

IMPORTANCE OF ANTENNA AND FEEDER SYSTEM TESTING IN WIRELESS NETWORK SITES

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Abstract—This paper describes the important aspects of testing the antenna and feeder system components of a wireless site. In many cases, wireless antennas and a feeder system are shared by multiple technologies to reduce implementation costs. These sharing arrangements give rise to complicated configurations that include various RF components, wherein any single component failure could adversely affect a particular technology or overall site functionality. Two categories of antenna system components—passive and active RF devices—are considered, and performance parameters for each component are presented. Component selection criteria and a testing process are proposed that could identify system problems before large-scale deployment takes place and that could improve overall site reliability.

Key Words—active RF component, antenna system, antenna system testing, component selection, diplexer, duplexer, field testing, IM, intermodulation, passive RF component, performance parameter testing, RF configuration, TMA, UMTS, wireless system testing

INTRODUCTION

The rapid growth of wireless networks, combined with real estate pressures, forces cellular operators to add new technologies to existing cell sites. As a result, state-of-the-art cell sites have evolved over the years with designs involving the elaborate combination of several technologies as well as auxiliary components [1]. These auxiliary components simultaneously transfer various technology signals and add additional flexibility to network operation. Though some of the components are basic and passive (diplexers, duplexers, and filters), engineers should carefully examine the components they plan to use along the cell site radio frequency (RF) paths.

The industry needs to pay special attention to manufacturer and third-party test data, because the failure of a basic component could lead to unnecessary, lengthy, and costly delays in launching a new technology in the network. Such a failure may also degrade the legacy network or a particular service. To avoid these scenarios, wireless carriers should establish pre-deployment processes for testing wireless network antenna and feeder system components. Testing that evaluates wireless network component performance in a controlled laboratory environment is vital to establish

component credibility for mission-critical wireless site deployment. Meanwhile, it must be recognized that the generic application of basic components may not be appropriate for all cell sites in the network or the market. This paper examines a few examples of basic antenna and feeder system component failures in a real network, the aftermath, and how these failures could be prevented through testing.

RIGOROUS TESTING—A BUSINESS NECESSITY FOR WIRELESS NETWORKS

Carriers and service providers deploying wireless networks should demand professional testing to ensure the success of site rollouts and upgrades and to establish their networks' credibility for customers' wireless applications. They are acutely aware of how costly it can be to deploy equipment that might fail in the future. If unstable components are deployed, carriers and service providers bear the cost of customer support and troubleshooting in the field. If the new network does not work reliably, customers will desert the fledgling service.

Optimal network performance and robustness are achieved through thorough and rigorous testing designed to reveal component flaws and

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The performance of basic antenna system components is often overlooked despite the fact that they pass through a complex mix of signals generated by different technologies.

ABBREVIATIONS, ACRONYMS, AND TERMS

BTS	base transceiver station
C/I	carrier-to-interference (ratio)
CDPD	cellular digital packet data
GSM	global system for mobile communication
IM	intermodulation
IM3	third-order IM
IP3	third-order intercept point
LAC	linear amplifier circuit
LNA	low noise amplifier
PIM	passive IM
RCM	radio configuration manager
RF	radio frequency
Rx	receive
TDMA	time division multiple access
TMA	tower-mounted amplifier
Tx	transmit
UMTS	universal mobile telecommunications system

weaknesses before products are shipped to the field, where finding and fixing problems can be logistically challenging and costly. New and complicated site configurations are introduced most cost effectively through step-by-step testing in a controlled laboratory environment before deployment. The equipment should be tested in all possible load, motion, environment, power, background interference, technology mix, and device configuration scenarios. The testing process should not leave any possible configuration or network vulnerability unchecked.

Testing passive and active antenna system components presents unique challenges, given the potentially high number of test parameters. Therefore, it is very important to identify the critical parameters and focus on their testing specifications. This paper outlines the testing requirements and ways to address them.

SITE COMPONENTS AND TESTING ENVIRONMENT

This section first presents antenna plumbing diagrams showing two or three technologies and reviews the components depicted in the diagrams. The section then continues with a discussion of the testing environment needed to measure component performance factors that are predictors of field behavior.

Complex Feeder Configurations

While the diagram shown in **Figure 1** may appear simple, the combined signal at the output is complex. Included in this signal are both a narrowband global system for mobile communication (GSM) signal and a wideband universal mobile telecommunications system (UMTS) signal, along with signal interaction products created by nonlinear effects and the mechanical impurities of passive and active components. A failure in a diplexer shown in **Figure 1** would result in service loss of one or both technologies and could even harm the base stations. Increased connection or component insertion loss can also impair service coverage and quality.

Since most components carry signals on multiple frequencies, intermodulation (IM) products in the RF components are a very important factor [2]. As described below, IM products, which can create excessive interference and impair service quality, can result from any factor that changes a component's mechanical or RF characteristics, such as excessive temperature, humidity, impurity, rusting, or improper connections.

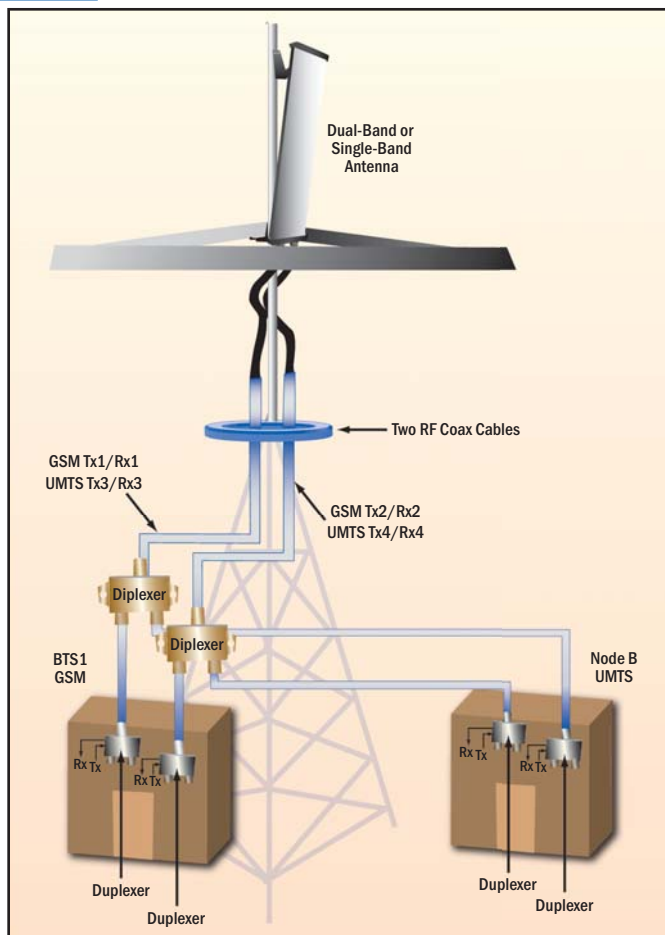


Figure 1. Example Feeder Configuration for UMTS and GSM Antenna Sharing

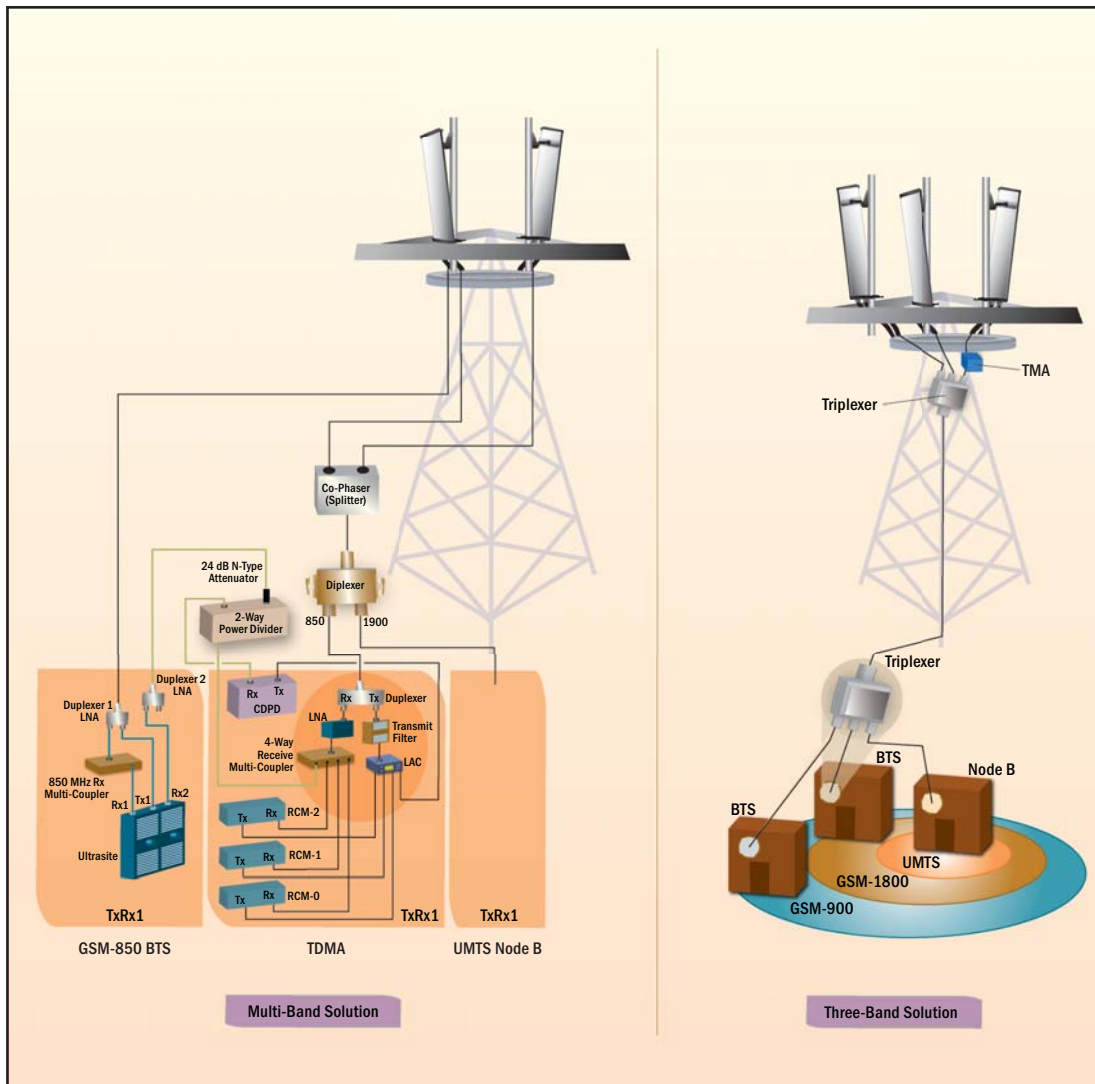


Figure 2. Two Examples of Feeder Configurations for UMTS, GSM, and TDMA Antenna Sharing

A low IM product results in better RF performance and is a parameter that shows the physical condition of all connections and the path the signal traverses.

IM occurs when a device exhibits nonlinear behavior for any reason. Nonlinearity can be caused by device corrosion over time, bad connectors, and various natural phenomena. If a tone signal with a frequency of f_1 is input to a nonlinear device, harmonics of f_1 are generated (i.e., $2f_1$, $3f_1$, $4f_1$, $5f_1$, etc.). Almost all devices show some nonlinear behavior. If two tone signals are fed together to a nonlinear device, both simple and combination harmonics are generated as a result of a multiplication process between the input frequencies. If the two original frequencies are f_1 and f_2 and the lower frequency is f_1 , frequencies $(f_1 + f_2)$ and $(f_2 - f_1)$ can be expected in the output. Further combinations including harmonics of f_1 and f_2 are generated as well. If the input signal includes more frequencies, the IM products are even more complicated.

IM testing is usually performed for all RF components to measure their linearity. A low IM

product results in better RF performance and is a parameter that shows the physical condition of all connections and the path the signal traverses.

Figure 2 presents a more complex, but also more realistic, situation representative of thousands of cell sites across numerous wireless networks. For example, a failure in the tower-mounted amplifier (TMA) results in UMTS system failure, but a failure in the triplexer affects all three technologies—UMTS, GSM, and time division multiple access (TDMA).

Although common in the field, such complexity is not necessarily easy to replicate in the laboratory environment, especially the many combinations of environmental, electrical, and RF factors. The extent of the issue becomes apparent if one replaces the technology mix illustrated here with the numerous combinations of technologies and components existing on any particular wireless network.

The maximum tolerable PIM performance for an RF device depends on the signals that traverse the device, the device's location in the RF system, and the signal power transmitted.

Testing Environment

The RF frequency bands from 30 MHz to 6 GHz and higher are overpopulated by signals and interferences generated by consumer and commercial wireless devices. The proliferation of such signals has made it practically impossible to test, verify, or tune RF devices without shielding them from the outside world. In some scenarios, a well-shielded and grounded test setup may be sufficient. However, providing an RF-isolated testing environment is critical in test scenarios where signal powers are very low, such as when measuring IM products. The basic requirements for an RF-isolated test area, or so-called RF chamber, are simple: all devices must be in an isolated environment that prevents all types of radiation from entering the system. This enables testing of the components under various RF conditions and measurement of the interference, linearity, and IM products.

Environmental chambers can create various humidity, thermal shock, and vibration scenarios and are very important in testing wireless feeder components as well as outdoor units. RF components are designed to operate in severe climate conditions for long periods of time. Therefore, environmental stress tests should be carried out where RF system performance is tested under a variety of conditions.

Electrical and radio power testing is also critical for most RF components. Power surges can occur for various reasons and can have a detrimental effect on RF component performance immediately or over time. Improper installation can also cause insertion loss and IM products. The proper performance of passive components depends greatly on their physical shape and dimensions. Therefore, any physical pressure or improper installation that affects the shape of a passive component will negatively affect its performance.

Combination testing is important. Experience shows that some problems develop in response to a combination of the elements and high power. For example, certain designs are prone to developing nonlinear effects [2] as a result of inevitable in-the-field corrosion and the expansion of passive elements induced by RF power and ambient heat. Combination testing can help identify these problems so that they can be addressed at the design stage before massive deployment of the component takes place.

Depending on the size of the RF chamber, assembled parts of the system can be tested in a controlled laboratory environment under various

conditions. Important performance parameters, including amplifier characteristics, insertion loss, performance, and IM products, can be measured to predict system behavior in a field environment.

PERFORMANCE REQUIREMENTS IN PASSIVE RF COMPONENTS

Key performance requirements for passive RF components such as diplexers, duplexers, cables, couplers, jumpers, connectors, and antennas are frequency response, RF loss, and linearity under various conditions. These parameters are highly dependent on the physical shapes and dimensions of the devices—characteristics that may degrade under certain circumstances and over time. Therefore, the metrics should be tested under vigorous conditions before deployment.

Passive components usually experience passive IM (PIM) [3]. When the input signal to a passive device includes more than one frequency, various products of the input harmonics are generated. If a product signal falls within the transmit (Tx) or receive (Rx) signal band, it passes through the transceiver filter and can easily desensitize the receiver. When the PIM power is comparable to thermal noise or other interferences, it can deteriorate receiver performance. PIM interference is generated in the signal path mainly because of poor connections between RF components. In some scenarios, if the physical shape of the passive component is altered during installation, the device may produce PIM. When poor quality materials with some level of magnetic hysteresis are used in the manufacturing process, PIM can also be generated. Rusted and contaminated surfaces also usually contribute to the nonlinearity of the device.

The aforementioned effects produce insertion loss in the device that weakens the desired signal and generates excess heat. Excess heat by itself can have damaging effects on passive component performance and durability. Laboratory tests show that PIM increases in a passive device as its temperature rises. PIM can also be generated in the tower, and especially in outdoor device connectors, by a phenomenon called “rusty bolt noise,” which is caused by erosion of the device in harsh environments.

The maximum tolerable PIM performance for an RF device depends on the signals that traverse the device, the device's location in the RF system, and the signal power transmitted. Antennas usually have very stringent PIM requirements because

they carry the full power of the base station as well as signals with various frequencies. On the other hand, the PIM requirements of the receiver filter located on the other side of the diplexer are not as stringent, because the receiver filter receives only very low signal power in a single frequency band. RF engineers should provide the maximum acceptable PIM levels for each component in the RF path based on a complete analysis of the feeder system. Example specifications for antennas are -100 to -110 dBm third-order IM (IM3) product power, measured with two 43 dBm carrier tone inputs. The common acceptable insertion and connection losses in passive components are between 0.1 and 0.3 dB. The following discussion examines the most common passive components.

Duplexers

Duplexers are used to simultaneously transmit and receive from a single antenna (see Figure 1). They are three-port devices comprising a combination of transmit and receive filters with a common antenna port. Duplexers are designed for various applications based on operational frequency and utility. Base station duplexers are designed to handle limited radio power and to be mountable in standard equipment racks. Duplexers must provide high isolation between the transmit and receive ports. The primary duplexer performance parameters are Rx frequency, Tx frequency, Rx insertion loss, Tx insertion loss, Tx/Rx isolation, average power, and IM.

It is important that duplexers provide low insertion loss to ensure that transmitter power is not reduced for transmission. They should also

provide high isolation to avoid receiver desensitization. High quality in duplexer manufacture ensures a low IM product.

Many site configurations require duplexers to be installed outdoors, thus creating the need for a wider operating temperature range in these components. Tight weatherproofing of duplexers is also necessary, because water condensation on internal surfaces degrades the frequency response and accelerates corrosion, which in turn creates nonlinear effects for the signal.

Diplexers/Triplexers

Diplexers and triplexers are designed to enable several systems on the same site to share feeders. Figures 1 and 2 show typical configurations for dual-band duplexers and for triplexers. Sites with dual-polarized antennas require double duplexers. Variants are also available, including a design providing a direct-current pass for a TMA. Main diplexer/triplexer performance parameters are port frequency, insertion loss, isolation loss, peak power, and IM.

A diplexer/triplexer with a low level of insertion loss, high isolation between bands, and low IM products has virtually no effect on the uplink and downlink signals and reduces infrastructure costs.

Figure 3 shows an example of a test setup in which duplexer and diplexer performance parameters can be measured under various field conditions. With the advent of multiport/multifunction test devices, the amount of equipment in the setup can be reduced.

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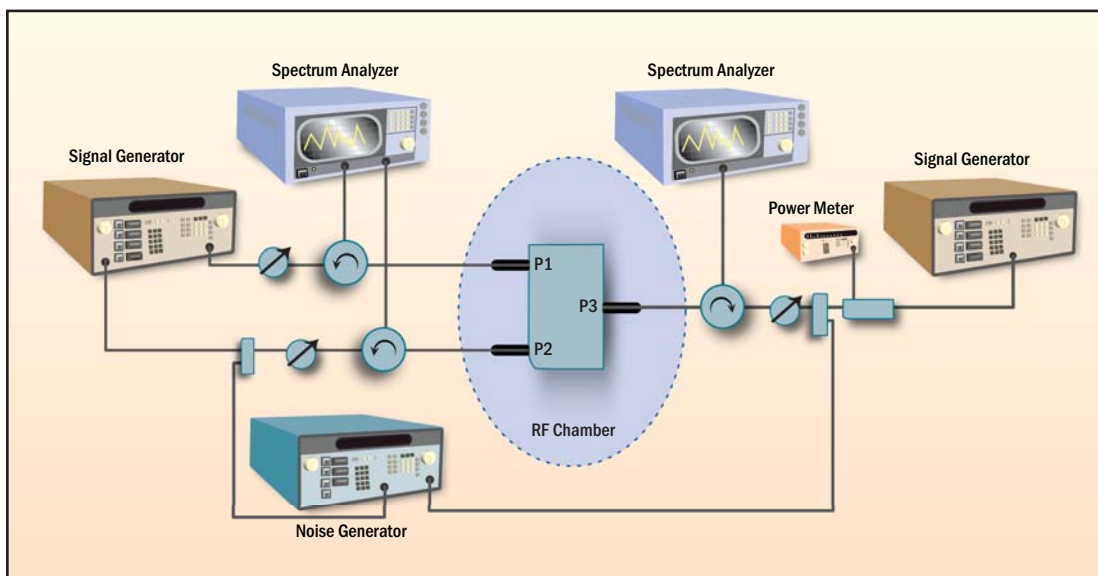


Figure 3. Test Setup to Characterize Diplexer/Diplexer Performance Parameters

PERFORMANCE REQUIREMENTS IN ACTIVE RF COMPONENTS

Active RF components, such as TMAs and active filters, require power (usually provided via the main coaxial cable). This section examines the performance of these active components. The most common parameters are sensitivity, output power, output harmonics, transient time, noise figure, gain, in-band frequency response, out-of-band rejection, insertion loss, power consumption, and operating frequency range. Laboratory test plans can be developed to test each of these active RF component performance parameters.

Amplifier and filter linearity is one of the most important performance parameters and the focus of this discussion. Nonlinearity can produce IM products and high frequency interference, which deteriorate system performance. On top of the nonlinearities and IM products created by mechanical impurities and corrosion, active components add their own interference due to inherent amplifier nonlinearity. Active IM differs from PIM, since amplifier gain varies with signal frequency.

Figure 4 shows the main input signals (f_1 and f_2) and IM products. A close examination of the frequency pattern shows that the IM3 products ($2f_1 - f_2$) and ($2f_2 - f_1$) are the most harmful to the main signal because they are very close to the signal tones. Figure 4 also depicts a relatively widely accepted laboratory method of testing amplifier linearity [4],[5]. In this so-called two-tone method, two input tone signals— f_1 and f_2 —having closely spaced frequencies are input to the amplifier under test. The IM3

distortion is, by definition, an outcome of the power of the two “close-in” IM3 signals relative to the power of the two input tones.

A more straightforward method of determining amplifier nonlinearity is to use the so-called third-order intercept point (IP3), as shown in Figure 4, which employs graphical extrapolation to calculate a figure of merit for IP3. The amplifier performance data is taken well below saturation level. The graph shows that the main signal outputs (f_1 and f_2) increase linearly as the input signals are increased. The amplifier gain is normalized to 1; hence, the slope of the curve (m) is equal to 1. The output signal power continues to increase until amplifier saturation level is reached, then the output follows a gradual roll-off.

The IM3 products are also plotted in Figure 4. Their power level is initially much lower but increases with a slope of 3 ($m = 3$). The IP3 is calculated theoretically by extending the two lines until they intersect. At the intersection point, the spurious IM3 signal has reached the level of the input tones, making the intersection point by definition the IP3. Data sheets generally provide IP3 values for linear amplifiers. Given an IP3, test operators can predict the IM3 products for a given output power; conversely, for a required output power and allowable IM3, they can specify a required IP3.

Active components are often combined with passive components. For example, a TMA often comes with a diplexer. In this case the same problems may develop, and the same RF chamber testing with an appropriate power and frequency mix is required to forestall future failures.

On top of the nonlinearities and IM products created by mechanical impurities and corrosion, active components add their own interference due to inherent amplifier nonlinearity.

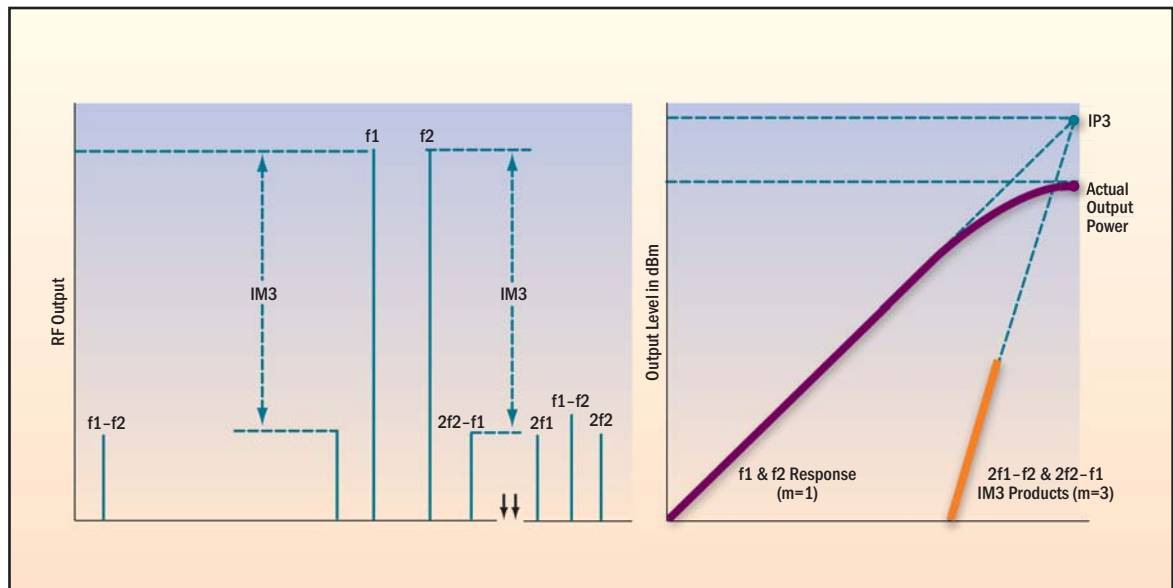


Figure 4. Tones, IM Products, and IP3 Calculation

IMPROVED ANTENNA SYSTEM INSTALLATION AND TESTING SOLUTIONS

The following three steps are proposed as a means of improving the site performance of antenna systems and reducing the probability of failure:

1. Order ample component testing and review all performance data and test results.
2. Prefabricate the antenna system at an onsite facility.
3. Conduct thorough system testing at the site, including complete component verification and sweep testing as well as pre- and post-construction drive testing.

Each of these steps individually may not be the ultimate solution to averting a problem; however, in combination they provide better protection against individual failure or unsuccessful integration of components in operation.

Component Testing

Ample component testing should be ordered from vendor, internal, and/or independent laboratories, with the antenna configuration specified precisely and with a frequency and technology mix requested that is specific to the network. In view of possible component failure at thousands of sites and potentially millions of dollars lost in replacement programs, even a five-figure sum spent on extra testing can be a very good investment.

System Prefabrication

Organizing an onsite prefabrication facility for the antenna system, such as shown in **Figure 5**, helps maintain a consistent level of quality in installation and workmanship. Taking this step usually eliminates issues arising from over-tightened connectors, shifted central conductors, and inconsistent weatherproofing of connectors—which, in turn, eliminates guesswork and aids in troubleshooting the components should in-service problems arise. Otherwise, time must be spent in the field eliminating poor installation and workmanship as reasons for poor performance before efforts are made to isolate the problem inside a component. In addition, prefabrication not only improves installation accuracy, but may also reduce overall implementation cost.

Site Testing

As a last-stage test to avert possible component failure, sweep testing of the installed and

existing antenna systems should be performed. Although this type of testing does not reproduce the potential problem, it does help in troubleshooting.

Pre- and post-construction drive testing is the ultimate form of testing in that it simulates user experience with the newly installed system. It is also the most expensive form of testing. However, it enables wireless operators to visualize to a great extent how component failure affects a network at the cluster level rather than at the individual site level.

CONCLUSIONS

Wireless operators use complicated multitechnology site configurations in an effort to reduce onsite implementation costs and realize schedule savings. Within these configurations, however, the failure of any single component can adversely affect a particular technology or the overall site functionality. This paper has presented important performance parameters for various RF components that should be verified by RF engineers in a controlled laboratory environment before a site configuration is approved. Antenna system installation and testing processes have also been suggested that can improve site implementation quality and reliability.

Pre-deployment component and system testing can play a significant role in establishing site configuration credibility under rigorous conditions and in reducing site failures. Thorough laboratory testing, prefabrication, and post-installation testing enable problems to be

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(Photo by Max Bondarchuk, BCI)

Figure 5. Pre-Installation and Testing Facility in a Bechtel Deployment Office

identified and corrected before components are introduced on a large scale. Taking these steps precludes the logistically challenging and costly prospect of finding and remedying problems in the field. ■

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BIOGRAPHIES



Aleksey Kurochkin, market manager for Bechtel Communications, is responsible for the entire site design and implementation cycle of UMTS technology in one of the most important regions for the largest US cellular operator. He is also a member of Bechtel's Global Technology Team and

BCTJ Editorial Council.

Formerly, as executive director of Site Development and Engineering for Bechtel Telecommunications, Aleksey managed the Site Acquisition and Network Planning departments and oversaw the functional operations of more than 300 telecommunications engineers, specialists, and managers. In addition, he originated the Network Planning department in Bechtel's Telecommunications Technology group. As a member of Bechtel's Chief Engineering Committee, Aleksey introduced the Six Sigma continuous improvement program to this group. He is experienced in international telecommunications business management and network implementation, and his engineering and marketing background gives him both theoretical and hands-on knowledge of most wireless technologies.

Before joining Bechtel, Aleksey established an efficient multiproduct team at Hughes Network Systems, focused on RF planning and system engineering. In addition to his North American experience, he has worked in Russia and the CIS.

Aleksey has an MSEE/CS degree in Automatic Telecommunications from Moscow Technical University of Communications and Informatics, Russia.



Esmael Dinan recently joined Sprint Nextel as a principal 4G capacity engineer responsible for providing capacity solutions for planning a nationwide mobile WiMAX network. Previously a key specialist on Bechtel's Global Technology Team, Dr. Dinan led the effort to support customers with plans for WiMAX equipment interoperability and conformance testing. He performed numerous key wireless technology assignments and played a key role in many aspects of the business unit's research activities, as well as on the Cingular RF engineering project. Dr. Dinan designed and engineered an RF engineering data management system, developed Cingular project RF engineering processes and procedures, designed and optimized UMTS networks, and verified and tested Dupont cryogenic TMA performance.

Before joining Bechtel in 2002, Dr. Dinan was product manager for the GMPLS control plane of the RAYStar DWDM optical switch at Movaz Networks, and lead network architect at Worldcom. He conducted research and development on access methods and performance modeling of 3G wireless communications and high-speed optical networks.

Dr. Dinan received his PhD in Electrical Engineering from George Mason University, Fairfax, Virginia, and is a registered Professional Engineer in Maryland. He has authored more than 25 conference papers and journal articles and has two patents on novel signaling mechanisms developed for 3G cellular networks. He is a member of the Institute of Electrical and Electronics Engineers.