at consultancy agencies or consults privately for the industries mentioned above.

WHAT CONCERNS AN RF ENGINEER?

RF engineers are most concerned about looming project deadlines, product reliability issues, product quality issues, and price/performance issues. It makes sense that someone with an engineering mind would demand that every product should perform better, be more reliable, and be affordable—while

WHAT DISCIPLINE OF ENGINEERS IS IN THE GREATEST DEMAND?



simultaneously complaining about customers demanding that their latest product be produced better and at a faster schedule. That desire to push the boundary of excellence does seem to keep a few engineers awake. One respondent reported, "How can I get people to see a vision and embrace it such that we are always moving forward," while another highlighted stress over "technical issues that I cannot yet resolve."

Contrary to popular mythos, it appears that RF engineers actually prefer working with peers in teams. They value the recognition they receive from their peers significantly. Yet RF engineers don't seem to appreciate that recognition as much as they enjoy compensation and the opportunity to design products that benefit society. For many, this may indicate that some stereotypes are true: Engineers are dreamers who are willing to put elbow grease behind their vision.

Given a list of the problems of funding, non-optimal components, and having to compromise designs approaches, the engineers polled said they are more impacted by the lack of qualified people to help get the job done. Another revelation is that RF engineers, though very opinionated, seem to care far less about the sociopolitical aspects of the workplace than they do about getting the job done.

One of the biggest complaints seemed to be engineers having to respond to customer's needs, even though they didn't deem those needs worthwhile. For example, one respondent listed this as a chief point of concern: "the growing gap between customers' desires and their willingness to pay, combined with the fact that we are in an industry with relatively few large customers and many small vendors."

HOW ABOUT OUTSOURCING?

Many RF engineers voiced concerns about outsourcing. Over half of the RF engineers surveyed reported that their companies outsource to some degree. Unlike many industries, however,

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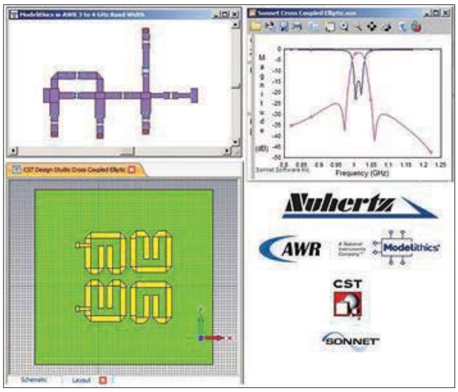

FILTERQUICK

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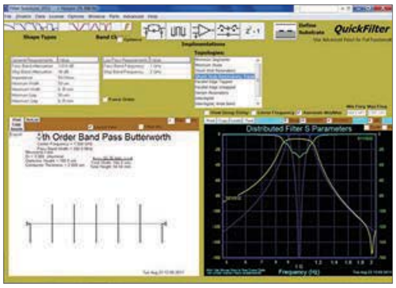

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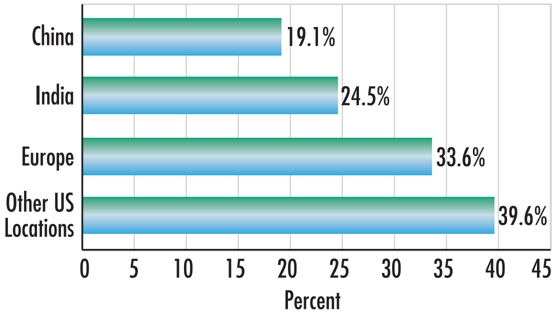
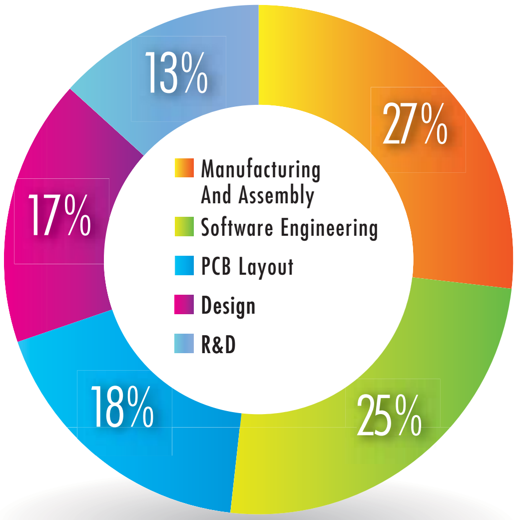
WHERE DOES YOUR COMPANY OUTSOURCE ENGINEERING WORK?



WHAT DOES YOUR COMPANY OUTSOURCE?



most of this outsourcing is directed toward other locations in the United States and Europe. Surprisingly enough, about a quarter of RF engineers shared that their companies outsourced work to India more than China. This may be due to the boom of IT firms available for contract in Indian markets.

According to our respondents, the two main reasons that their companies outsourced was due to a lack of in-house talent/specialty skill and to save money. The next reasons were to save time and better utilize existing engineering resources. These responses seem to indicate that a majority of the outsourcing work may take place in a field other than RF engineering—mainly software. To note, most RF engineers—nearly 90%—were confident that their companies were not looking to outsource in the future.

For the negative effects of outsourcing, RF engineers listed fewer engineering jobs being available, lower employee morale, new hires with reduced salaries, and less opportunity for advancement. When asked if they were personally concerned about their jobs being outsourced, however, over 75% of respondents shared that they had little to no concern. This could be another indicator that the jobs being outsourced are not specifically related to RF engineering.

A LITTLE BIT ABOUT AN RF ENGINEER

Considering the RF engineers currently employed in the United States, which comprised half of our list (followed by Europe and Asia and then showing smatterings across the globe), a full quarter are working in California. They must be enjoying the weather. Surprisingly, New York State was the next-largest employer. Texas, New Jersey, Massachusetts, Maryland, and even Florida also provide significant home bases for many RF engineers.

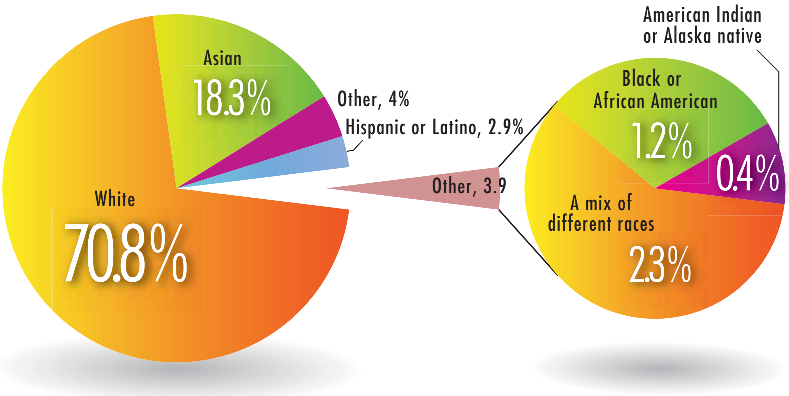
With Maryland, Massachusetts, and Pennsylvania all showing significant numbers of RF engineers, the Northeast coast is the area with the largest concentration of RF engineers. In smaller numbers, however, RF engineers are surprisingly spread out across the country. This could be the result of the majority of RF engineers working for companies that are worth less than $25 million. These smaller companies may be located in areas that are less likely to be the hubs of commerce.

In terms of schooling, RF engineers tend to be highly educated. Over half of RF engineers are equipped with either a Master's or a Doctoral degree. Another third have a Bachelor's degree and may even have had some additional graduate studies. The level of study achieved may be a factor of the lengthy stay many RF engineers have had at their companies, during which they benefited from continuing-education benefits and/or support.

A FEW STARTLING NUMBERS

RF engineers are not likely to relocate anytime soon, as the average age of the engineer who responded to our survey is 51. With almost half of the respondents older than 55—and more than half of those engineers older than 60—this could be

RF ENGINEERS DIVERSITY FACTOR



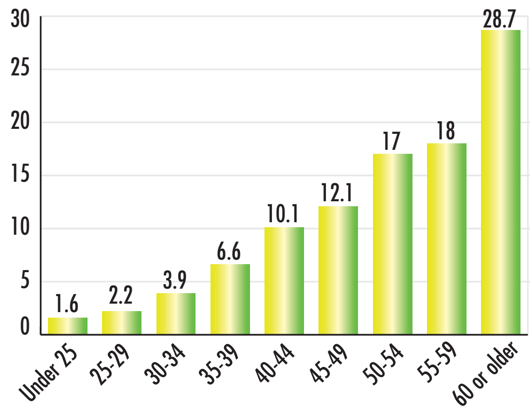
a sign of a troubling trend in our industry. There are likely to be many openings for skilled and experienced RF engineers in the next 5-10 years. In addition, most RF engineers identify as being white, which corresponds to the majority of RF engineers originating from the United States and Europe. The next largest ethnic demographic is Asian, with only a smattering of other ethnicities. The huge majority of our RF engineering respondents are also men, with women coming in at only 3%.

These demographics bring up some startling and significant truths. The diversity of RF engineers is currently very narrow. If this doesn't change, there will be fewer and fewer skilled engineers to take on the latest challenges. In our results, this gap was underscored by the total percentage of RF engineers who are younger than 30—less than 10%.

If RF engineering firms don't jump on the bandwagon by encouraging STEM education in ethnically diverse and mixed-gender environments, there may be fewer young people and students who would even consider a career in RF engineering. Meanwhile, the projections for the advancement of connectivity through communications and the wireless world are predicted to skyrocket in the next 10 to 15 years.

To fill the coming void, companies who employ RF engineers may need to bring on less skilled engineers with an interest in RF. They can then leverage the more experienced, and even retiring engineers, to coach and mentor them to a higher level of technical achievement. This method may be counterintuitive for many organizations to employ. But as the resource of available RF engineers shrinks, so will the industry's options.

RF ENGINEERS: AN AGING POPULATION [%]



STUDENTS AND NEW HIRES

Most RF engineers seem to feel that recent graduates and students aren't adequately educated to be a productive member of the workforce. Almost half feel that these new recruits need as much as a year or more to be able to do their jobs independently upon being hired. These results coincide with RF engineers reporting that their companies appear to be hiring more engineers who were not born or raised in the United States.

The majority of RF engineers (over 70%) share the opinion that education abroad is poorer at preparing a new hire for real-world job duties. Although some of these new hires may have had some education in the United States, the majority seem to be educated abroad.

For instance, one respondent claims, "Most engineers from abroad seem to have less practical experience." Another comments, "Engineers from abroad are very heavy on theory/textbook, but have little practical knowledge." Of course, such statements may not be reflective of where the engineer was raised, as much as where they were educated. Another respondent, "Engineers we hired with either U.S. or foreign undergraduate degrees both seemed smart and competent—though they both had U.S. graduate degrees."

Most RF engineers seem to feel that US universities are focusing on the right material; they are just not enabling the students to have enough hands-on experience. In addition, almost three-quarters of RF engineers feel that internships, or cooperative education, should be mandatory for engineering education. When RF engineers work for companies that have developed a relationship with a local college or university, they believe the organization can more effectively hire new graduates with the skill sets they are seeking.

Unfortunately, less than half of RF engineering companies seem to be fostering any STEM education whatsoever. This situation may need to be change rapidly, as less and less U.S. engineers are coming from these companies' local communities.

CONTINUING EDUCATION

Consistent with many other technology fields, RF engineers mostly continue their education from engineering/technology publications. Seminars, webcasts, and white papers are also highly popular. Engineering textbooks, trade shows/conferences, and engineering association meetings also rank on the list of favorites. It's not surprising that the most accessible educational tools are the most popular, as many RF engineers confided that they are having more and more difficulty keeping current due to time constraints.

RETIREMENT

According to almost 70% of RF engineers, their companies are funding part of their retirement. The majority of this funding is in the form of a 401(k) or similar plan. Unlike many other industries, over 40% of RF engineers are also looking forward to a pension. A quarter of them enjoy either stock options or employee stock ownership.

Of course, much of this retirement assistance depends on the continuing health of these engineers' current/former employers. Given the impending lack of RF engineering knowledge, it may behoove RF engineers and their employers to enhance the drive for STEM education with youth. Otherwise, many RF companies may lack the employee base upon which they may continue to grow into the very bright future for this field. mw

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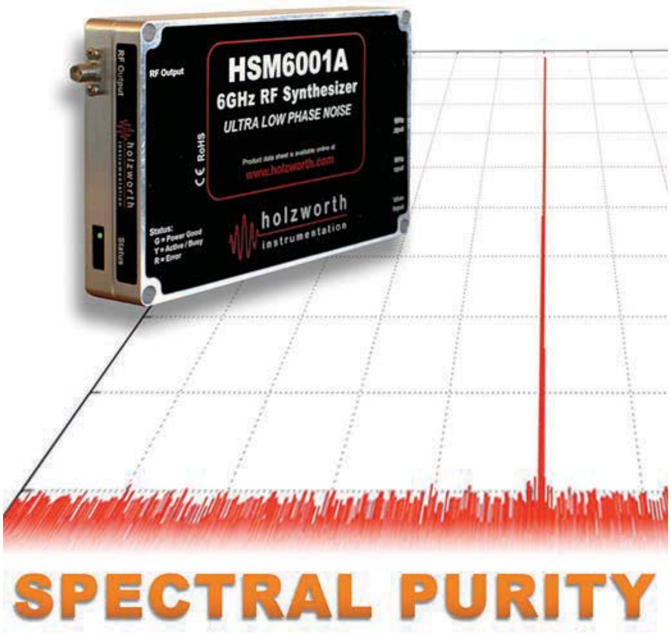

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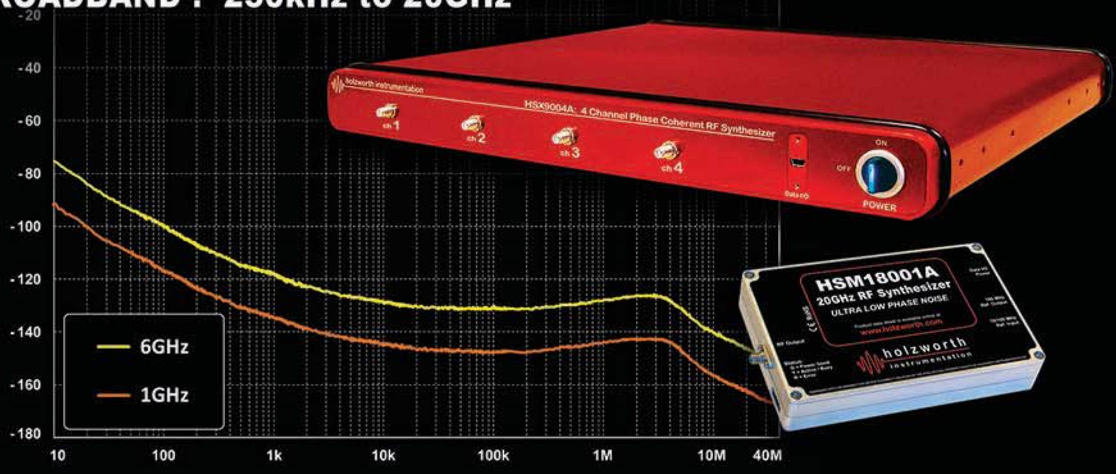

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- 1.0" cube, 1.25" cube, and 1.75" cylinder packages
- 130 dBc/Hz @ 100 kHz at 18 GHz
- 128 dBc/Hz @ 100 kHz at 20 GHz

TO-8 Low-Noise Oscillators
Permanent Magnet and Electromagnetic Designs

- 2-4 GHz, 3-6 GHz, and 3-8 GHz bands
- 128 dBc/Hz @ 100 kHz offset
- .25", .35", and .50" tall versions

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MARKETS SERVED INCLUDE Test & Measurement Instrumentation, VXI & VME miniaturized instrumentation, PXI and Compact PCI miniaturized instrumentation, ELINT and SIGINT receivers, SATCOM and TELECOM applications, digital TV conversion, FM CW radar, ESM, ECM & EW, avionics, and astronomy.
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Simple and Easy to Use!

MLBS-Synthesizer Test Box – 600 MHz to 20 GHz
Standard models cover the 0.6 to 2.5 GHz, 2 to 8 GHz, 8 to 20 GHz and 2 to 20 GHz frequency bands. All versions of the MLSP synthesizer product family can be easily inserted into the test box. Tuning consists of a control knob, key pad, USB and Ethernet connections. Units provide +10 dBm to +13 dBm output power levels and are specified over the lab environment of +15°C to +55°C and are CE certified.

Units are provided with a power cord, USB cable, Ethernet cable, CD incorporating a users manual, quick start guide and PC interface software.

MLBF-Filter Test Box – 500 MHz to 50 GHz
Standard models utilize any Bandpass or Bandreject filter manufactured by Micro Lambda today. Bandpass filter models cover 500 MHz to 50 GHz and are available in 4, 6 and 7 stage configurations. Bandreject (notch) filter models cover 500 MHz to 20 GHz and are available in 10, 12, 14 and 16 stage configurations. Units are specified to operate over the lab environment of +15°C to +55°C and are CE certified.

Units are provided with a power cord, USB cable, Ethernet cable, CD incorporating a users manual, quick start guide and PC interface software.

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MLTO-series TO-8 Oscillators
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MLSMO-series Surface Mount Oscillators
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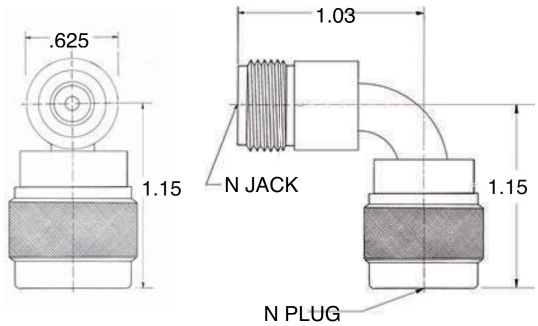
EMAIL | umpinc@pacbell.net
TEL | +310.320.1244
FAX | +310.320.9729

Ed Jacobs | Manager
22129 S. Vermont Ave.
Torrance, CA 90502

COMPANY PROFILE

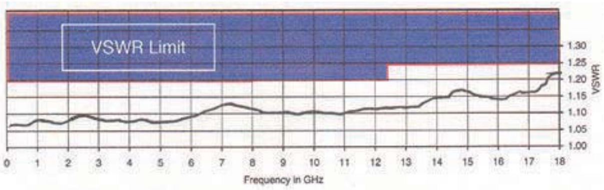
UNITED MICROWAVE PRODUCTS, founded in 1975 and located in Torrance, Calif., is an industry leader in innovative design. We began with the design and manufacture of specialty RF connectors, cable assemblies, and associated microwave products. Being committed to high-quality parts, competitive pricing, and on-time delivery makes us a viable source for RF connectors and cable applications. An assortment of products can be found on our website, unitedmicrowave.com.



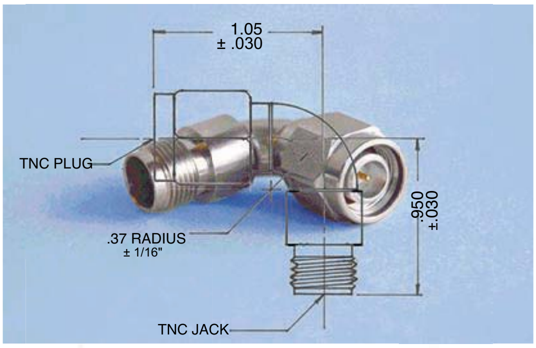
5. VSWR NOT TO EXCEED
   1.20: 1 FROM 8GHz TO 12.4 GHz
   1.25 : 1 FROM 12.4GHz TO 18 GHz
4. ADAPTOR TO MEET OR EXCEED ALL SPECIFICATIONS PER MIL-39012
3. FINISH:
   BODY : PASSIVATE PER QQ-P-35
   CONTACT: GOLD PER MIL-G-45204: TYPE II, CLASS 2, OVER COPPER PER MIL-C-14550, CLASS 4
   COUPLING NUT: PASSIVATE PER QQ-P-35
2. MATERIAL:
   BODY: STAINLESS STL PER QQ-S-763 TYPE 303
   CONTACT: BERYL. COPPER PER QQ-C-530 & BRASS PER QQ-B-626
   COUPLING NUT: STAINLESS STL PER QQ-S-763 TYPE 303
   INSULATOR: TEFLON PER MIL-P-19468A
1. MATING DIMS IN ACCORDANCE WITH MIL-STD-348

NOTES :

1521 N PLUG to N JACK RIGHT ANGLE



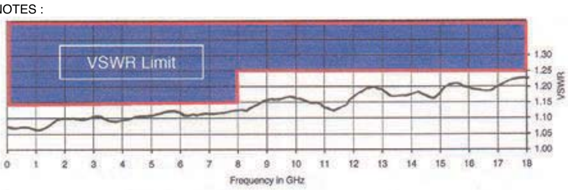
1-9	10-24	25-49	50-99	100+
$152.00	$145.00	$137.00	$123.00	$122.00



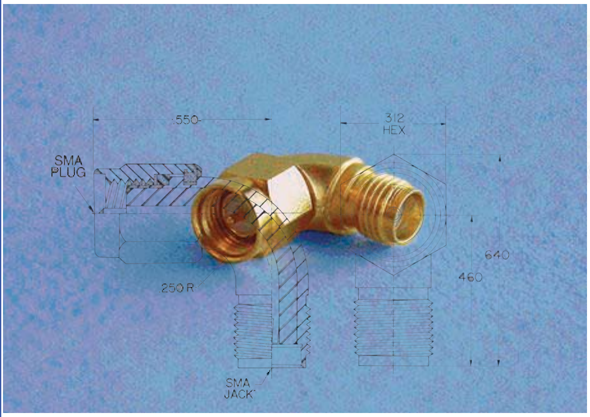
5. VSWR NOT TO EXCEED
   1.15 : 1 DC-8GHz
   1.25 : 1 8-18 GHz
4. ADAPTER TO MEET OR EXCEED ALL SPECIFICATIONS PER MIL-39012
3. FINISH:
   BODY AND COUPLING NUT: PASSIVATE PER QQ-P-35
   CONTACT: GOLD PER MIL-G-45204: TYPE II, CLASS 2, OVER COPPER PER MIL-C-14550, CLASS 4
2. MATERIAL:
   BODY: STAINLESS STL PER QQ-S-764 TYPE 303
   COUPLING NUT STAINLESS STL PER QQ-S-764 TYPE 303
   CONTACT: BERYL. COPPER PER QQ-C-530
   INSULATOR: TEFLON PER MIL-P-19468A
1. MATING DIMS IN ACCORDANCE WITH MIL-STD-348

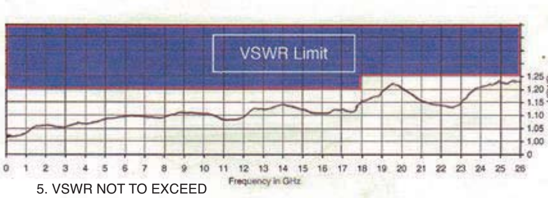
NOTES :

6421 TNC PLUG TO TNC JACK RADIUS RIGHT ANGLE



1-9	10-24	25-49	50-99	100+
$132.50	$129.75	$127.25	$124.75	$122.50



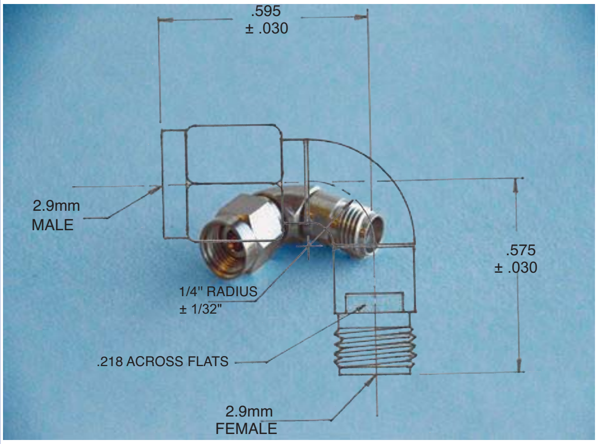


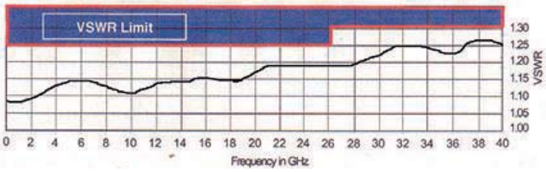
5. VSWR NOT TO EXCEED
   1.20 : 1 DC-18 GHz
   1.25 : 1 18-26 GHz
4. ADAPTER TO MEET OR EXCEED ALL SPECIFICATIONS PER MIL-39012
3. FINISH:
   BODY AND COUPLING NUT: GOLD PER MIL-G-45204:
   OVER NICKEL PER QQ-N-290
   CONTACT: GOLD PER MIL-G-45204: TYPE II,
   CLASS 2, OVER COPPER PER MIL-C-14550, CLASS 4
2. MATERIAL:
   BODY: STAINLESS STL PER PER QQ-S-764 TYPE 303
   COUPLING NUT STAINLESS STL PER QQ-S-764 TYPE 303
   CONTACT: BERYL. COPPER PER QQ-C-530
   INSULATOR: TEFLON PER MIL-P-19468A
1. MATING DIMS IN ACCORDANCE WITH MIL-STD-348

NOTES :

370-26 SMA PLUG to SMA JACK RIGHT ANGLE 26GHz

1-9	10-24	25-49	50-99	100+
$38.50	$37.50	$34.25	$31.50	$29.00



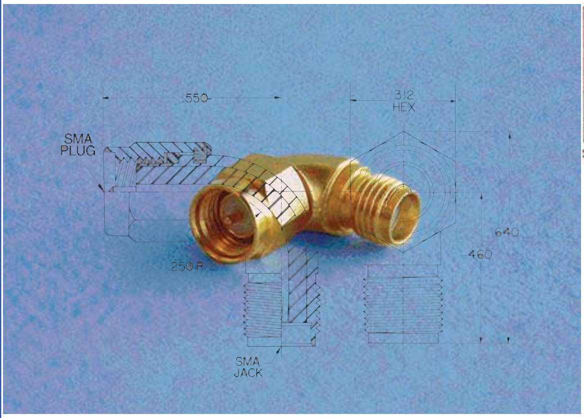


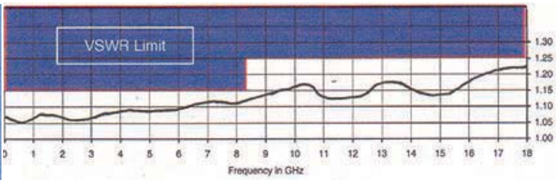
5. VSWR NOT TO EXCEED
   1.25 : 1 DC-26GHz
   1.30 : 1 26-40GHz
4. ADAPTOR TO MEET OR EXCEED ALL SPECIFICATIONS PER MIL-39012
3. FINISH:
   BODY AND COUPLING NUT: PASSIVATE PER QQ-P-35
   CONTACT: GOLD PER MIL-G-45204: TYPE II, CLASS 2
2. MATERIAL:
   BODY: STAINLESS STL PER QQ-S-764 TYPE 303
   COUPLING NUT STAINLESS STL PER QQ-S-764 TYPE 303
   CONTACT: BERYL. COPPER PER QQ-C-530
   INSULATOR: TEFLON PER MIL-P-19468A
1. MATING DIMS IN ACCORDANCE WITH MIL-STD-348

NOTES :

370SF-40 RAD 2.9 MALE to 2.9 FEMALE SWEEP RIGHT ANGLE

1-9	10-24	25-49	50-99	100+
$210.00	$200.00	$195.00	$190.00	$188.00





5. VSWR NOT TO EXCEED
   1.15 :1 DC-8 GHz
   1.25 :1 8-18 GHz
4. ADAPTER TO MEET OR EXCEED ALL SPECIFICATIONS PER MIL-39012
3. FINISH:
   BODY AND COUPLING NUT: GOLD PER MIL-G-45204:
   OVER NICKEL PER QQ-N-290
   CONTACT: GOLD PER MIL-G-45204: TYPE II,
   CLASS 2, OVER COPPER PER MIL-C-14550, CLASS 4
2. MATERIAL:
   BODY: STAINLESS STL PER PER QQ-S-764 TYPE 303
   COUPLING NUT STAINLESS STL PER QQ-S-764 TYPE 303
   CONTACT: BERYL. COPPER PER QQ-C-530
   INSULATOR: TEFLON PER MIL-P-19468A
1. MATING DIMS IN ACCORDANCE WITH MIL-STD-348

NOTES :

370 SMA PLUG to SMA JACK RIGHT ANGLE 18GHz

1-9	10-24	25-49	50-99	100+
$38.50	$37.50	$34.25	$31.50	$29.00

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2.9mm FEMALE TO 2.9mm MALE RADIUS RIGHT ANGLE

SDRs Leap Ahead

Advancements in GPPs and FPGAs have merged with software-based development platforms to enable the latest in communications technology.

From tactical communications to the common smartphone, highly configurable hardware can remove the design/development and end-user costs associated with having to upgrade system hardware for a simple feature change. Instead, a software upgrade can be instantly transmitted through the existing wireless infrastructure as soon as an upgrade becomes available.

By developing their own software, users also can implement a host of desired features without significant knowledge of the underlying hardware. Such scenarios—which would have been a dream only a few years ago—are now very much a reality, thanks to software-defined radios (SDRs) and Universal Software Radio Peripherals (USRPs; *Fig. 1*).

1. Modern SDRs have the ability to link with other SDRs for test & measurement and research & development purposes. (Courtesy of National Instruments)

To create a layer of digital abstraction, SDRs leverage the power of modern general-purpose processors (GPPs) and clever reprogrammable-logic systems, such as field-programmable gate arrays (FPGAs). De-embedding the hardware from the digital plane eliminates the need to physically adjust RF/microwave components to enable behavioral feature changes, such as implementing the latest LTE standards. When an SDR operates as a USRP with virtual hardware instrumentation, it can extract and analyze information within complex RF signals.

Accurate analog-to-digital converters (ADCs), which are placed on either generic or application-specific peripherals, map RF signals to a lower frequency. The ADCs can digitize those signals using downconversion. These signals are then converted into digital recreations of the waveforms. Processing is done using digital-signal-processing (DSP) techniques that are often implemented with the DSP cores of a FPGA.

Clearly, such flexible radio architectures could enable the same hardware to be used to implement a wide range of telecommunications applications. This task could be done on the fly, without the designer needing significant RF/microwave knowledge, and potentially using community-generated code. As a result, this approach easily translates into dramatically lower development and upgrade costs.

Beyond telecommunications, SDR features also offer a host of advantages. Among other benefits, for example, tactical radios could adjust their communication algorithms based upon field conditions. Test and measurement instruments can receive cost-effective, software-licensed upgrades, which allows them to advance with the latest techniques. For their part, consumer products gain the ability to adapt to various wireless network situations for an optimum user experience. The applications that can benefit from SDR approaches are essentially infinite, given the ability to more easily generate the software backbone.

According to James Kimery, director of marketing for National Instruments, "Today, what's driving a lot of momentum with SDR technology is that the software elements are available. Software is more plentiful and there is a community where code is shared, which helps with rapid adoption." Yet the hardware to implement advanced SDR technology is still relatively expensive for certain applications. As a result, SDRs are more often used in applications in which the cost of the initial unit is offset by inexpensive upgradability and versatility. Two examples are tactical/public-safety radios and cellular base stations.

As the range of SDR applications is vast, so is the rest of the SDR landscape—especially considering form factors, capabilities, software tools, and companies offering SDR solutions. Companies like Rohde & Schwarz offer highly rugged and flexible SDRs for mission-critical systems *(Fig. 2)*. For low-cost rapid-prototyping structures, firms like Analog Devices and Peregrine make whole RF-transceiver systems-

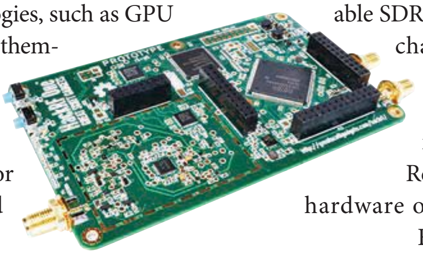
2. Many tactical radios systems are designed with SDR backbones, which are capable of rapid software upgrades and modularity. (Courtesy of Rohde & Schwarz)

on-a-chip (SoCs) that lend themselves to SDR implementation.

Even small hobbyist companies, such as Great Scott Gadgets and Ettus Research, are rolling out affordable SDR prototyping units that previously would have been too expensive for the hobbyist consumer. Meanwhile, companies like National Instruments and Nutaq are producing high-performance SDR modules and test/measurement equipment.

Driving this boom of SDR hardware and software development is the increased accessibility to integrated, low-power, and high-performance RF transceivers, Kimery says. "RF integrated circuits (ICs) are continually being offered in wider frequency ranges with smaller form factors. They consume less power and have a rich set of abilities. The performance of FPGAs also can't be underestimated."

Such DSP density enables the rapid calculation of complex mathematics. Given the innate property of FPGA DSP systems for parallelization, they also enable SDR configurations that use multiple FPGAs in tandem. Other technologies, such as GPU and multicore CPU combinations, may lend themselves to SDR processing in the future. As FPGA SDR development is currently more streamlined for high-bandwidth operation, FPGAs may dominate the SDR markets for the time being. However, future research and developments could adapt GPU technology to take advantage of its parallel-processing capabilities.



3. There are many project—or hobbyist level—SDRs being built with sophisticated performance characteristics that can reach 6 GHz. (Courtesy of Hacker RF)

Of course, implementing DSP technologies using FPGAs invites a challenge: Software must be developed that can use these devices' extensive capabilities. Ultimately, software performance depends upon the environment in which the software is designed. But its success also depends on the length of time that it takes for the software to be developed. To increase the ease and speed of software development for SDR applications, organizations like GNU Radio, Mathworks, and NI have developed graphically based programming languages.

This style of programming could lead to a more intuitive programming design, which enables a software system to more closely resemble the hardware that it controls. Some examples of these environments include GNURadio, Matlab/Simulink, and Labview. With a well-developed hardware and software partnership, SDR technology could be adapted to almost any telecommunications application.

Given the increased interest in smart automobile systems, for instance, the Institute for Electrical and Electronics Engineers (IEEE) has developed standards for wireless access in vehicular environments (WAVE or IEEE 802.11p). One aim of automobile manufacturers has been to eliminate the wired connectivity between the many sensors and subsystems within a vehicle. Doing so has the ability to reduce costs and service time while enabling new features and allowing user customization. SDR technology could benefit this market, as highly integrated SDR devices could be used and flexibly configured throughout the automobile environment.

An area that is drawing attention from the industry as well as research and development groups is millimeter-wave technology. Building traditional radio architectures that are suited for millimeter-wave applications is generally costly, highly specialized, and prone to error. A millimeter-wave structure's behavior is highly influenced by its direct environment. As a result, it must change its behavior according to environmental stimulus to provide adequate performance.

Meanwhile, millimeter-wave technology is advancing very rapidly, as there is a lot of interest in using millimeter-wave technology for the next 3GPP installment of Fifth-Generation (5G) telecommunications. Yet these rapid developments and unsolidified standards make investing in current hardware for millimeter-wave applications a potential risk. A highly adaptable SDR with built-in flexibility to environmental changes may allow for higher-performing millimeter-wave technologies. In addition, the use of USRP components may reduce the hardware configuration risks.

Recent advances in SDR technology include hardware offerings like GPPs integrated with an FPGA in a single device, a "cell-phone"-grade complete RF front-end module, and advances in software support for SDRs. The Xilinx Zynq-7000 series of programmable SoCs, for example, includes the ARM Core Cortex processors, a wealth of I/O, on-chip memory, and a programmable logic center. In theory, strapping a Zynq device to an integrated RF front-end module would create a standalone and capable SDR with minimal hardware development and an already rich software environment.

Meanwhile, Peregrine's Global 1 RF front end is reported to achieve gallium-arsenide (GaAs) -level performance using silicon-on-insulator (SoI) CMOS technology. In doing so, it could potentially replace the RF front end of a cell-phone with LTE capability.

In summary, more capable DSP cores are being included with advanced programmable-logic devices. This trend elevates the importance of the software that can harness these powerful devices. At the same time, the latest RF system-integration approaches are preparing to enable radio platforms with virtually infinitely configurable hardware and a rapidly reprogrammable structure. These advances could even allow for previously untapped markets for SDRs—namely, wireless Internet and cellular—to see a revolution in flexibility. Considering the push for 5G technologies and the proliferation of the Internet of Things, SDR technology may pave the way to massive-element wireless systems. mw

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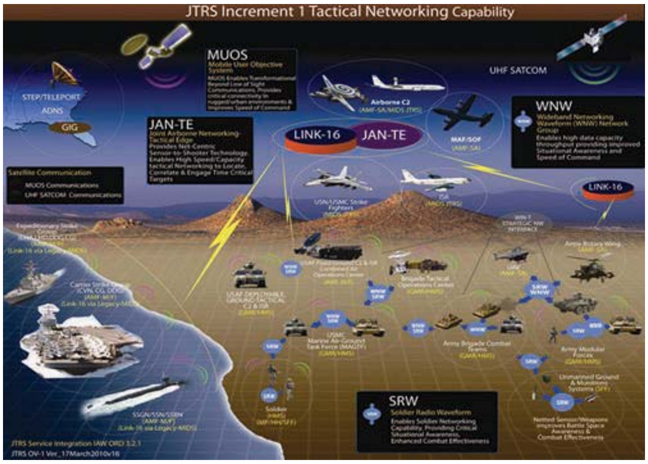
Our equipment has been selected as the equipment of choice for major programs such as Warfighter Information Network Tactical (WIN-T), Multi User Objective System (MUOS), Joint Tactical Radio System (JTRS), and the Modernization Enterprise Terminal (MET) programs.



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Sophisticated Satellite link emulation

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250 MHz bandwidth

Test solutions for ....

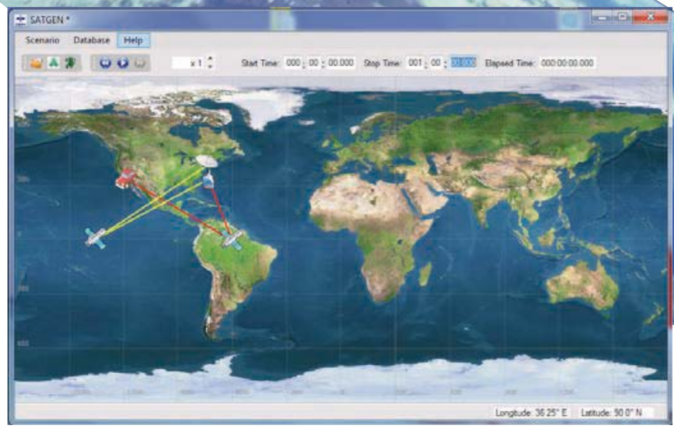
WIN-T - warfare information networks, tactical

MUOS - mobile user objective system

JTRS - Joint Tactical Radio System

IRIS - Internet routing in space

Software showing mobile link setup



dBmCorp, Inc
32A Spruce Street ◆ Oakland, NJ 07436
Tel (201) 677-0008 ◆ Fax (201) 677-9444

dBm

RF Test Equipment for Wireless Communications

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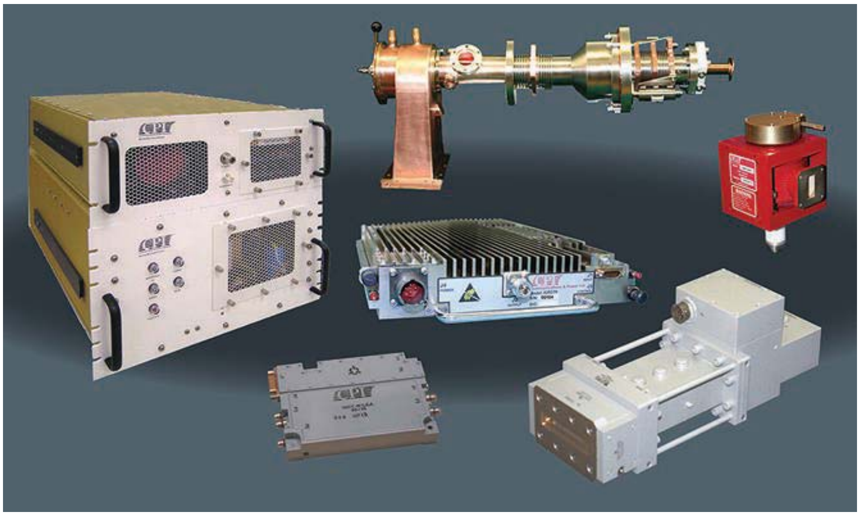
We are certified to ISO9001: 2008 and AS9100C



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- Integrated Microwave Assemblies
- Receiver Protectors
- Control Components
- Transmitters
- Amplifiers
- Modulators
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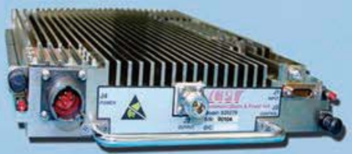
Solid State Power Amplifiers

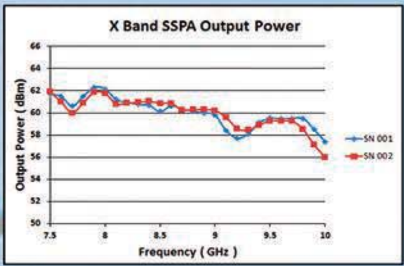
X-Band

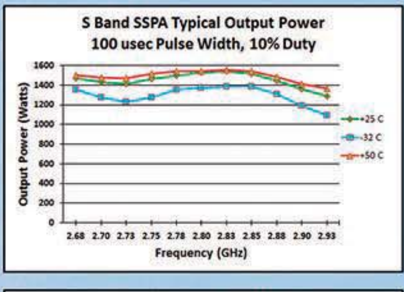


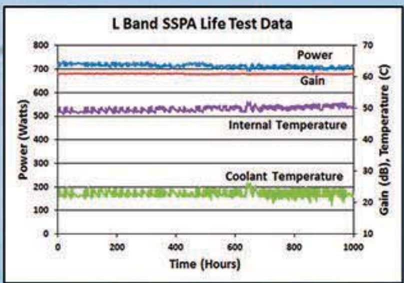
S-Band

L-Band

GaN Solid State Amplifiers







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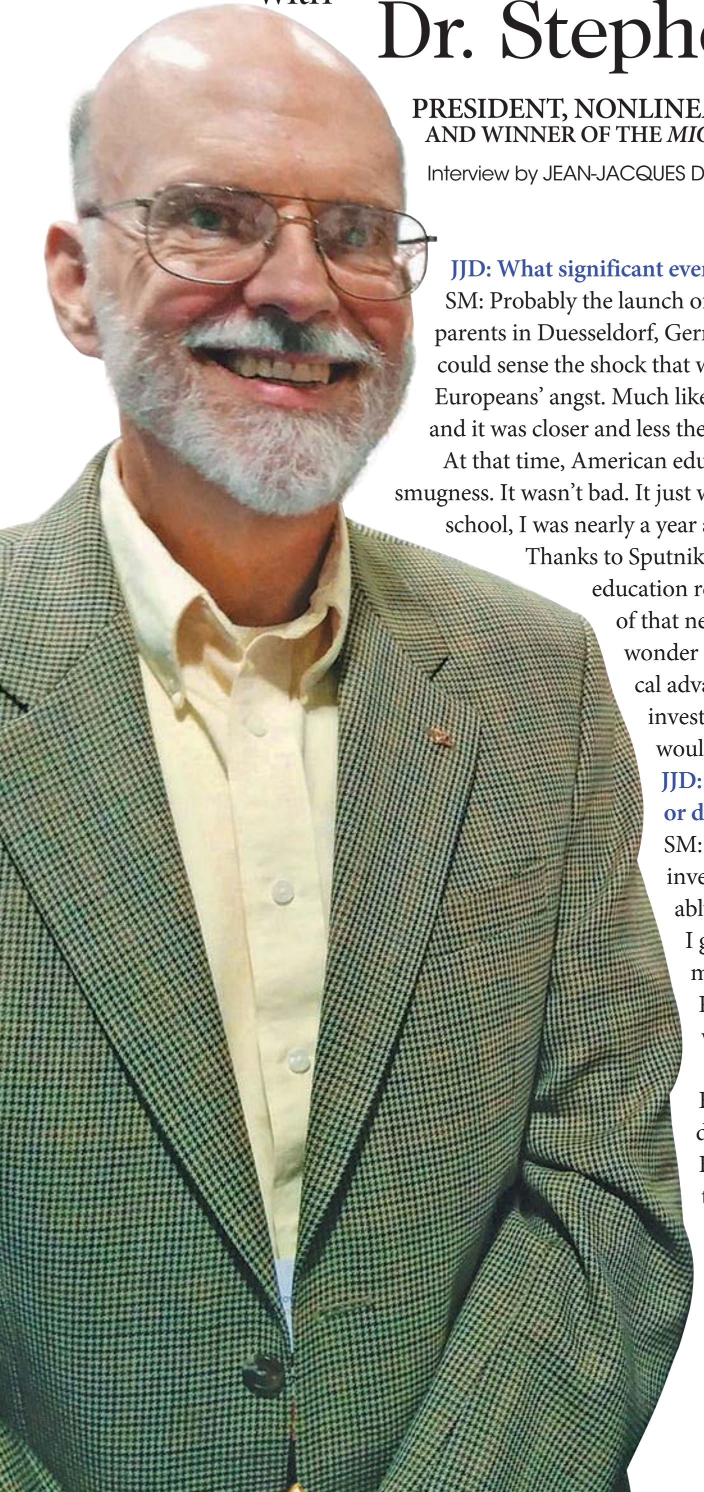
LEADERS IN MICROWAVES Q&A

Inside TRACK with Dr. Stephen Maas



PRESIDENT, NONLINEAR TECHNOLOGIES INC., AND WINNER OF THE *MICROWAVES & RF* LIVING LEGENDS AWARD

Interview by JEAN-JACQUES DELISLE

JJD: What significant event most influenced your career?

SM: Probably the launch of Sputnik in 1957. I was eight years old, living with my parents in Duesseldorf, Germany. Even from the opposite side of the Atlantic, we could sense the shock that went through American society, and we especially felt the Europeans' angst. Much like Americans, Europeans perceived a "Communist threat," and it was closer and less theoretical for them than for Americans.

At that time, American education had evolved into complacency and self-satisfied smugness. It wasn't bad. It just wasn't very good. After only two years in a European school, I was nearly a year ahead of my classmates when I returned to the U.S.

Thanks to Sputnik, though, all that started to change. Math and science education received the boost it needed, and I was a direct beneficiary of that new emphasis. I couldn't have been born at a better time. I wonder how many people understand that the huge technological advances of the last 30 years or so are the direct result of the investment in science education of the 1960s. Without that, we wouldn't be where we are. Someone else would be, but not us.

JJD: If you could have worked with anyone in the field, alive or dead, who would it be and why?

SM: An obvious choice would be Edwin Armstrong, the inventor of not just the superheterodyne receiver but arguably of modern radio technology. When I read his papers, I get the feeling that I think much like he did. Another of my heroes has always been Benjamin Franklin: a genuine Renaissance man and radical thinker with a penchant for wise, dry humor. Beyond that, many people I admire are from very different fields: the Philadelphia artist Thomas Eakins, who knew exactly what needed to be done and didn't let the people who set the styles dissuade him; Jacob Bronowski; Bertrand Russell... I could go on, but I guess that's a decent sampling.

JJD: What led you to focus on nonlinear circuits?

SM: I had developed an interest in low-noise mixers, primarily from working in radio astronomy in the 1970s. In those days, mixers were a hot research topic.

Of course, in dealing with mixers, you come face to face with nonlinearity. There's no way to avoid it. By the 1980s, microwave FETs were good enough that low-noise mixers weren't needed below about 15 GHz. But putting substantial, low-noise gain ahead of a mixer exacerbated distortion. As FETs got better, they got smaller and distortion got worse.

In spite of this, academic research in the '80s remained focused on low noise. But in industry, distortion was the greater problem, and no one seemed to be addressing it. It sounded new and interesting to me, and I had a bit of a head start from the mixer work, so I began working on it. *The Nonlinear Microwave Circuits* book was one result. It helped me organize my thinking, figure out things I didn't know, and put the field into a coherent form.

JJD: How did you come to write your first book?

SM: I returned to graduate school to finish my Ph.D. after several years in industry. By then, I had acquired a wife, a kid, and a mortgage, so I couldn't afford to stop working and become a full-time student. I worked all day and studied all night. Then, when it was over, I was completely at loose ends. I didn't know what to do with myself. I needed some kind of project. I discovered that Artech House was open to new proposals, so I put together a proposal for the mixer book. Despite the fact that mixer theory had been a hot research topic for the previous decade, no one had written a comprehensive book on the subject. So there was a clear opportunity. Perhaps for that reason, Artech was willing to take a chance with someone they had never heard of, and they accepted the proposal.

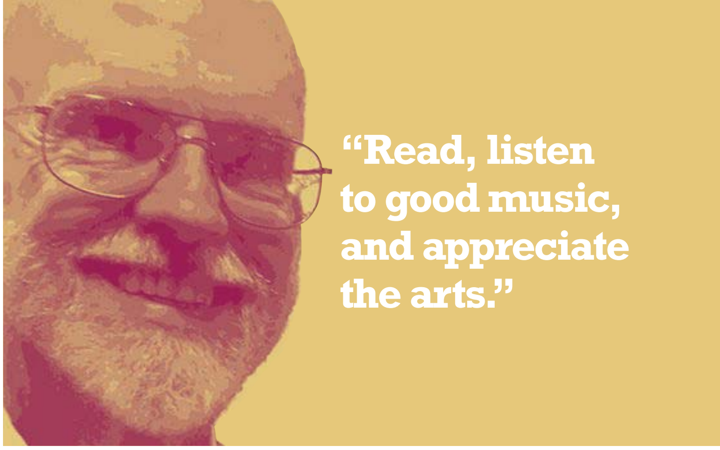
Your readers might be amused to hear that I wrote the mixer book and, to a large degree, the later ones so that I could use them as a reference myself. I don't have all that information at the top of my head, so I often have to refresh my memory. It's nice to have a book that explains things the way I understand them. The process of writing a book also required getting my thoughts in order and filling gaps in my knowledge. It's a nice way to develop a deeper understanding of a subject.

I was unprepared for what happened when the book hit the streets. Suddenly, I was "the guy who wrote the mixer book," and lots of people knew who I was. I received quite a few unsolicited offers to consult, job offers, and so on. As a person who is generally pretty reserved, I found it all a little scary.

JJD: Would you say many engineers avoid "hard" problems like nonlinearity? Is this hurting development in the field?

SM: I don't think that's really a problem. Many technologies have a high intellectual cost of entrance—for example, electromagnetics and solid-state device physics, as well as nonlinear circuit theory. In spite of their difficulty, there's no shortage of people entering those fields. It is important, however, that we develop the tools that make those fields accessible to everyone who needs to deal with them. We also must make sure that they understand the fundamentals necessary to use them.

In my case, that means developing circuit-analysis software. Using that software effectively does not require knowing



nonlinear circuit theory in detail. But it does require knowing a few things about termination criteria, number of harmonics, preventing ill-conditioning, and perhaps a few more things. Same story with electromagnetic simulators: You need to know some basic electromagnetics and some facts about the way the simulators work and their limitations. But you don't need to understand the details of what's going on underneath.

JJD: What would you recommend to young engineers after all of the experiences in your career?

SM: **One:** Stay technical. It's more fun, and if you're really good technically, you'll always have a job. **Two:** Develop your communication skills. This is every bit as important as technical skills. **Three:** Don't worry about money, glory, status, career, or any of that peripheral stuff. Stick to the knitting, and you'll be surprised how those things take care of themselves. **Four:** Develop a sense of history. Technologies evolve as much for historical reasons as technical ones. An understanding of history will show you, among other things, which technologies have a future and which are likely to be dead ends. **Five:** Read, listen to good music, and appreciate the arts. This tells you a lot about how humans think and create. It's not as far from technology as you might imagine.

JJD: What technological innovation had the most impact in the field during your career? How did it change things for you?

SM: The computer—and especially the small, powerful desktop computer. I didn't do much with computers until minicomputers became common around 1980, but they rapidly became a big part of my life. I probably don't have to explain why. But I should note that virtually all circuit design these days, linear or nonlinear, involves numerical analysis. The ability to have easy, quick access to circuit analysis and other kinds of computation has changed all of our lives. Without it, we'd still be, technologically, in 1963.

JJD: What was the greatest challenge you faced in your career?

SM: Probably the fact that I'm really not all that smart. I was never one of those guys who seem to waltz through school effortlessly. I always harbored a boundless jealousy for the people who did. It took me a long time to understand things, and I was continually struggling to keep up and keep my head above water. Eventually, though, I realized that it was an advantage, as I had to learn how to dig into a subject and explain it to myself, get the subtleties, and avoid conventional wisdom. I'm still not so quick on the uptake sometimes. But when I finally figure something out, I usually know it in good depth. mw

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JEAN-JACQUES DELISLE | Technical Contributor

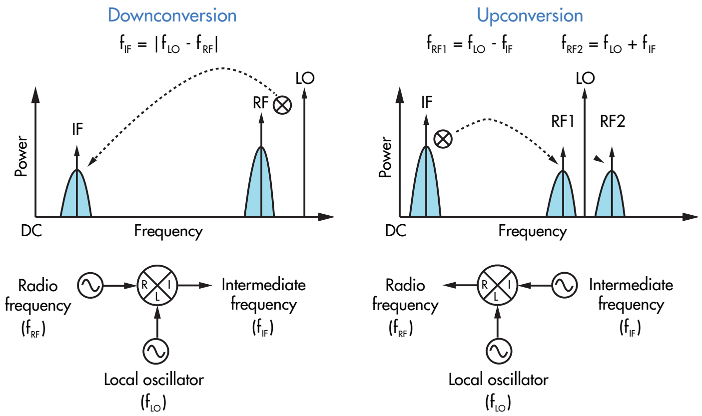
Mixers Pine for Linearity And Dynamic Range

RF mixer technology must keep pace to avoid being the limiting factor in new devices.

While Reginald Fessenden worked for the U.S. Weather Bureau in the early 1900s, he was determined to advance radio principles so a network of coastal radio stations could transmit weather information over long distances. Fessenden invented a principle of combining two radio signals to form a reduced composite of the signals in the audible spectrum—a process known as heterodyning. Building on this work, Edwin Armstrong later developed the first super-heterodyne receiver.

Modern mixers have moved far beyond this heritage to multiply or divide RF signals well into the millimeter-wave range. Yet the advanced behavior of these mixers requires increasing complexity in an industry that demands never-ending performance enhancements.

Mixers are used wherever significant frequency translation is needed. Using the dynamics of a nonlinear node and clever circuitry, which forces some linear behavior from the mixing device, two input signals can be multiplied or divided *(Fig. 1)*. Diodes, Schottky diodes, bipolar-junction transistors, or field-effect transistors can be used as nonlinear elements.



1. Upconversion and downconversion are two critical operations for mixers. For high-frequency signal transmission, upconversion is often used. For test and measurement applications, in contrast, the downconversion of signals from higher frequencies allows for precision measurements.

Creating an upconverted or downconverted output signal requires the use of a local-oscillator (LO) input signal, an intermediate-frequency (IF) input/output signal, and an RF input/output signal. The most common mixers use the switching action of the LO to drive a nonlinear junction in and out of conduction, thereby clipping the RF signal. As no device is ideal, several unwanted frequency products are generated by the mixing action. One figure of merit for mixers reveals how well these products are suppressed. Other figures of merit include spurious-free dynamic range (SFDR), noise figure (NF), input third-order intercept point (IIP3), the 1-dB compression point, conversion gain, and isolation.

Among the various types of mixers, there are two main categories: passive and active mixers. Passive mixers generally have higher 1-dB compression points, a lower NF, and a higher IIP3. Active mixers tend to have much lower power consumption and even a potential increase in conversion gain, although they trade off lower power for lower linearity. Both passive and active mixers can be divided into several classes: single-device, single-balanced, double-balanced, and triple-balanced (double-double-balanced mixer).

Single-device mixers use a nonlinear component for the mixing action. Often, they require injection filters, as they do not attenuate the LO signal in the output. The benefit of single-device mixers is that they are capable of reaching millimeter-wave frequencies. Using two nonlinear devices connected via a 180° or 90° hybrid can improve the isolation between the LO and output signal. The resulting device is called a single-balanced mixer. Balanced mixers tend to have lower frequency capability and require baluns. According to Christopher Marki, director of operations for Marki Microwave, "Mixer frequency coverage is [usually] governed by the balun. Magnetic baluns work very well below 3 GHz, and many companies make such mixers. Non-magnetic, or capacitive coupled, baluns are fantastic in 2-GHz and higher applications. Those baluns are [usually] limited to several octaves. Mixers have a sort of 'gain/bandwidth' product that is mostly related to baluns."

Using a network of four nonlinear devices with multiple hybrids, baluns, or transformers produces a higher-performing mixer class, which are referred to as double-balanced mixers. The double-balanced mixer benefits from the rejection of spurious/intermodulation products, better isolation among all ports, and modulated noise rejection in the LO signal. Compared to single-device mixers, balanced mixers boast limited requirements for additional filters and generally broader bandwidth. Higher LO power is necessary for balanced mixer operation to avoid high conversion loss. Often, LO amplifiers are included in mixer designs for this reason.

To meet these demands, the design figures of merit for linearity and SFDR must increase. The devices also need to operate with overlapping or near-overlapping input and output signals. Using an unbalanced mixer with various filters for increased isolation does not always provide the necessary frequency operation. In these cases, more advanced circuit typologies may be required.

For example, the triple-balanced mixer is the culmination of two double-balanced mixers combined using a push-pull drive configuration. These mixers can support overlapping RF, LO, and intermediate frequencies while flaunting the highest spurious noise suppression of the classes. The higher-bandwidth capabilities and low-conversion-loss aspects of the triple-balanced mixer are among its additional design advantages. Using near-ideal commutating switching techniques and internal feedback circuitry to enhance performance, triple-balanced mixers can be pushed to very high linear behavior.

2. Mixers that require magnetic baluns are still large compared to most RF/microwave circuit components. Even for surface mount, the smallest offering from Marki Microwave is only 0.32 inches on a side. (Courtesy of Marki Microwave)

CHALLENGES OF DISCRETE AND INTEGRATED MIXER TECHNOLOGY

Mixers are manufactured to many size, frequency, and power constraints. The two main styles of mixers are discrete (hybrid) and integrated (monolithic) mixers. Discrete mixers typically use silicon-based Schottky diodes, whereas integrated mixers use NPN transistors for active types and FETs for passive types. Discrete mixers can achieve a higher linearity response and lower NF response than active mixers. Yet they also are known for increased cost, a larger footprint, and often higher power requirements *(Fig. 2)*.

Discrete mixers require matched diode structures and carefully chosen components. The demands for decreased size and lower-power operation translate into more challenging requirements for these mixers. Marki says, "Mixers that require magnetic baluns are still very large. Our smallest is 0.32 in. on a side. These mixers use magnetic baluns that often dwarf the rest of the RF circuitry, and they are very tall. There is no clearly demonstrated and viable way to eliminate these 'old school' wire-wound ferrite cores from the assembly." Minimizing component sizes to reduce the overall footprint generally requires a decrease in a device's RF power, which impacts the response's linearity.

Integrated mixers can be designed to high tolerances. Enabled by integrated matching techniques, such mixers may incur lower costs by taking advantage of silicon processes. As noted by Tom Schiltz, design section leader of high-frequency products for Linear Technology, "Advanced silicon-process technologies offer higher speed and a wider operating frequency. But they come at the expense of lower breakdown voltages, which can limit mixer IIP3 and input-signal handling capability." He also warns that "integrated mixers are limited by the parasitics of packaging technologies available today and the electrostatic-discharge (ESD) circuits that are required to protect the device."

When it comes to limitations in active mixers, another consideration is the size of the baluns used in the designs. Baluns require significant space on chip. Off-chip baluns may be used, but they increase the overall mixer footprint while adding parasitics to the design. These factors lead to double-balanced mixers being the popular choice for integrated mixers. After all, the footprint and performance drawbacks of on-chip baluns make triple-balance implementations challenging for low frequencies.

Clearly, the increased performance requirements for RF/microwave devices lie heavily on the side of mixer manufacturers and designers. Schiltz notes, "In RF systems, the mixer is usually the limiting factor for system linearity. Furthermore, mixers produce undesired mixing products that must be filtered and increase the system noise floor, which limits receiver sensitivity."

Linearity is one of the major enabling factors for higher data rates for communications technology, increased accuracy for test and measurement applications, and reliability for electronic-warfare and military applications. As such, the pressure is on to push the boundaries of mixer technology.

For sub-6-GHz RF mixers, tunability features are beginning to emerge that limit the effects of process, temperature, power, and frequency variations. These techniques use toggle pins enabled by DC control in critical locations throughout the mixer circuit. Software-control and feedback methods may be used to enhance the linearity or sideband suppression of the next generation of RF mixers. Marki says, "The reconfiguration of 6-GHz and higher mixers is not supported in a meaningful way yet. But I think some microwave and millimeter-wave mixers may support this in the future." mw

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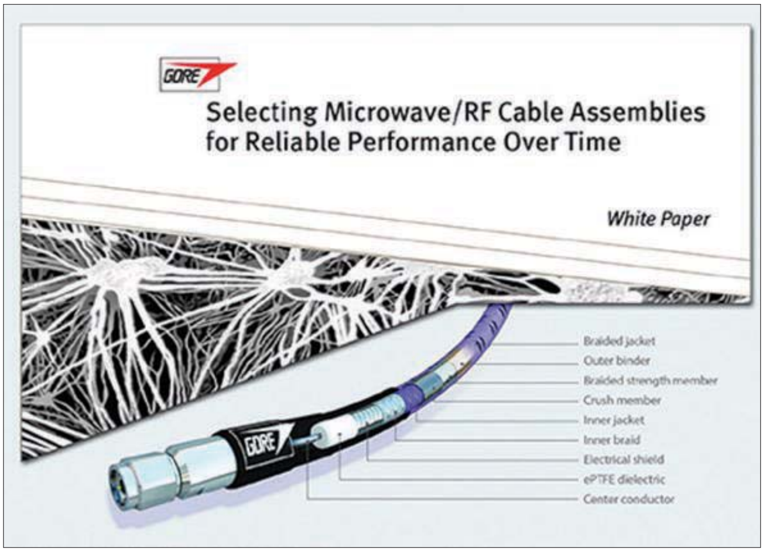

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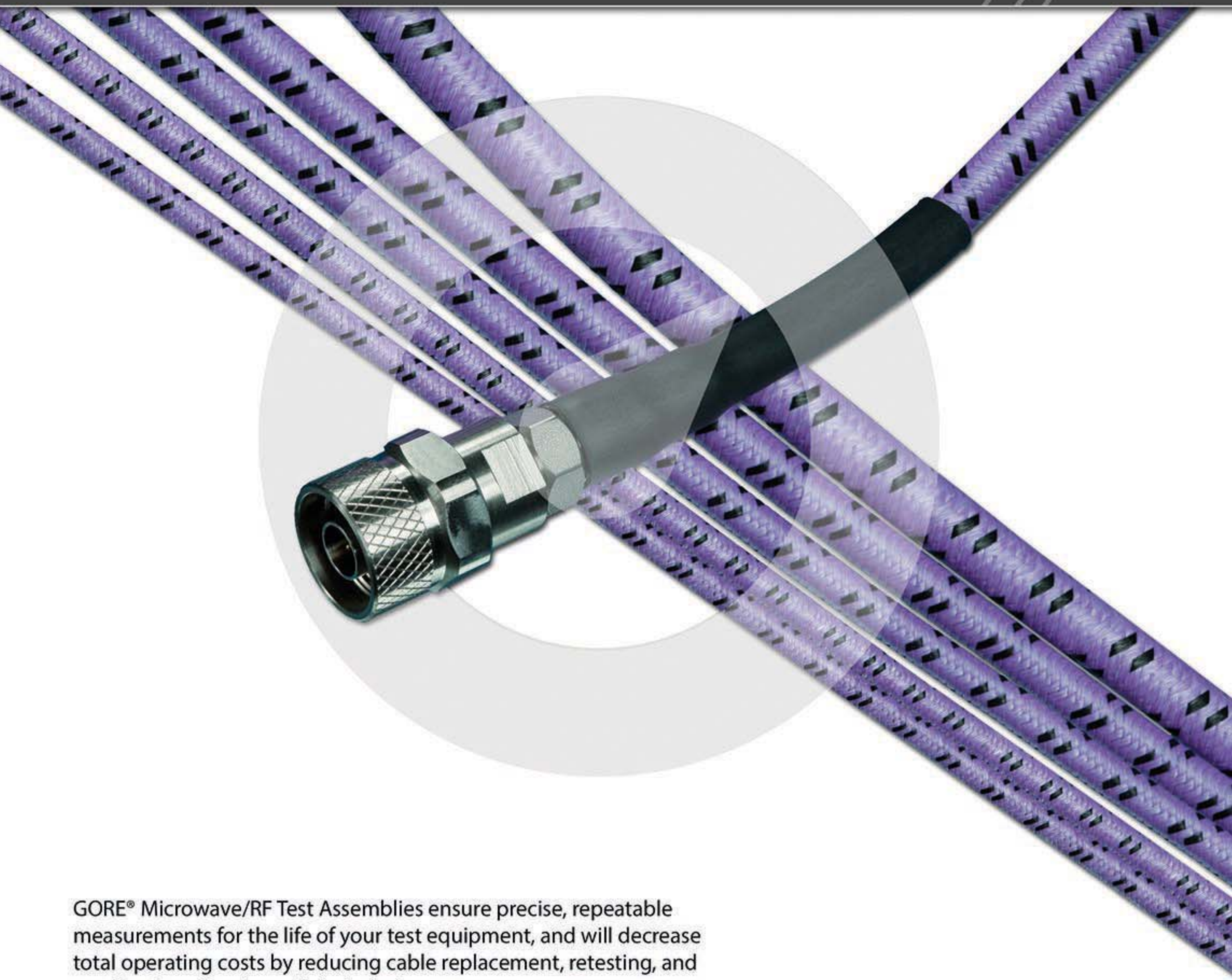

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Measure Interference in Crowded Spectrum

Understanding how to choose and use the right measurement equipment can help when attempting to zero in on interference signals in densely packed spectrum.

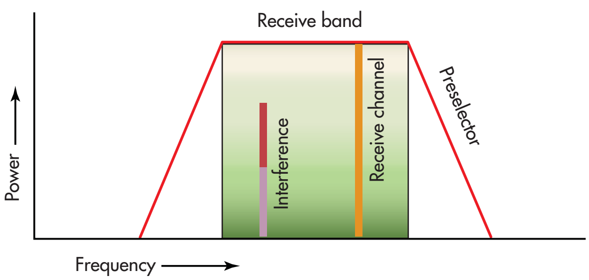
Wireless technology is so widespread that the frequency spectrum can be quite crowded. Almost every portion of available frequency spectrum is shared by multiple services and/or applications, requiring practical, effective control of interference. To eliminate interference, it must first be isolated and identified. Hunting down sources of interference can be challenging, if not nearly impossible.

One example is trying to find short-duration intermodulation signal products without the right tools, or without knowledge about antenna types, signal characteristics, and other factors. Hopefully, this overview of interference-locating techniques and some examples will help accelerate the success of future interference-hunting efforts.

Locating interference starts with finding the right measurement tool, a process that can be aided by understanding the differences between different spectrum analyzer types. Two common types are swept-tuned spectrum analyzers and real-time spectrum analyzers. Swept-tuned spectrum analyzers are typically based on a superheterodyne receiver architecture, in which signals are mixed with a tunable local oscillator (LO) to cover a bandwidth of interest from a starting frequency to a stop frequency.

A real-time spectrum analyzer samples a portion of the frequency spectrum and uses digital-signal-processing (DSP) techniques to analyze the captured spectrum. Filtering occurs in both approaches, and filtering helps set an analyzer's resolution bandwidth (RBW), by which signals closely spaced in frequency can be isolated and identified.

Interference can cause degraded system performance. For example, the unwanted energy may be causing coverage, reception, or access problems for a communications system. Problems can include an adequate signal but poor reception; an adequate signal but intermittent or no access; or a poor signal and no reception. Three basic types of interference are the most common:



1. Interference can occur when there is energy inside the preselector of the victim receiver.

- Co-channel interference is one of the simplest forms of interference, where more than one transmitter can be found on the same channel. This is not unusual, given that many frequencies and frequency bands are at least partially shared by numerous applications or users.
- Adjacent-channel interference results from energy originating from a transmitter other than the one intended. Such a secondary transmitter could be geographically close or close in operating frequency, and operate at a much higher power level than the intended transmitter.
- Intermodulation-based interference occurs when energy from two or more transmitters mixes together to create spurious signal products or frequencies. In general, third-order spurious products are the most common intermodulation interference caused by only two sources, although this type of interference can be triggered by more than two sources. Transmitters that produce this type of interference are usually close together and at higher power levels.

Figure 1 shows the simplified function of a preselector filter within a receiver. Although the filter is tuned to remove interference, interference can occur in a receiver when there is energy inside the preselector's filter bandwidth. Suitable energy within the preselector bandwidth can impact receiver performance; it does so by blocking the receiver directly from detecting a desired signal, or else through a form of desensitization in which lower-level signals are not detected.

Protocol-based test tools have often been used to identify interference. While they are useful in finding interference, such tools are also limited in providing insight into how a system might be affected by interference and in identifying the types of interference that can cause the most harm to a system. For such purposes, a spectrum analyzer provides a clear view of a given portion of spectrum, thus pinpointing where interference might fall relative to a communications system of interest.

When seeking a spectrum analyzer for finding interference, a key specification to consider is probability of intercept. This simply refers to the minimum duration of an interfering signal and the chance that the analyzer can detect and display it. Swept-tuned spectrum analyzers typically have a low probability of intercept, meaning that the interfering signal must be present for tens of milliseconds. Real-time spectrum analyzers have a high probability of intercept to their maximum span, with the capabilities of detecting signals as brief as microseconds. Such analyzers can identify signals of much shorter duration than a traditional swept-tuned spectrum analyzer.

Spectrum analyzers show captured signals on a logarithmic (rather than linear) scale, with signals and interference displayed in decibels (dB) or decibels relative to 1 mW (dBm) power. The logarithmic scale makes it possible to show a much wider dynamic range on an analyzer's screen than a linear scale.

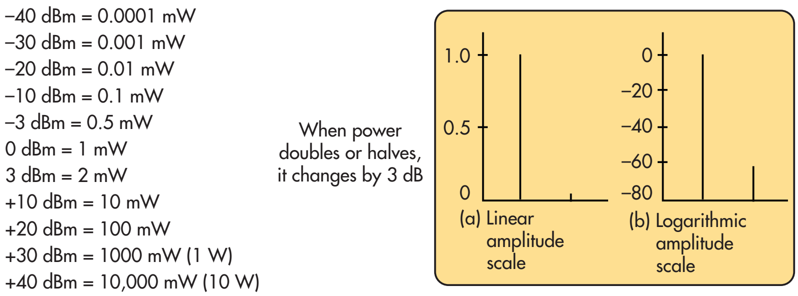
There are a few tricks to relate dBm values to a linear difference *(Fig. 2)*. Because it is logarithmic, every 10-dB change in power is a power of 10 change in wattage. Similarly, a 3-dB change in power represents a doubling (up 3 dB) or halving (down 3 dB) of wattage. Measurement of +30 dBm is the same as measuring 1 W, while measuring +33 dBm is the same as measuring 2 W. This can be significant, since most spectrum analyzers are limited to about +30 dBm input power, and feeding an analyzer excess power can damage the instrument.

For interference applications, a spectrum analyzer's RBW control is very important. A filter helps discriminate between wide- and narrow-bandwidth signals in the same span by changing the RBW value *(Fig. 3)*. If the RBW is set too wide [*Fig. 3 (left)*], smaller signals close to larger signals will be lost. A narrow RBW filter can easily discriminate between two signals that are close together, but it will slow down the spectrum analyzer. This requires a longer measurement duration to ensure signal probability of intercept.

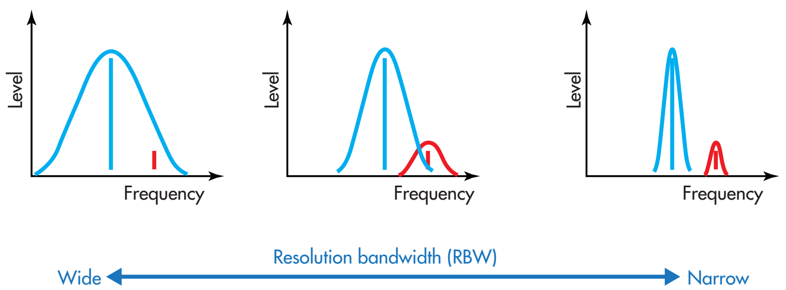
For a comparison, analyzers were used to view activity in the 2.4-GHz Industrial-Scientific-Medical (ISM) band. The left side of *Fig. 4* shows a traditional swept-frequency spectrum-analyzer display. The type of detector, number of traces, RBW setting, and number of trace points all contribute to the speed of the acquisition. The right side of *Fig. 4* shows a real-time spectrum analyzer display of the same spectrum with somewhat more information.

For each pixel on the display, the real-time analyzer keeps track of how often energy is measured at that pixel with a decay function, essentially mimicking old-fashioned phosphorous displays. Real-time spectrum analyzers are available with real-time bandwidths to 165 MHz and real-time transform rates to 390,000 transforms/s. In this view, color shows how often a signal appears, with red indicating the noise floor and blue the Wi-Fi signal.

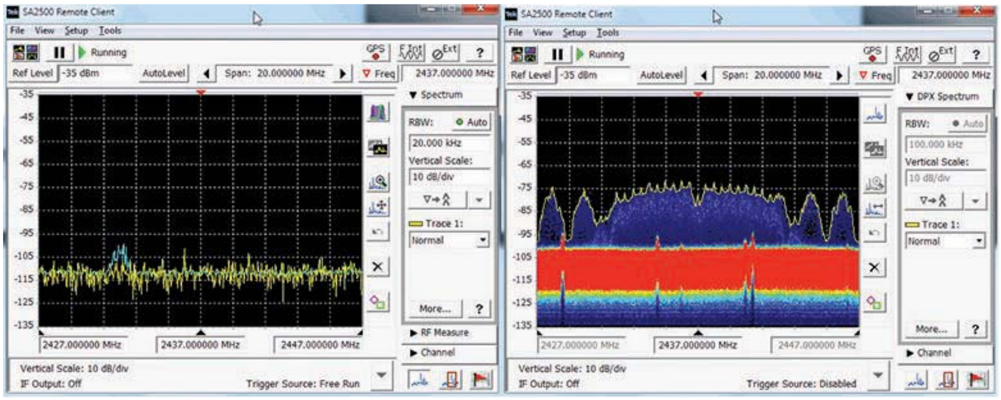
Another powerful tool available with a real-time spectrum analyzer is the spectrogram. It is akin to adding time as a third dimension to a traditional power-versus-frequency plot, providing the spectrum analyzer with a history of previous measurements in the frequency domain. As each spectrum measurement is made, the result is "turned on edge" and added to the bottom of the spectrogram. This pushes the older spectra up the display. Each line of the spectrogram is made in this way.



2. The logarithmic scale provides the ability to look at very fine signals. This means that a very small signal change on a spectrum analyzer display equals a very large change in the linear output of a signal.



3. This shows why RBW setting are important for interference applications. Wide RBW is faster, but may lead to missed signals.



4. A real-time spectrum analyzer display shows much more information than a traditional display.

The horizontal axis is frequency, exactly as in the spectrum display. The power of each signal (represented by vertical height in the spectrum display) is now represented by different colors. The vertical axis is now time, with each line representing the time required for the FFT to be performed. As shown in *Fig. 5*, the spectrogram can record spectrum for long periods of time and the user can then playback any problem periods.

Measuring and locating interference is often a matter of situational awareness. Enough must be known of the surroundings to determine whether an analyzer display is showing a system problem or an interference problem. Gaining an understanding of the frequency band of interest is essential, learning, for example, whether it is licensed or license-free spectrum; what the band plan is for the spectrum; and whether co-channel services are in use. Various channel plans may be based on a class of service, with different power levels for each.

A spectrum display may show much different power levels regarding whether a portion of the spectrum is used for uplink or downlink functions. The class of service also dictates emission bandwidth and modulation type. In addition, certain digitally modulated signals can have much higher crest factors than their analog counterparts.

Spectrum shape is important, too. This is equivalent to occupied bandwidth. Much can be learned about an unknown signal by its spectrum signature. Occupied bandwidth, crest factor, and duration are unique properties that can help identify an unknown signal.

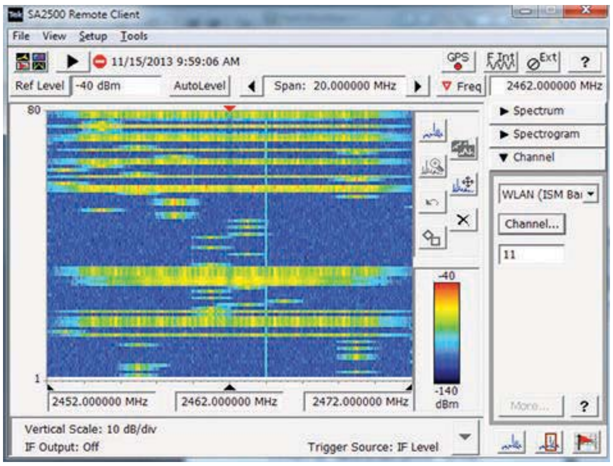
In terms of their effects on signals, environment factors are difficult to classify. Signals can be affected differently. A communications system, for instance, may be surrounded by buildings or in a wooded area. Even more, the impact of a wooded area can change depending on the time of year. Signal and environmental factors must be understood when analyzing potential interference, and maintaining logs of signal activity can help to discover when interference actual occurs.

Locating a signal involves triangulation. The basic principle behind triangulating a signal is straightforward: determine bearings; measure azimuth and signal strength from two different locations; then plot the bearings on a map. In theory, the interference is originating from the location on the map where the two bearings intersect. But in practice, it can be somewhat more complicated to locate the source.

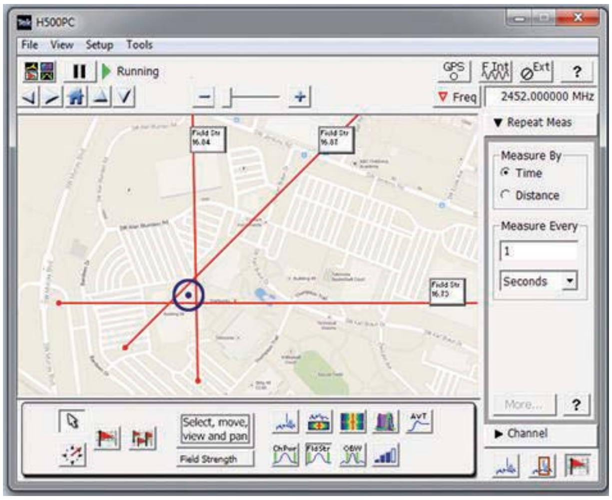
Antennas can cause some of the triangulation complexity. A multiband, directional antenna has different directivity characteristics based on frequency, which can be plotted on a chart. The back of the antenna also has a pattern, resulting in a front-to-back ratio. Such directivity characteristics can impact any attempts to locate a signal source. Understanding an antenna's pattern can ultimately help to achieve optimum results with that antenna.

The radio horizon of a subject receiver can complicate interference investigations. Cities, in particular, can pose difficulties because of their large numbers of reflections. Obtaining as many lines of bearing as possible can minimize the problems, with an increase in the lines of bearing helping to reduce the amount of uncertainty in an interference search.

For any sweep of the horizon, a good practice is to have an external attenuator connected between the antenna and the spectrum analyzer, so that attenuation can quickly and easily be added to the receive signal path. Spectrum analyzers often have more sensitivity than required, and the additional



5. The spectrogram allows you to record spectrum for long periods of time and playback problem periods.



6. Lines of bearing on a map show the target ellipse or area of uncertainty.

attenuation can help minimize the effects of RF clutter as the antenna moves closer to the interference emitter.

Many spectrum analyzers include a mapping function that can help when plotting bearing lines. In the screenshot depicted in *Fig. 6*, the lines of bearing show the location of the target ellipse or area of uncertainty. In this case, the power levels are fairly high, meaning the area of intercept is fairly small. This increases confidence that the target is actually in that area.

Closer to the target, directional antennas are less useful since their directivity is more compromised. In such cases, a monopole or near-field antenna can provide better results. The pattern of the near-field antenna is of interest, since the antenna's null rather than its peak can provide more directivity; it may even provide more directivity than a larger, more directed antenna.

As an example, assume a Wi-Fi network with degraded performance. The following is known about this IEEE 802.11bgn Wi-Fi network. It operates within the license-exempt, 2.4-GHz ISM band. It maintains co-channel operation with other electronic products, including cordless telephones, baby monitors, and Bluetooth devices. Wi-Fi is a time-division-duplex (TDD) network, with transmission and reception both occurring on the same channel. Furthermore, it employs a channel plan with 11 discrete channels (with only three clear channels: 1, 6, and 11).

When interference is suspected as a problem, an SSID scanner may be used to determine if there are co-channel issues, and how many access points are visible from the current operating location. In this case, a protocol scanner identified three access points, with channel 6 showing as the strongest.

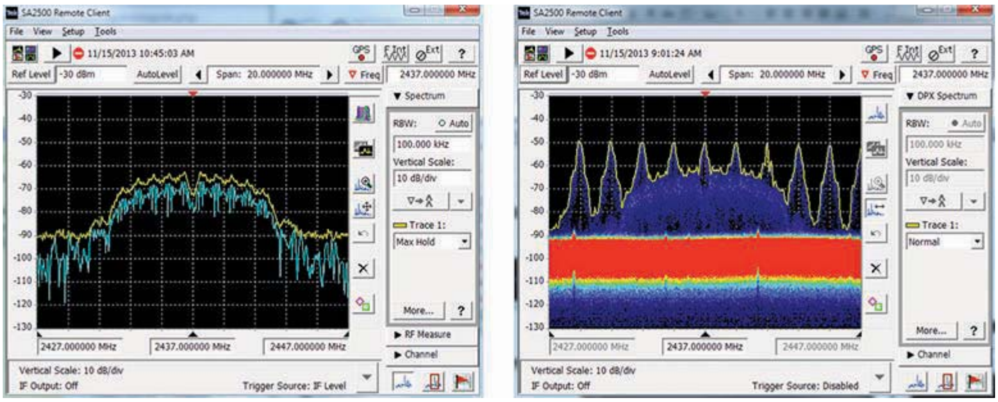
When a traditional spectrum analyzer was used to view channel 6, conditions appeared reasonable, even with the instrument's "max hold" and "averaging" functions turned on and with a triggered acquisition that performs measurements only when a specific signal power level has been reached. A real-time spectrum analyzer view of this same channel 6 reveals more activity, including a number of other carriers over the top of the signal *(Fig. 7)*.

Why did these signals show on the real-time display and not the swept-tuned display? Most likely they are high-speed, frequency-hopped signals that went undetected by the swept-tuned analyzer. Since this is the 2.4-GHz band and Bluetooth is part of this band, these could be Bluetooth signals.

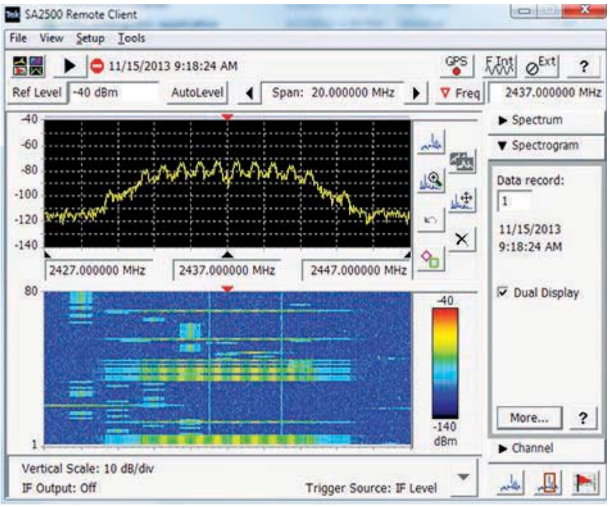
To confirm this, the next step was to turn on a signal classification database. By declaring a region in a signal, a spectrum analyzer can suggest what signal activity might be present. In this case, it indicated that 2.441 GHz is actually a Bluetooth channel—in particular, Bluetooth channel 39. As such, it is highly probable that this is a Bluetooth signal.

A longer-term spectrogram measurement showed a fair amount of Bluetooth activity directly on that "Wi-Fi" channel. Both classes of service are supposed to be friendly when it comes to sharing spectrum; however, *Fig. 8* shows that there is a great deal of Bluetooth activity right on top of this channel. There are two very small spurious signals inside the span which might be invisible in a regular spectrum display, particularly if the "max-hold" function was used.

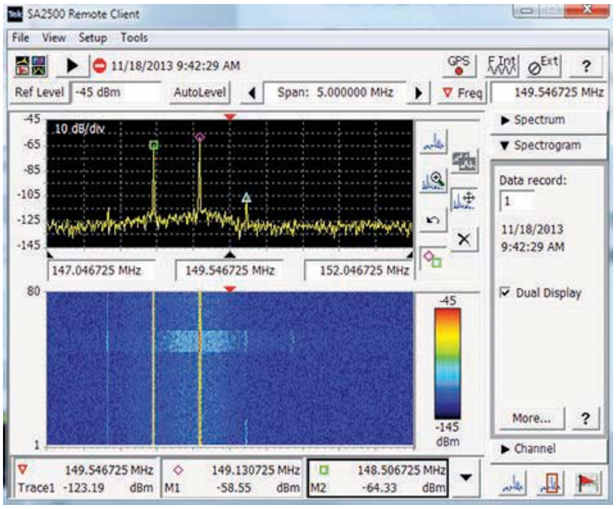
As another example, consider an antenna farm with multiple transmitters facing system degradation of some form. The frequency of the victimized receiver is 149.77 MHz. The VHF land-



7. The real-time display shows a number of fast signals not visible in the traditional spectrum analyzer display.



8. This spectrogram display shows the Bluetooth activity that represents interference for Wi-Fi systems operating in the same portion of spectrum.



9. Using a spectrogram display over time can confirm the presence of intermodulation signal products.

mobile frequency plan has no defined frequency separation for transmit/receive functions, unlike applications at UHF and 800 MHz. Also, depending upon the time of year and location, there could be a great deal of propagation at this frequency.

In general, VHF applications are typically very narrow bandwidth, with occupied channel bandwidths as narrow as 6 kHz. Hence, radio receivers will be very sensitive compared to WiMax, LTE, or Wi-Fi stations.

An initial analysis suggested that the interference consisted of frequency-shift-keying (FSK) signals from the image of the class of service, and it is apparent that two frequency hops are clearly defined. A spectrogram analysis shows a point in time when another signal occurs on top of the initial signal. This additional signal is wider but of shorter duration, possibly resulting from intermodulation.

For intermodulation to occur, two or more sources are required. In this case, two sources are higher in power level but lower in frequency. For analysis, the next step involves examining the intermodulation mix to determine if the signal product would impact the system of interest. By using the spectrogram to study a longer period of time, it is possible to identify an intermodulation product, shown as the center line in the spectrogram display in *Fig. 9*.

The power of frequency number one is changing; it is actually increasing. And when the power increases, the result is an intermodulation product between the two frequencies on top of the assigned frequency.

With so many different electronic devices producing signals, it would be difficult to imagine that interference simply does not exist for a particular band. A real-time spectrum analyzer can help isolate and identify interference, with a much higher probability of intercept than possible with a traditional swept-tuned spectrum analyzer. For analysis, a spectrogram can offer assistance when studying spectrum activity over a time period of interest.

Because of the ever-changing wireless signal environment, as shown by the Wi-Fi example, traditional spectrum analyzers do not provide the capability to reliably detect and identify interference, but real-time spectrum analyzers have proven to be quite useful tools for finding interference. mw

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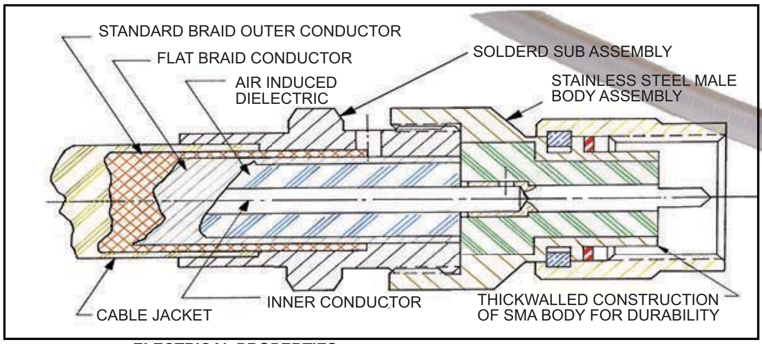

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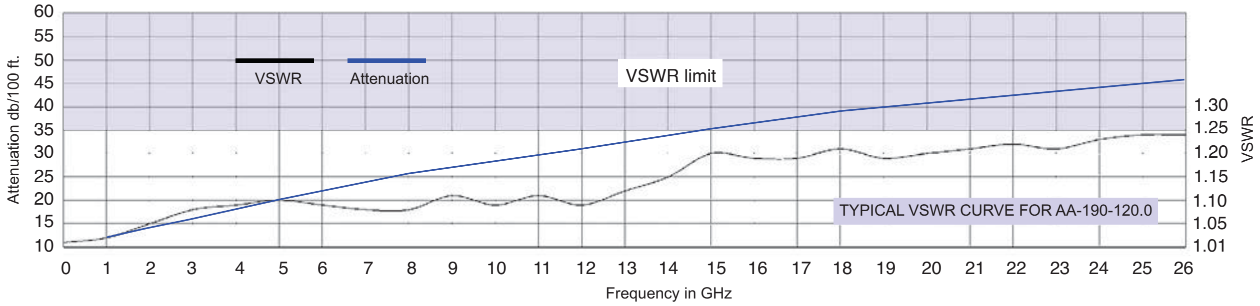

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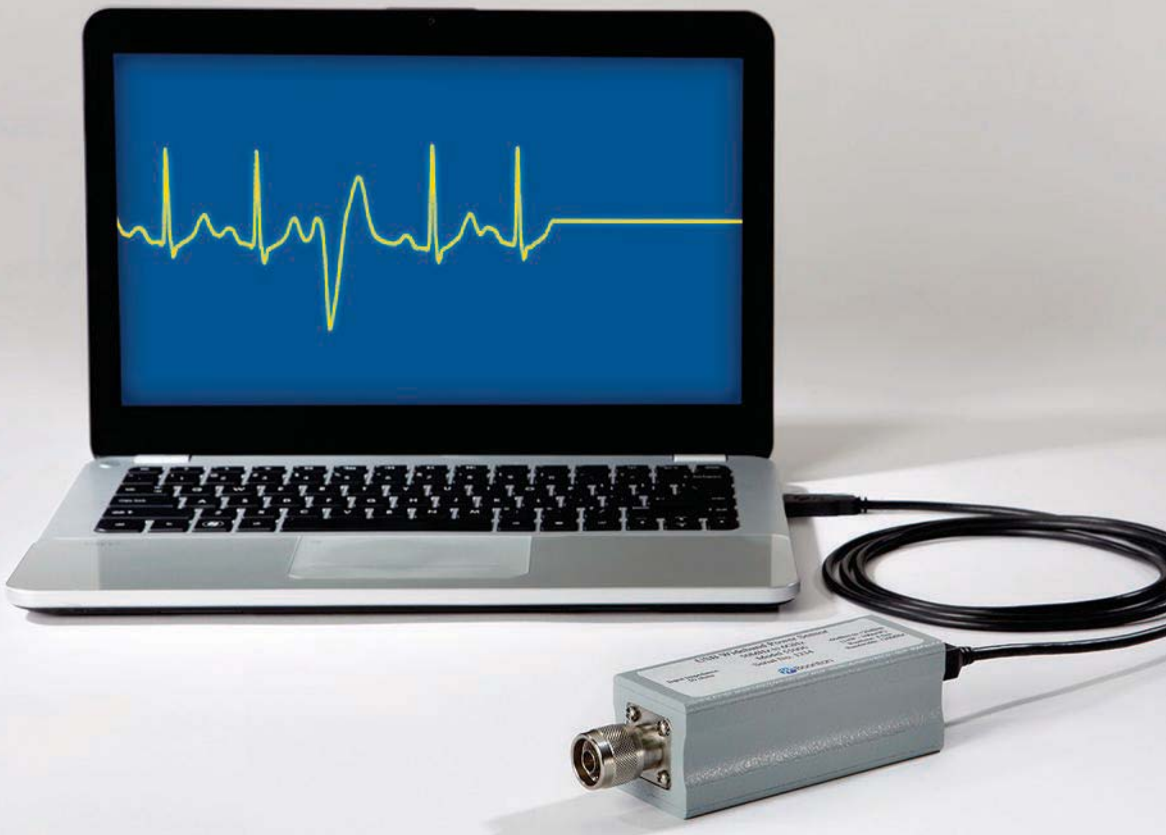

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