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Design Issues in Extreme EMC Environments

by Scott Behan, CAP Wireless, Inc.

Few environments present electromagnetic compatibility (EMC) situations as extreme as those faced by designers and manufacturers of radio-frequency (RF)/microwave amplifiers. Substantial efforts must be made to ensure that the signals observed are amplified or generated by the equipment being designed and manufactured, rather than radiated by unknown equipment and amplified by the equipment under test.

In some cases, it may also be necessary or desirable to minimize the interference imposed by some of the products under test upon common wireless devices in the vicinity. For example, it is possible for a mobile phone power amplifier (PA) manufacturer who tests devices using actual or simulated mobile signals to interfere with real mobile phone signals in the proximity of the test area, which is not only inconvenient but possibly illegal.

This article examines some of the effects of electromagnetic interference (EMI) in extreme environments, and discusses some methods that can be used to mitigate the occurrences, as well as some issues that must be avoided.

RF, RF Everywhere

If humans were able to detect RF and microwave radiation as visible light, it would appear that the entire world is illuminated, virtually everywhere, all the time. The explosive growth of the wireless revolution has resulted in an almost incalculable amount of wired and wireless devices that radiate intentionally and often unintentionally in the RF and microwave spectrum, at frequencies ranging from a few tens of kHz to almost 100 GHz.

This proliferation of wired and wireless devices is most dense in populated urban environments, but is substantial as well in rural and even remote locations. The

presence of even one human almost guarantees some kind of RF signature. This level of RF intensity includes spectral output from intentional radiators, like cell phones and computers with WiFi, as well as unintentional radiators, like electric motors, fluorescent lamps, and digital devices. Add to this the number of devices that are only intended to receive (at this point in time) signals from remote transmitters (radios, televisions, global positioning system (GPS) receivers), and it becomes evident just how pervasive the RF presence is.

As an example, Table 1 lists the electronic devices within the author's office (five feet), surrounding company office space (5-50 feet), and adjacent lab (50-500 feet). Power amplifier product development and testing are done in the lab; until one sits down and takes stock of the surrounding environment, it is easy to overlook the fact that over one hundred possible sources of interference exist in the form of everyday electronic tools.

In the presence of so much intentional and unintentional electromagnetic radiation, how do electronic product designers and/or manufacturers ensure freedom from interference, proper operation, prevention of damage, minimization of data loss, and so on? Add to these issues the myriad of modulation techniques, from orthogonal frequency-division multiplexing (OFDM) and code division multiple access (CDMA), to Gaussian minimum shift keying (GMSK) and quadrature phase-shift keying (QPSK) or other quadrature amplitude modulation formats, and the possibilities for unanticipated, untested interference are, literally, endless. Various power levels, frequencies, code formats, and burst rates from devices that are unable to communicate and coordinate with one another create unlimited opportunities for interference.

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Effects of EM Proliferation on the Environment

The ubiquitous presence of RF and microwave signals manifests itself in multiple ways upon the environment. Perhaps the most noticeable and prevalent of these is the increase in ambient noise levels (for a detailed discussion of noise, see the Burr-Brown Design Seminar on Noise and Interference¹).

Noise is present in all environments, with the power predictable by the formula kTB , (Boltzman’s constant multiplied by the temperature multiplied by the bandwidth over which the noise power is measured². This thermally-generated noise is a natural physical occurrence, which limits the lower power level with signals that can be discerned. With the proliferation of electronic devices, the local noise floor may be much higher than the thermal noise floor, effectively “jamming” some types of communication. While regulatory agencies do their best to define and regulate the amount and frequency of electronic emissions through frequency licensing and equipment performance limitations, these regulations

unfortunately must acknowledge the limitations of practical electronic equipment.

While limits are placed upon the amount of power that may be radiated to accommodate practical circuitry, the power, even though low, still propagates. This “artificial” noise floor manifests itself in different ways. Within desired operational bands, the additive radiated noise of a particular product appears with similar characteristics of the natural noise floor, just at a higher level. Any amplification will magnify the natural thermal noise signature and contribute an additive amount of noise related to the characteristics of the device. These amplified, radiated noise levels are usually extremely low in practice, so it often is not obvious that they affect other equipment.

As shown in Figure 1, communications signal modulation can appear as noise to other equipment that is not specifically configured to receive or accept that modulation. CDMA mobile telephony is a good example. The multiple overlapping

Within 5 feet	5 - 50 feet	50-500 feet
Laptop computer w/WiFi	Several PCs w/monitors, mice, keyboard (some wireless)	900 MHz 30 watt amplifiers
Dual band mobile phone	Wireless network router	900 MHz GSM LNAs
Bluetooth wireless mouse	Network server	XC band TVRO block down converter
Bluetooth wireless keyboard	Wireless and wired thermostats	2-20 GHz 20 watt Spatium power amplifier
Numerous USB flash drives	Coffee maker	Two network analyzers
USB camera	Refrigerator	Power meter
Land-line digital phone	Water heater/chiller	Two spectrum analyzers
Personal digital assistant (PDA)	Document shredder	Soldering irons
Fan	Hearing aids	More fluorescent lights
Fluorescent lamp	Wireless headphones	Chest freezer
Wireless key fob	Six automobiles	Numerous automobiles
AC power supply for laptop	Alarm system	Exterior lighting
	Printers	Cell phone reseller
	Fax machine	Six high temperature environmental ovens
	Scanner	LPK prototype board builder
	Numerous mobile phones	Refrigerator
	Two additional PDAs	Water cooler
	Numerous fluorescent lights	Printer
	Two microwave signal sources	Numerous computers w/monitors and keyboards
	Two 500 watt 170 MHz power amplifiers	
	Wirebonder	
	HVAC unit	
	Soldering irons	
	Network analyzer	
	Two power supplies	
	Telephone PBX system	

Table 1: Electronic devices in close proximity to the author’s desk generating RF signals that are potential sources of interference.

orthogonal codes of the CDMA transmission appear as thermal noise to equipment not configured to receive that modulation. In most cases, the presence of the effectively higher noise floor presented by a CDMA system is not apparent to a user of other equipment. Alternate equipment affected by a high signal level environment either has adequate signal-to-noise level to function, or it does not. The user's experience is either that his communication device works, or it doesn't. Just because it can't be detected doesn't mean it doesn't happen.

A common example of annoying contributed noise is when a ringing global system for mobile communications/enhanced data GSM environment (GSM/EDGE) mobile phone is close to a digital land line phone that is in use. The return RF signal sent out by the mobile phone is of sufficient power and appropriate modulation that it interferes with the audio modulation of the land line. A similar example is audio noise induced in an AM radio by the close proximity of power transmission lines.

Spurious signals are a common interference source, potentially resulting in loss of data or communications. Technically, noise power is a spurious signal, but spurious signals are generally considered to be undesired harmonically- or intermodulation-related frequencies that generate repeatable, measurable power above thermal noise. Every device with a signal source (oscillator) will also produce harmonics. Usually the harmonic levels are sufficiently filtered so that the power is not a concern, but occasionally equipment conflicts will arise where one device has sensitivity to a second or third harmonic of another item.

Rogue equipment, or equipment that is operating improperly with respect to its power or frequency output, is also a

contributor to environmental interference. This source of interference is less likely to occur than either the increased noise floor or the spurious signals, but can still be a potential source of EM pollution. The author's personal experience is with an old remote control for security gate access. A mechanical ferrite core became loose after many years, and shifted internally, changing the transmit frequency, which rendered the unit ineffective. The unit transmitted 50 MHz low until the discrepancy was resolved. While this situation likely did not cause any ill effects to the surrounding environment, it illustrates the potential for rogue devices to generate interference.

The Effects of Interference in an RF Amplifier Manufacturing Environment

Effects of Ambient on Equipment in Design and Test

RF and microwave amplifier manufacturers are adversely affected not only by intended radiating devices operating correctly, but also by any and all devices generating power levels anywhere within the operational bandwidth of the amplifier. Also, due simply to the nature of the product, amplifiers tend to amplify both desired and interfering signals alike, if they are within the operational bandwidth capability of the device.

Several key amplifier measurements can be easily affected by RF interference, including noise figure and noise power, intermodulation and harmonic performance, spurious level measurement, and amplifier stability verification.

Noise Figure

Noise figure is a figure of merit used to describe the amount of degradation to the signal-to-noise ratio induced by a component. Noise figure is often measured using a noise figure meter and noise source³. Since this measurement reflects the excess noise created by a system, keeping external, additional excess noise out of the measurement system is imperative in order to generate an accurate measurement. During the author's career, he has observed several instances of increased noise figure measurements occurring between the hours of approximately 8:00 a.m. and 5:00 p.m. The noise figures of the same device, when measured outside of that time slot, in the same configuration, without change, are reduced by two or three tenths of a dB, a substantial amount for low noise amplifiers.

Intermodulation/Harmonics

Intermodulation and harmonic content are additional measurements where electromagnetic interference can introduce measurement errors. Errors can be introduced in at least two ways:

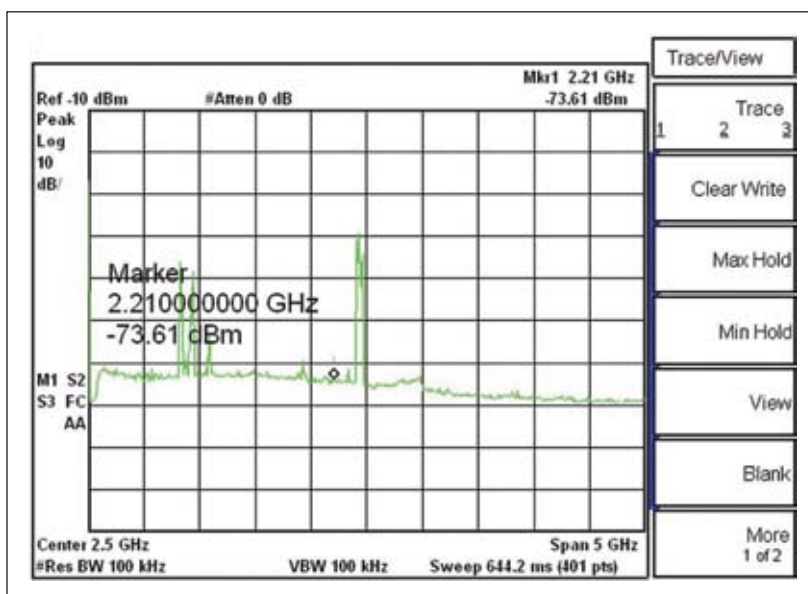


Figure 1: Sample of the detected spurious RF picked up by an 1800 MHz low noise amplifier during tuning using a maximum hold to capture even fleeting signals. The signal just below the center of the band is WiFi from an adjacent computer.

1. Stray signals can enter an amplifier measurement setup, be amplified, and generate harmonic and intermodulation products;
2. Stray signals can enter an amplifier measurement set up and, if at the appropriate frequency, be mistakenly identified as intermodulation or harmonic products.

Care must be taken to specifically identify fundamental test frequencies and to calculate and verify the frequencies of intermodulation and harmonic content, or to avoid the presence and introduction of potentially interfering signals into the test environment.

Spurious and Oscillation Measurement

Spurious signal measurements are probably among the most difficult to ensure that the measurements are truly from the device under test and not from amplified interference. Any suspected out-of-specification spurious signal present at the amplifier output must be identified and evaluated as a truly spurious signal. This task can be arduous due to the often specious nature of both internally-generated spurious and externally-applied interference. Additionally, since spurious signals can be present or generated both within and outside the operating bandwidth, the spectrum of research may extend well beyond either end of the desired bandwidth, resulting in even greater search and evaluation time.

In addition to being affected by EMI, each of these measurements is also affected by the time, frequency, and modulation nature of the interfering signal. External signals can be steady state (or nearly so), such as a commercial radio or television transmitters; bursty, such as legacy push-to-talk communications used in aircraft VHF systems; variable power, such as CDMA or other mobile telephony; cyclical, such as an airport radar sweep rotation; or, perhaps worst of all, drive-by one-shot, such as a mobile phone user driving through the neighborhood.

Effects of Equipment in Design and Test on Ambient

The effects of ambient electronic interference on the test and measurement process are not the only concern for designers and manufacturers. The potential issues created by the testing of amplifiers, particularly high-power amplifiers, upon the local RF environment must also be considered. RF amplifiers, especially during the development phase, are often tested without lids or shielding to facilitate the development and alignment process. While the alignment is proceeding, the amplifiers can and do radiate some level of RF power. (This can also be an issue for personnel safety, but that is another topic.) If the amplifier creates spurious signals, oscillates, or has high intermodulation or harmonic power levels, these signals, in addition to any fundamental signals, will invade the local RF environment, causing disruptions.

When testing high power amplifiers, one should be aware of the frequencies being tested, and limit testing to the lowest extent possible, as well as implement other mitigation

techniques if there is a likelihood of generating interfering signals.

Effects of Equipment in Design and Test on Electronics

In the amplifier test environment, it is also necessary to be concerned with the other types of products and frequencies that are being developed, produced, and tested. Most amplifier manufacturers develop and produce devices that operate for different applications at different frequencies and power levels. Also, it is not uncommon for some testing to involve high power amplifiers at one test station, and low noise testing of another product at another station. There may be, but most likely is not, coordination between testing activities to minimize the possibility of co-test interference generation.

All of the aforementioned effects of the ambient environment interfering with the test environment can be applied to the co-test situation. Due to the proximity of the devices in test, the interfering power levels can be considerably higher than those from the ambient environment. Also, the frequencies involved may not be standard frequencies expected for particular device operation.

As an example, the author's company builds a broadband 2-20 GHz, 20 watt nominal solid state power amplifier that is used for numerous applications. During testing, this amplifier is routinely tested for gain using a network analyzer, which results in a swept high-power signal being generated from 2-20 GHz. Additionally, the unit is tested for saturated and one dB gain compression powers at multiple frequencies, and harmonic performance and intermodulation levels are characterized. Even with careful test configuration, some amount of signal leakage occurs. The leakage is almost always detectable at other test stations, and must be considered during the evaluation of other products.

Mitigation

Most, if not all, of the potential issues created by interference in a microwave amplifier facility can be constrained or mitigated through the use of proper procedures and techniques. A detailed discussion of these techniques is available in several excellent application notes by equipment manufacturers such as Agilent and Anritsu. Some of the common sense practices for minimizing EMC/EMI problems in an amplifier lab include:

- Use of properly terminated transmission lines;
- Use of instrument quality terminations;
- Verification that all connections are properly tightened and torqued;
- Limitation of current to avoid damaging and interfering oscillation.

The use of solid-state amplifiers such as a solid-state power amplifier (SSPA), for example, the Giga-tronics GT-1000A, rather than a traveling wave tube amplifier (TWTA) as a driver or test amplifier can also reduce many potential issues.

The SSPA needs no time to warm up, so does not need to be left on for stability. In addition, SSPAs typically have much lower thermal noise signature than TWTAs, and the harmonic and intermodulation content of solid state amplifiers is typically much less than that of tube amplifiers.

Chambers and Screen Rooms

The use of anechoic chambers and screen rooms, when available, can minimize both the effects of ambient electromagnetic signals on equipment and reduce the potential emissions from getting into the ambient environment. Typically, low noise work is performed in a screen room, and any power work is done outside of a screen room. High-power leakage in a screen room just creates a microwave oven.

Once the environment is free of extraneous RF, it is important to keep it that way. Cell phones and other transmitting devices won't function within a screen room, and will only contribute to the EMI, so they should be left outside.

Environment Characterization

In some cases, it may be difficult, expensive, or impossible to reduce or eliminate potential EMI sources from impinging on measurements. In those situations, characterization and publication of known local frequencies of interference can reduce troubleshooting time. Signals are to be expected in the AM and FM radio bands and mobile phone frequencies, and, if the location is near an airport or public safety office, additional frequencies can be expected. Researching the environment and verifying signal presence and type in a published list can save time in the future.

Design Actions

During the design stages, the use of various techniques can reduce interference opportunities not only during the development stage, but also when the product is complete and in production. Circuit shielding, prudent use of RF and microwave absorber material, and compartmentalization and filtering are all effective methods for containing and reducing interference. Implementation of capacitive and Pi filtering elements to reduce conducted interference are also key. The inclusion of DC-DC switching regulation adds another dimension of potential interference to be evaluated, particularly on the conducted emissions.

Summary

RF/microwave amplifier laboratories are among the most challenging EMI/EMC environments. RF is everywhere and, in a world dominated by electronic devices, it is not only naive but impossible to ignore the effects that both intended and unintended electromagnetic interference can have on the development and manufacture of electronic products.

Fortunately, most of the issues created by interference can be easily and effectively resolved with the use of proper procedures and techniques during both the development and

production stages. In most cases, these interference issues can be resolved or prevented using common sense. Take proper precautions. Communicate with team members. Identify concurrent testing. Know what to expect. Rationalize the results. If the results don't make sense, investigate. Document anomalous performance with detail. Keep power levels as low as is reasonable. Reduce harmonics and intermodulation products. Most importantly, know the surrounding environment and know the products being developed and tested. □

Scott Behan is vice-president of marketing at CAP Wireless, Inc., and can be reached at scott.behan@capwireless.com.

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