Application Note #56
Proper Use of RF Field Probes Used in EMC Radiated Immunity Testing

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RF field probes are perhaps one of the most underrated components of a radiated immunity test system. While we rely heavily on data sheets to select all the other devices required to **generate** a given field level, only a live test using a trusty field probe will **measure** the resultant field level and thus, validate the RF test system. While we assume that all measurements meet the accuracy published in the probe's data sheet, it must be noted that these indispensible tools can be a source of considerable error if not used correctly. This application note will review the underlying concepts of field measurement with an emphasis on the proper application of field probes.

Broadband Isotropic RF field probes are commonly used in immunity testing applications. Insuring the accuracy of these very precise measuring devices over their entire frequency range can be challenging for both the probe designer and the user. To minimize errors, the user should understand how these devices operate and what influences could affect their resultant readings.

Test methods

There are two generally accepted methods used to determine field strength; the closed-loop method and the substitution method. While each method has its advantages and disadvantages, ultimately the test standard will determine the method used.

Closed Loop Method: In this method an RF field probe is positioned in front of or on top of the EUT during susceptibility testing. The field is adjusted to the intended field strength for each frequency step across the entire test frequency band. Since the commonly used diode-type field probe can not accurately measure a modulated RF signal, one must either apply correction factors to the probe readings or take measurements using only a CW signal and only apply modulation later during the actual test run.

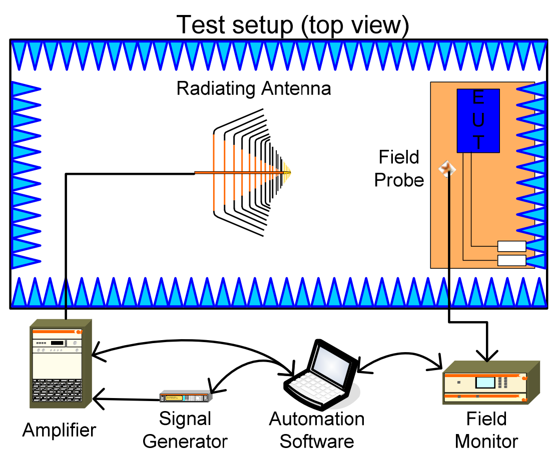

Figure 1: Closed Loop Method

Closed loop testing provides a "real-time" reading of field level as well as a direct correlation between instantaneous field level and the operation of the test device. This Immediate feedback adds confidence in both the system performance and the immunity of the EUT. Closed loop testing also proves to be the fastest method since no additional time is required to calibrate and level the RF field. Some argue that this approach is a better representation of the actual RF levels seen by the EUT. This method is a good choice for testing small EUTs where reflections from a relatively small reflective surface area have a minimal affect on the RF field. As the size of the EUT increases a point is reached where reflections from the larger reflective surface area of the EUT will have a noticeable affect on the field. The resultant standing waves create an unstable situation whereby the probe readings can vary dramatically when moved about the room or as a function of frequency. In short, the results are unpredictable and most likely unrepeatable from one setup to another, not to mention from one test lab to another.

MIL-STD-461 is one example of where the closed-loop method is mandated.

Substitution Method: In this method the RF field is first calibrated in an empty chamber. For every increment of frequency the system is adjusted to achieve the test level and the RF drive level is recorded. All readings are conducted with a CW signal in order to insure proper levels. Armed with the room calibration data, the actual immunity test is run. The EUT is positioned in the test environment and the drive levels noted during the calibration phase are replayed to produce the CW field and the appropriate RF modulation is then applied. Since this method does not require field monitoring during the test run, probe errors resulting from EUT effects on the field are eliminated. One drawback of the substitution method is that additional time must be allotted to perform the calibration/leveling phase prior to the actual test run. Regardless, this method has become more accepted and is referenced in many EMC test standards.

While not required, a probe is often used during the test run just to monitor the RF field. This direct feedback assures system performance. For example, a simple test equipment failure, cable failure or even human error would be picked up by simply monitoring the field during the test run.

Both IEC 61000-4-3 and DO160 use the substitution method but use different calibration procedures.

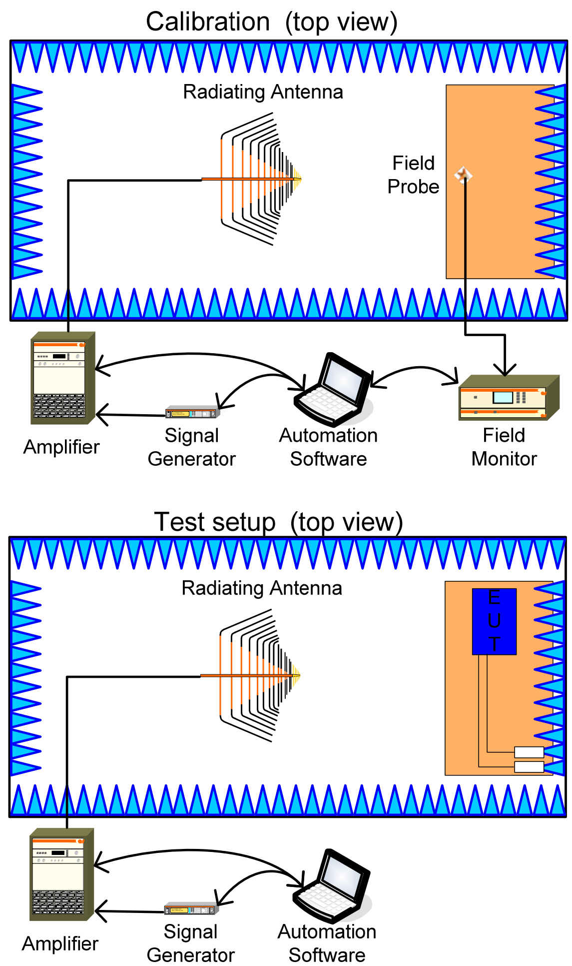

Figure 2: Substitution test method

Important concerns when using RF probes

Harmonics:
If the RF amplifier is operating in saturation or exhibits harmonics, the field will consist of more that just the test frequency. For example, the output of a TWT amplifier operating at a fundamental test frequency of 1GHz could contain a 2GHz harmonic just 3dB down from the level of the fundamental. This output coupled to a typical antenna that exhibits increasing gain as a function of frequency could actually yield a field where the harmonic level is greater than the fundamental. Since the RF field probe reads total energy, the displayed field level would be much higher than the actual field at the desired 1GHz test frequency. If this source of error is not understood and controlled, results of the immunity test are invalidated. The simplest way of minimizing harmonic related errors is to either select an RF amplifier with low harmonics or at very least operate well below the amplifier's saturation point. In the event that these precautions are not practical, one must apply low pass filters to absorb the harmonic energy.

In an effort to control harmonic related errors, some standards mandate a maximum harmonic content within the RF test field of -6dBc while others focus directly on the RF power amplifier and mandate that its harmonics be held to no greater than -15dBc.

Let's take a look at the -6dBc field requirement. By reducing the harmonics to this extent, the harmonic power is ¼ that of the fundamental power which results in an acceptable amount of field probe error.

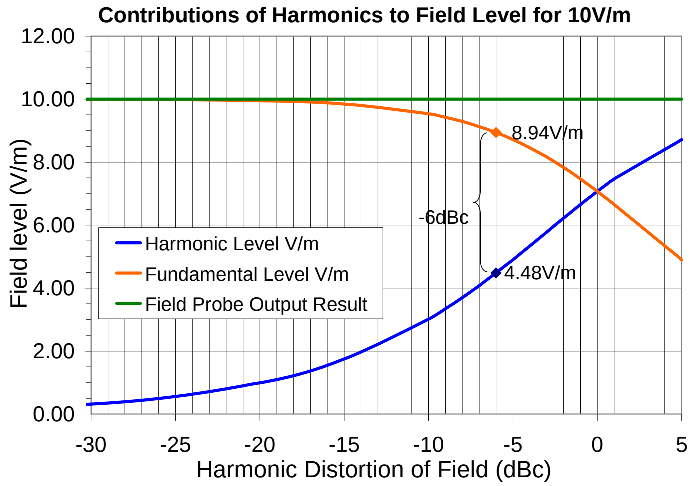

Figure 3: Graph of the Fundamental and Harmonic Relation to Field Strength Reading

Given that a -6dBc harmonic level within the test environment is satisfactory, let's work back to determine the maximum acceptable level of harmonics from the RF power amplifier.

1) Some antennas exhibit as much as 5 dB more gain at the harmonic frequency that at the fundamental test frequency.

2) Typically a 3dB margin is applied to account for variables like probe and test environment inconsistencies.

3) Summarizing the above observations:

Spec requirement		6dBc
Max antenna gain between harmonic and fundamental		5dB
Other effects from setup and room (safety factor)		3dB
	Total	**14dB**

While it can be seen that a minimum of -14dBc harmonic distortion from the RF power amplifier is acceptable, one should strive to reduce amplifier distortion even further to minimize any error caused by harmonics. From the above graph it can be seen that the -6dBc requirement will result in about an 11% margin of error. The equations in Annex A can be used to more accurately calculate the contribution of harmonics on probe error.

Probe Positioning: When a probe is used during an immunity test, it is recommended that the probe be positioned in the same orientation as during calibration. There are some common sense rules that can be applied when positioning a probe in the test field.

- Use the probe on axis when the polarization of the field is known; this is accomplished by aligning one of the probe's axis with the horizontally polarized field and one with the vertically polarized field.

- Make sure the probe's metal housing is not causing reflections. This is common when using a "stalk" type probe with a square housing located about 10 inches from the probe. The flat reflective housing should not be located directly behind the probe since this can cause a reflection. The reflection can result in standing waves at the probe head. This is especially possible above 1GHz.

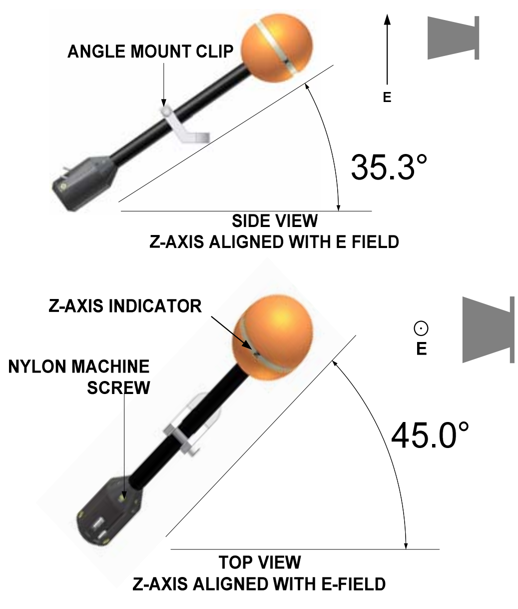

Figure 4: Probe Alignment

- For closed loop testing it is best to keep the probe in a position where direct reflections from the EUT will not cause a standing wave at the probe head. It is therefore best not to place the probe in front of the EUT. Since this may not be possible, experiment with various locations or use multiple probes to find a way to achieve a stable field.

Due to the orthogonal design of an isotropic field probe, one would expect field readings totally independent of probe position. Regrettably this is not the case and a figure of merit has been established. The isotropic field response provides the variation one can expect as a function of probe positioning. To preclude this error component, orient the test probe in the exact position as that used when running the calibration.

Calibration Factors: Ideally a field probe would provide an exact reading of the test field across its entire frequency range. Since this is unpractical, field probes are supplied with correction factors that when applied result in a value within the stated accuracy of the probe. Correction factors are obtained by a periodic calibration performed by a qualified calibration lab. These correction factors need to be applied to the readings of all probes in order to meet published specifications.

Some newer probes such as those sold by AR RF/Microwave Instrumentation do offer the ability to automatically apply correction factors if the system is configured to communicate the test frequency to the probe monitor. This must be done since the correction factor is a function of frequency and the probe does not have the ability to sense the test frequency. This inability is generally not an issue since automated test software can easily parse out correction factors as a function of frequency and supply this data to the probe. While some test facilities do not apply correction factors unless they are greater than 0.5dB, this policy is ill advised since this is an error component that is easily corrected. Since there are other sources of error that are not so easily corrected, it makes no sense to overlook one that can be dealt with so easily.

Note: Some probes may state that they store a correction factor in an EPROM and apply corrections automatically. Keep in mind that these factors are used for internal compensation of probe circuitry and are not to be confused with the calibration factors provided by the calibration lab.

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Modulation Correction Factors: Most standards require the RF test signal be modulated. Since common diode-type probes do not exhibit a linear response to modulated fields throughout their usable range, readings should always be taken with a CW signal. One simple way around this probe shortcoming is to create a custom calibration for the particular modulation in use. This calibration is accomplished by first adjusting the system to produce the required CW field level. At this point apply the modulation mandated by the standard and note the resultant field level. This new reading will represent the required test level with modulation at the test frequency and will be very reproducible for that specific frequency and field level. This reading should not be scaled up or down since the field probe does not respond linearly to modulation across its frequency range.

Note: A Thermocouple probe directly measures the average amplitude of a repetitive modulated field, but the modulation envelope would need to be known if a maximum reading was required. Since thermocouple probes are less sensitive and have a narrower dynamic range than diode-type probes, they are not commonly used in EMC immunity applications.

Temperature Compensation: If there is a significant variation of temperature between probe calibration and the actual test run, it is likely that the probe reading will contain a error component directly proportional to the temperature variation. Some probe manufacturers supply a temperature correction equation that must be applied to correct for ambient temperatures that differ from the temperature at which the probe was calibrated at. Since high field levels and even operating EUTs can generate a great deal of heat, it is difficult to actually determine the "dynamic" heat fluctuation at any given moment, much less apply the correction factor. Thus, this cumbersome chore is often ignored leading to a major source of error. AR RF/Microwave Instrumentation recognizes how difficult this correction process can be and has instituted automatic internal temperature compensation in all of its laser powered probes. As long as the probe is used within its stated parameters, no additional temperature compensation is necessary.

Zeroing: In an effort to minimize probe error, some probes incorporate an internal reference and automatically initiate a zeroing function to partially offset probe error resulting from internal component drift.

Zero Offset: A word of caution regarding the use of a zero offset function, if available. Unfortunately some probes allowed users to "zero out" static probe readings prior to conducting a test. While it seems like the logical thing to do, adjusting the probe in this manner introduces an error component equal to the adjusted signal level, since in reality, most probes are not designed to read zero in the absence of a field. The relatively small steady-state reading represents the noise floor of the probe itself or more likely the noise floor plus the ambient field within the test lab. Operators have mistakenly believed that they must force this reading to zero to minimize probe error but in fact, the probe is not affected by this small initial offset. The zero offset function should only be used by qualified personnel conducting the periodic probe calibration at a certified calibration lab and never adjusted in the field.

Conclusion

The ultimate goal with all immunity testing is to minimize errors and measurement uncertainty. By insuring the integrity of the test system one can expect reproducibility between setups in the same lab as well as from outside labs. If field probes are used within the guidelines noted in this application note, accurate, repeatable results are possible. To achieve this goal, not only should field probes be used correctly but the entire test setup along with procedural details needs to be documented in detail. Finally, it is important to keep in mind the capabilities and limitations of any measurement device to insure that erroneous data is not taken.

Annex A

If one harmonic is dominating, then the equations listed below can be used to find the values. The dominating harmonic would most likely be the 2nd or 3rd harmonic.

$$V/m_{Total} = \sqrt{V/m_{Fundamental}^{\ 2} + V/m_{Harmonic}^{\ 2}}$$

$$V/m_{Fundamental} = \sqrt{\frac{V/m_{Total}^{\ 2}}{1 + (10^{\frac{dBc_{Harmonic}}{20}})^2}}$$

$$V/m_{Harmonic} = \sqrt{\frac{\frac{V/m_{Total}^{\ 2}}{-2}}{1 + (10^{\frac{dBc_{Harmonic}}{20}})^{-2}}}$$

$$V/m_{Fundamental} = \frac{V/m_{Harmonic}}{10^{\frac{dBc_{Harmonic}}{20}}}$$

$$V/m_{Harmonic} = V/m_{Fundamental} \bullet 10^{\frac{dBc_{Harmonic}}{20}}$$

Note: Since *dBc* refers to the level of a harmonic relative to the carrier, in most situations this will be a negative number. This is of course desirable, and the greater this negative number, the better. Unfortunately, there are situations where harmonics can exceed the carrier and in this case, the *dBc* figure is a positive number