Application Note #60
Harmonic Measurement for IEC 61000-4-3 and other Radiated Immunity Standards

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In the rush to complete RF immunity testing on schedule, it is not all that unusual to overlook inherent test equipment limitations. While some test equipment characteristics such as power amplifier harmonics are obviously a limiting factor, the broadband characteristics of antennas, directional couplers, power meters and isotropic field probes can hardly be considered a limitation for most applications. However, when used with power amplifiers exhibiting significant harmonic distortion in Immunity test systems, the broadband characteristics of these devices can result in measurement uncertainty and unacceptable errors.

A case in point is the ubiquitous broadband isotropic field probe that provides an E-field reading representative of the total energy from all frequencies within its operating band. Given the ideal, albeit rare, case of a pure sinusoidal signal, field probes provide an extremely accurate reading. To the extent that additional frequencies are present, errors are introduced and depending on the number and strength of the additional signals, a point is reached where the field reading is totally unrepresentative of the required test level at the desired frequency. The most troublesome unwanted frequencies are harmonics generated by RF test system nonlinearities. Often power amplifiers, especially those driven into saturation, are a major source of harmonics. To a lesser extent signal sources, directional couplers, and antennas exhibit some degree of nonlinearity and also contribute to the system level harmonics. Accordingly, the IEC 61000-4-3 has instituted system requirements intended to limit the allowable harmonic levels in the test field.

While it is imperative to consider instrument harmonic levels supplied by instrument vendors, test engineers must also confirm manufacturer's data by testing. While this paper specifically addresses ways to check for harmonic levels mandated by IEC 61000-4-3, the procedures can be readily applied when testing to other RF immunity standards.

Harmonics

Harmonics are unwanted frequencies generated by system nonlinearities. They are multiples of the fundamental test frequency and generally, the higher the multiple, the less the amplitude of the harmonic. All "real" test systems have a finite amount of nonlinearities and thus, exhibit some degree of harmonic distortion. The test engineer must ultimately determine acceptable levels of harmonics. His determination is primarily based on test standard mandates. In EMC testing applications, RF power amplifiers are responsible for most of the unwanted harmonics.

Understanding harmonics in an amplifier

All amplifiers exhibit harmonic distortion to some extent. While some applications like industrial RF heating and plasma generation are not affected by harmonics, high levels of signal distortion will introduce unacceptable errors when testing for EMC immunity. Accordingly, harmonic distortion is a key power amplifier specification. It has been proven that properly designed Class A amplifiers when operated in their linear region have acceptable levels of harmonics and are an ideal choice for EMC test applications.

Keep in mind that even a properly designed, robust Class A RF power amplifier does not guarantee a distortion free test field. Care must be taken to operate within the linear range of the amplifier, even at the sacrifice of a smaller output signal. While driving the amplifier harder will indeed provide greater field strength, the inherent signal distortion resulting from a spike in the harmonic levels will introduce uncertainty and error in the resultant E-field. Ultimately, the question becomes, "Just how much input signal is required to ensure the desired signal purity in any given application". Application Note #45 addresses this concern in quite some detail relating various levels of compression to signal distortion. It can be seen that an EMC amplifier should not be operated beyond the 1dB compression point. In fact, operating in a more linear region below the 1dB will drastically minimize harmonics. Another less desirable option is the use of harmonic filtering at the output of the amplifier. Since this approach adds cost, insertion loss and complexity to the system, it should only be considered when there is no other practical option. For example, some TWT amplifiers are best served by the use of harmonic filters.

Since it is all but impossible to predict the cumulative effect of all the system devices on the purity of the E-field, a system level measurement must be taken. While vendor data should be consulted and relied on when selecting a power amplifier, there is no substitute for actual system measurements when it comes to validating the viability of a system design.

How do multiple signals influence power measurement?

Most field probes and power heads use diode sensors with broadband characteristics. These devices are not frequency selective and will measure all signals within their operating range. The resultant reading is the square root of the sum of the squared amplitude of the fundament and all harmonics present. Clearly, harmonics will add uncertainty and error to the field measurement. Harmonics are inevitable and eliminating them completely would be a very costly proposition. Thus, the conundrum is determining what would be an acceptable level. Fortunately IEC 61000-4-3 provides guidance in this area. The latest version of IEC 61000-4-3 states the following: "For all frequencies where harmonics are produced at the output of the amplifier, the rejection of these harmonics in the field by more than 6 dB below the fundamental is adequate." In other words, there is now a 6dBc harmonic requirement in the test field. Note that dBc is a measurement of a specific harmonic level in relation to the carrier. A measurement of -6dBc by definition means that the amplitude of the harmonic is 6dB less than the carrier amplitude. Past IEC 61000-4-3 standards have specified the output harmonic level from the power amplifiers. The latest version of the standard considers the entire system when it mandates a 6dBc requirement. This level takes into account the fact that the transmitting antenna operates more efficiently at the 3rd harmonic than at the fundamental. It is not uncommon to see as much as a 5dB gain variation. As discussed in IEC 61000-4-3 annex D, limiting all harmonics in the test field to -6dBc will result is no more than a 10% field strength error. Figure 1 graphically plots this relationship. Note that with a -6dBc harmonic level a field probe reading of 10V/m actually represents about a 9V/m carrier level. If the test calls for more accuracy, the harmonics must be further reduced. For example, a 5% error in field strength requires the harmonic to be at least -10dBc. Standards that do not take into consideration the

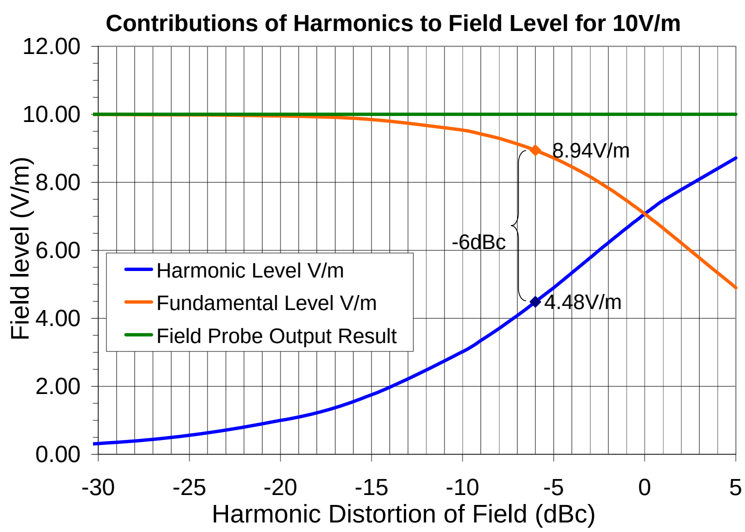

Fig. 1: Single Harmonic Contribution to Measured Field

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effect of the transmitting antenna concentrate on the power amplifier harmonics. For example, older versions of IEC 61000-4-3 limited amplifier harmonic levels to -15dBc. When compared to the new -6dBc total field specification, the -15dBc results in slightly less field level error.

Methods of Measurement

There are two generally accepted methods used to determine the harmonic content of a test field. In both cases a frequency selective device is required to measure the level of the fundamental frequency as well as the harmonics. The most popular instrument used for this purpose is a spectrum analyzer. The required frequency range of the spectrum analyzer is determined by the frequency range mandated in the EMC standard. For example, since IEC 61000-4-3 covers 80MHz to 6GHz, the spectrum analyzer should have a minimum bandwidth of 80MHz to 18GHz in order to respond to at least the 3rd harmonic. For the rare occasion where there is significant harmonic content beyond the 3rd harmonic, a higher frequency analyzer is required. In most cases harmonic levels are inversely proportional to frequency and are not a factor outside the operating band of the amplifier. Since there are some exceptions to this general rule, it is prudent to always verify harmonic levels by testing. One needs to look no further than to some TWT amplifiers which exhibit significant harmonics well beyond the frequency band of the amplifier. The message here is to be keenly aware of the predicted harmonic levels as published by the amplifier manufacturer, but always test to verify the published data.

Receive Antenna Method

The test setup used for this method replicates that used for the actual test. Since the harmonics are measured directly without the need for calculations, it is the preferred method providing the most accurate data.

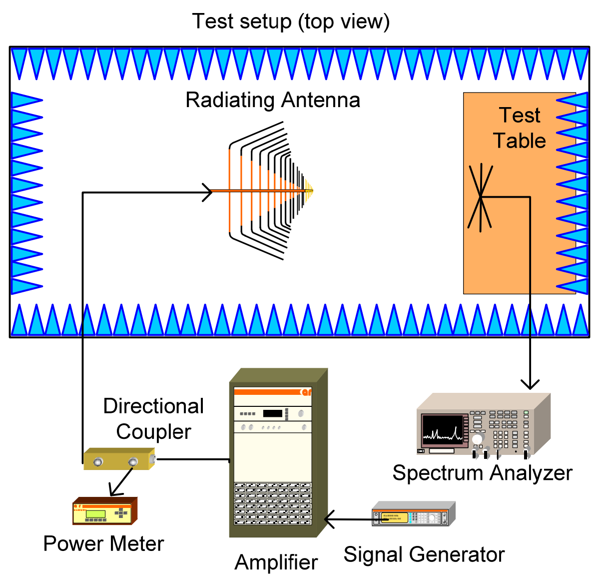

Fig. 2 Basic Setup Diagram for Receive Antenna

Required equipment

Spectrum analyzer 80MHz – 18GHz
Receive antennas
Coax cables, calibrated for losses
Optional: Control software

Selection of equipment

As noted above, the spectrum analyzer used is primarily determined by the test frequency range of the EMC test standard. The IEC 61000-4-3 covers 80MHz to 6GHz. To measure out to the 3rd harmonic, the spectrum analyzer must cover 80MHz to 18GHz. An ideal solution for the receive antenna would be one that covered the entire frequency range of 80MHz to 18GHz. Since typically this is not possible, the next best approach is to break the overall band up to coincide with the band breaks of the transmit antennas.

Recommended frequency assignments for both transmit and broadband biconical receive antennas are shown below. This is an ideal solution since each receive antenna covers the harmonics from each transmitting antenna. Since there is no need to switch in additional antennas, this is a rather simple solution. While not as elegant as a single receive antenna, it is the next best thing and quite amenable to control via software.

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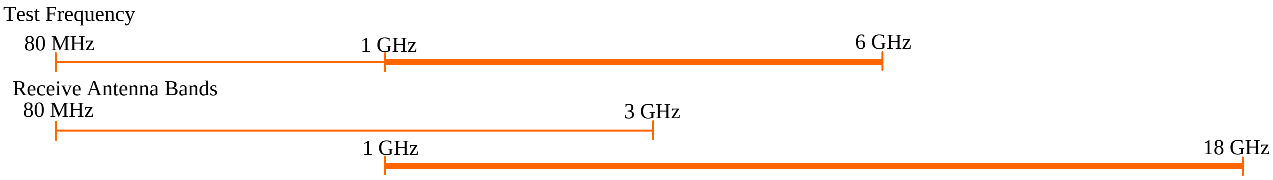
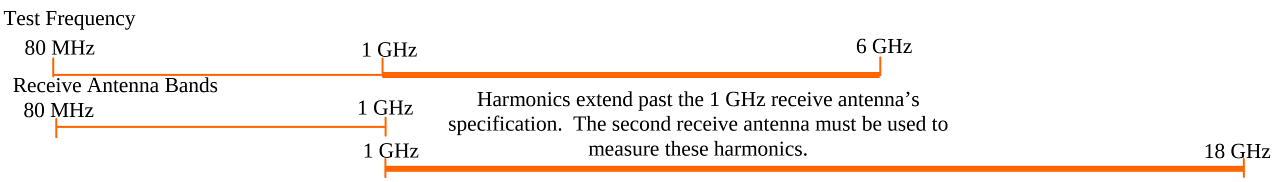


In the event that a single receive antenna were not available to respond to the 3rd harmonic of each transmitting antenna, one could opt for a less desirable, overlapping approach as shown below. This setup is commercially available by combining a Biconical Log-Periodic with a double-ridge antenna. It can be seen that the lower frequency transmit antenna requires both the receive antennas to adequately cover all the harmonics. This is a much more difficult setup to implement either manually or via software control.



Procedure

1. Setup test as shown in Figure 2
2. Begin the test at the lowest frequency point and adjust the output of the power amplifier to generate the required test level. The test level used to measure harmonics must replicate the actual level used for EMC testing. Since IEC 61000-4-3 calls for 80% amplitude modulation, adjust the level to 18V/m CW or 10V/m with 80% amplitude modulation. By doing so, the additional power required to provide the modulation is accounted for and the resultant effect on harmonic levels is produced.
3. Measure the fundamental field level as well as the 2nd and 3rd harmonics with the receive antenna. Higher level harmonics are generally not a problem and do not require measurement.
4. Correct readings by applying the receiving antenna's calibration factors and adjust readings to account for all cable losses.
5. Calculate the relative level (dBc) for each harmonic, where dBc = harmonic level – fundamental level.
6. Step to the next test frequency according to the test standard and repeat 1 through 5.
    a. If it appears that the harmonic measurements are high enough to require the use of a higher frequency receive antenna, in the interest of time hold off on switching out the receive antenna., Continue testing and take all measurements possible. At the completion of the test, switch to a higher frequency receive antenna and run the test again to fill in the missing harmonic measurements.
    b. If amplifier harmonics trail off significantly as measurements are taken at higher test frequencies AND the amplifier is not being driven close to saturation, testing can be halted and it can be assumed that the rest of the harmonics will be within required levels.
7. Setup for the next amplifier band and repeat the above steps.

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Directional Coupler/s Method

The Directional coupler method can also be used to measure system level harmonics. This approach is more complex than the receive antenna method and given the following inherent uncertainties, it is the least desirable choice.

- The transmit antenna is usually not calibrated. Since the manufacturers test data is not specific to the actual transmit antenna used, relying on vender supplied "typical" data for the antenna gain results in error.
- The out of band performance of the transmit antenna where harmonics are present is usually unknown.
- The harmonic test may require additional directional couplers than used during the actual EMC test causing small changes and disruption to the calibrated test setup.
- Calibration of the coupled ports of the directional coupler might be required.

Based on an assumption that harmonics should fall off at the top end of the amplifier band and not reappear at points outside the band of the amplifier, one can limit the extent of measurements taken. However, tests should be run to backup any assumptions made.

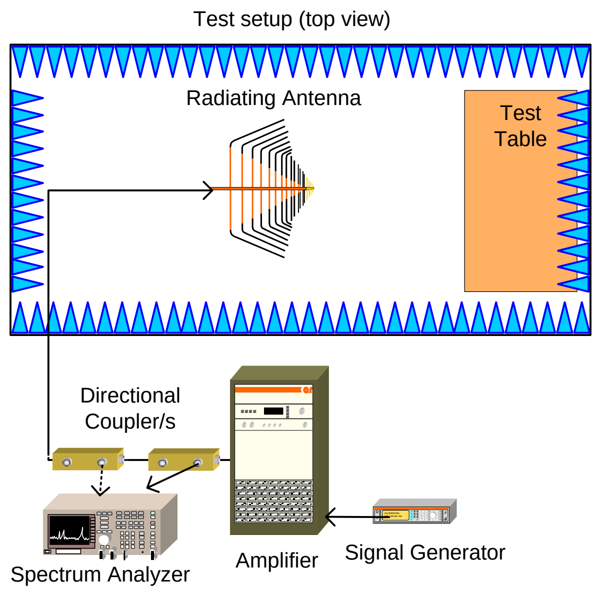

Fig. 3: Basic Setup Diagram for Directional Coupler

Required equipment

Spectrum analyzer 80MHz – 18GHz
Directional coupler used during test
Any additional directional couplers for higher frequency measurements
Coax cables calibrated for losses

Optional: Control software*Selection of equipment*

In addition to the considerations noted with the receive antenna method covered above, additional directional couplers must be compatible with the power amplifier in terms of power handling capability as well as frequency range.

Procedure

1. Setup test as shown in Figure 3
2. Begin the test at the lowest frequency point and adjust the output of the power amplifier to generate the required test level. The test level used to measure harmonics must replicate the actual level used for EMC testing. Since IEC 61000-4-3 calls for 80% amplitude modulation, adjust the level to 18V/m CW or 10V/m with 80% amplitude modulation. By doing so, the additional power required to provide the modulation is accounted for and the resultant effect on harmonic levels is produced.
3. Measure the fundamental field level as well as the 2^{nd} and 3^{rd} harmonics using the directional coupler. Higher level harmonics are generally not a problem and do not require measurement.
4. Correct readings by applying the directional coupler's calibrated coupling factors and adjust readings to account for all cable losses.
5. Apply the transmitting antenna's gain to the readings.
   a. If the harmonic level is outside the known gain of the antenna, use the last know value. Estimating the unknown gain can contribute significant error to the results.

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6. Calculate the relative level (dBc) for each harmonic, where dBc = harmonic level – fundamental level
7. Step to next test frequency according to the test standard and repeat 1 through 6.
    a. If it appears that the harmonic measurements are high enough to require the use of a higher frequency directional coupler, in the interest of time hold off on switching out the directional coupler., Continue testing the frequencies and take all measurements possible. At the completion of the test, add in the higher frequency directional coupler and run the test again to fill in the missing harmonic measurements.
    b. If amplifier harmonics trail off significantly as measurements are taken at higher test frequencies AND the amplifier is not being driven close to saturation, testing can be halted and it can be assumed that the rest of the harmonics will be within required levels.
8. Setup for the next amplifier band and repeat the above steps.

Note: care should be taken that if an additional directional coupler is used it does not add significant losses to the test system.

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