Application Note #44
RF Field Probe Selection for EMC Testing

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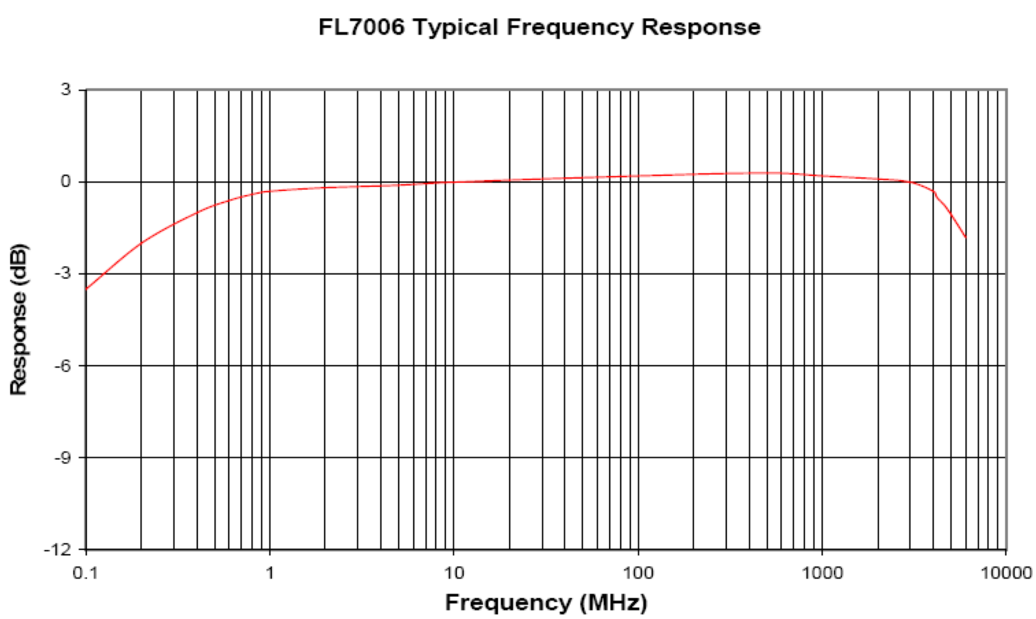
Often underestimated, RF field probes are critical to the implementation of a proper radiated immunity test system. All too often, system specifiers gloss over this essential element after having spent a considerable amount of time and energy selecting components required to "generate" the required RF field. After all, what good is an RF field if you can't reliably measure it?

In an effort to simplify the process of probe selection, this application note will focus on the salient specifications of RF field probes. Given a thorough understanding of how RF field probes are specified, one can then make informed decisions as to which probes are best suited for a particular application.

RF Field Probes Specifications

Frequency Response is undoubtedly the most important probe characteristic. It is defined as the frequency range the probe will respond to. Since no probe can provide a completely flat response across the entire frequency range, this spec is always accompanied by a tolerance figure, generally provided as a ±dB allowable variation band. An example of a typical frequency response is shown in Figure 1. The frequency response shown in Figure 1 is that of an actual probe designed to cover a heavily used frequency range. If the probe does not cover the entire frequency range of the test application, multiple probes may be required.



Calibration Factors are supplied with every probe and should be updated on a periodic basis, usually once a year. The calibration factors yield a curve that is the inverse, or mirror image, of the frequency response curve. These corrections are provided in terms of dB adjustments and as multiplication factors. When applied, the effect is to flatten the probe frequency response across the entire frequency range to minimize errors. Calibration factors are usually provided for each individual axis as well as for the composite reading. Maximum field measurement accuracy is achieved when the detailed 3-axis calibration is applied. Since measurements are never absolute, calibration labs issue a statement of uncertainty that lists the anticipated error range (±dB or %) for their measured data. The calibration lab measurement uncertainty has a trickle down effect and impacts the measurement uncertainty of the EMC lab using the field probe.

Calibrations can be offered in two different versions:

1. In the USA, a NIST traceable calibration is a calibration that has been carried out with equipment that can be traced back to a National Institute of Standards and Technology (NIST) calibration. Other countries may have their own nationally recognized calibration lab for traceability; for example, PTB in Germany and NPL in England.
2. An ISO 17025 accredited calibration is the newest form of calibration. It requires the calibration lab be held to very high quality standards. To comply, the lab must be audited and carry a certificate of conformance from a recognized body, such as A2LA or NVLAP in the United States. To be accepted worldwide, the recognized body must have mutual recognition agreements (MRA's) that facilitate mutual recognition of test reports. This calibration is also NIST traceable.

- Standard used for calibration: IEEE std. 1309:1996
- Appendix of IEC 61000-4-3 is under review for a procedure for probe validation when used for IEC testing.

Sensitivity/Dynamic Range – Sensitivity determines how small an RF signal a probe can respond to accurately. The sensitivity of RF probes is especially important when low field strengths need to be measured. Some specs call for a field level of 1V/m or even less, which may be below the sensitivity of many probes, or very close to its noise floor. The most sensitive probes can accurately measure a few hundred mV/m. Dynamic Range is the total range of RF field coverage a probe will respond to. The greater the dynamic range the better a probe is suited to address test applications that span the gamut from low to high field strengths. Example: 0.5 – 800V/m for 0.5 MHz – 6 GHz, 1.2 – 800V/m for 100 kHz – 0.5 MHz

Linearity is the measure of deviation from an ideal response over the dynamic range of the probe. Linearity data is provided since the response of an RF probe will vary somewhat as a function of the applied field level. This slight variation introduces an additional error component that must be considered when testing at levels other than that used during calibration. For example, one might encounter a variation of ±0.5dB across a dynamic range of 0.5 – 800 V/m.

Overload refers to the field level where damage can occur to the probe. Care should always be taken not to exceed this field strength with the probe present, even if it is turned off. Overload can be stated as a max pulsed level or a CW level. Example: 1000 V/m CW

Isotropic Deviation is the variation of the probe's response from ideal as it is rotated in the field. While this deviation in measurement is usually verified at one frequency and in one rotational plane, some advanced probe calibrations offer a much more expanded calibration with isotropic response measurements taken at many frequencies. Figure 2 shows a typical isotropic response of a probe as it is rotated around the critical angle. If calibration factors were applied to each axis, the resultant curve would approach an ideal concentric circle, or completely isotropic. The term isotropic gives the impression that measurements are taken as the probe is rotated in every direction. This is not so do to time factors and cost of calibration. This undesirable error component can be minimized by attention to physical design. The minimal isotropic deviation of spherical probes discussed later is a case in point. Example: ±0.5dB 0.5 MHz – 2 GHz.

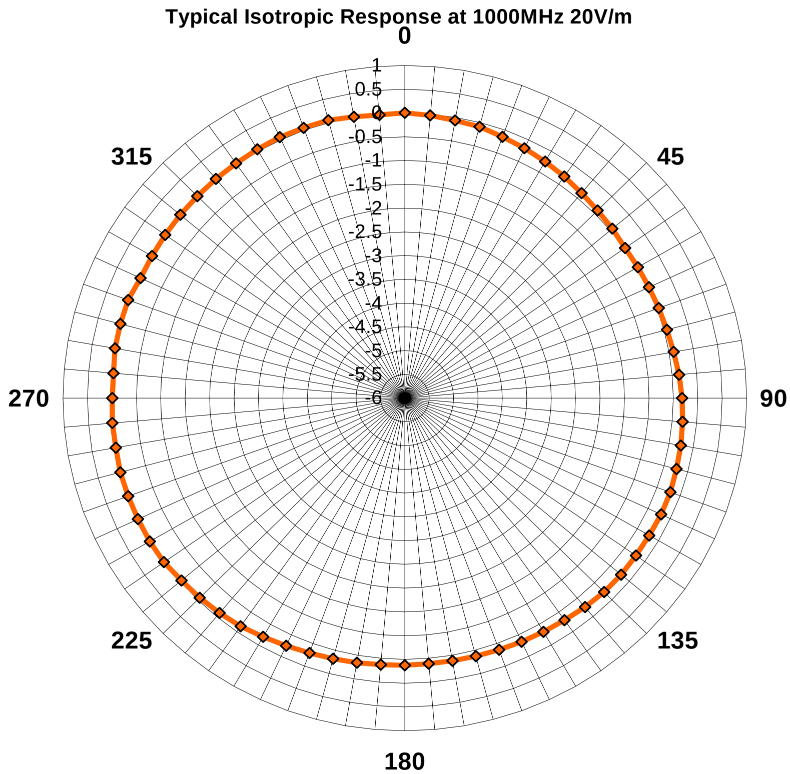


Figure 2: Isotropic Response

Response time is the time a probe takes to respond to an applied RF field. In many CW applications, this is not a concern. However, response time is important when measuring a short duration signal. In general, probes with faster response times are more versatile and may shorten the total test time, by allowing for shorter dwell times. Response time should not be confused with sample rate, explained below. Example: 20msec

Sample rate is the rate at which information can be retrieved from the probe. This time factor is in addition to the probes response time. As noted above, the probe takes a finite amount of time to "measure" the field (response time). The probe then periodically "looks at and reports" this measurement (sample rate). A high sample rate affords a quick response to RF field changes as well as reduces the total test time. Example: 50 samples per second

Probe Type generally refers to the configuration of the probe sensors. Most modern probes are isotropic. An isotropic RF field probe measures the total value of the field level and is unaffected by field polarity. This is accomplished by summing measurements from three different sensors placed orthogonal to each other. Some older probes used only one sensor and thus, measured fields in one polarity at a time (non-isotropic). Probes are further separated as to which component of the electromagnetic field the probe responds too, the electric field or the magnetic field.

Sensor Type is the "business end" of the probe that responds too the RF field and provides the measurement. Most probes today use a diode type sensor. Diodes have excellent sensitivity as well as a large dynamic range. Another type of sensor is a thermocouple type sensor. Unlike the diode sensor, a thermocouple sensor has less sensitivity and less dynamic range but has the unique property of being able to measure the true RMS levels of the field throughout its range. Measuring the true RMS level is useful for measuring a modulated signal with known parameters. A third type of sensor which is very new and still in development is the electro-optical sensor or laser sensor. The laser sensor should not be confused with a laser powered probe which is defined later. Given their popularity, most RF field probes today use a diode type sensor.

Temperature Stability is the deviation of the probes reading over the operating frequency range as a function of temperature. Most probes require a correction formula be applied when used at temperatures that differ from that used at the time of calibration. AR's newer designed probes, such as the FL7000 series, have incorporated temperature compensation within the probe. This unique feature frees one from operating temperature concerns and the need of applying an additional correction formula to the results. Example: ±0.5dB over operating temperature range

Control refers to the method used to communicate with the probe. Fiber optic control is the only viable choice available for EMC testing. Fiber optic cables are nonmetallic and thus, will not interfere with the radiated immunity test setup. Furthermore, they are not susceptible to data corruption from voltage/current induced by the RF field.

Data returned from probe – this is the information obtained by the probe. There are two basic methods currently used. The first and most complex method returns data from each axis separately, as well as a composite reading of all three axis. The second simpler method only returns a composite reading of the three axis. In most cases, only the composite reading is required. If the application requires a determination of the polarity of the field, then a probe that can parse out readings from the individual axis is required. Standards such as Ford's ES-XW7T01A278-AC radiated immunity for bands 6 & 7 and mode tuned reverberation testing actually mandate probes that are capable of providing individual axis readings.

Power Requirements refers to the method used to power the probe. There are presently two versions available; battery powered and laser powered. Probes cannot be directly powered by AC during use since the metallic power cord would adversely effect field uniformity and energy induced by the RF field in the power cord may introduce errors in the field measurements.

- Battery powered probes contain batteries in the probe housing. While battery powered probes remain a viable choice, the trade off is reliability. Rechargeable batteries are most often used and suffer from a limited charge life as well as occasional failures. Since some probe vendors require that the probe be returned to the factory for battery replacement and recalibration, a simple battery failure can totally shut down an immunity test system. To minimize down time, AR's FP7000 and FH7000 series of battery powered probes use standard size AA rechargeable batteries that can be easily replaced by the user with no recalibration required.

- Laser powered probes have been designed to address the reliability issues encountered with rechargeable batteries. A high energy laser driver delivers Infrared (IR) energy to the probe via the same fiber optic cable used for communications. A converter within the probe converts the IR back to electricity to power the probe. Unlike a probe that relies on rechargeable batteries for power, a laser powered probe can operate indefinitely which translates to a vast improvement in reliability and productivity.

    - Laser safety must be considered whenever products are used that contain high energy lasers. Some markets, such as the European Union, require that international standards be met before laser based products can be sold. While low power class 1 laser products can be easily placed on the market, the high power class 4 lasers used in RF field probes require extreme safety measures to protect the user from laser injury. AR has gone far beyond the required safety requirements and has insured complete safety by implementing the following measures in its line of FL7000 probes.

1. Spring loaded shutters on the fiber optic cables. These shutters close when the fiber is removed from the socket and automatically open when the cable is reinserted. In addition to the obvious high level of safety the shutters afford, they also protect the fiber from dirt and dust which can damage a fiber connection permanently, especially when transmitting high energy laser power.
2. Fiber optic loop back is a fiber cable loop from the FI7000 laser driver to the probe which loops back to the driver. This safety loop includes both the high power send and return fiber connectors. If this loop is broken in any way, the high power laser is switched off immediately.
3. A communication ping is sent from the FI7000 laser driver every 300ms. If the probe does not respond, the high power laser is switched off immediately.
4. A key switch on the front of the FI7000 requires the user to physically turn the key after system power-up to turn the high power laser on. This manual lockout precludes the possibility of an automated process remotely initiating the laser and placing the operator at risk.

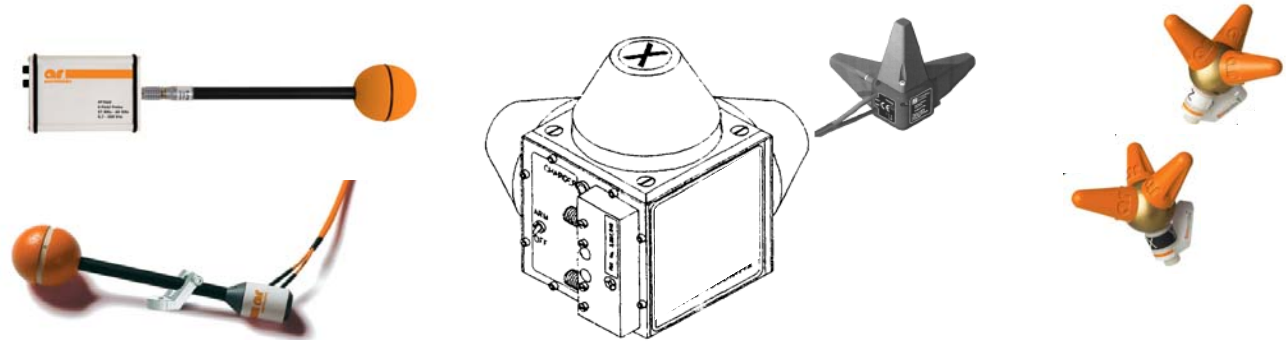
With all of these extraordinary safeguards in place, the AR laser probes have been classified as class 1 laser products, which are considered safe for all users.

Configuration/Dimensions/Weight are very important considerations when matching a probe to a specific application. In general, there are three different probe configurations to choose from. In addition to the ubiquitous stalk and cube type probes, one can now choose one of the newer, recently introduced sphere probe configurations. (See figure 3). Some applications require a small probe to fit inside small areas like TEM Cells, striplines, tri-plates, GTEMs or small enclosures where larger probes simply can not be used. This is not the only aspect of size to consider since the RF probe itself does have an adverse effect on the RF field it is trying to measure, and in general, smaller probes will distort the RF field to a lesser extent.

- Stalk probes separate the RF sensors from the reflective electronic housing via a stalk. Moving the electronic housing away from the sensors improves the performance of the probe. The housing is made as small as possible to minimize the effect on the RF field measurements. While the stalk probe is a very good approach, the overall physical size resulting from the use of the stalk precludes its use in applications requiring a smaller probe.

- Cube probes place the electronics between the isotropic RF sensors. This solves the size problem of the relatively large stalk probe which may be too large for some applications. Cube probes come in various sizes. In general, the smaller the better since a small probe has less effect on the RF field resulting in improved performance.

- Sphere Probes improve on cube probes by housing the electronics in a small sphere that inherently has less of an effect on the RF field. In addition, the minimal field distortion is not position dependent since there are no flat probe surfaces to contend with making probe orientation having little to no effect on the reading. The result is that a spherical probe yields a flatter frequency and isotropic response than the other probe configurations.



Stalk Probes Cube Probes Sphere Probes (Starprobe™)

Figure 3: Different Probe Configurations

User Interface – There are a few choices available for interfacing with RF field probes. One can use a field monitor in a manual mode of operation, bypass the field monitor and connect probes directly to a computer, or for maximum versatility, use a field monitor in a system configuration to achieve both manual and automated testing.

The field monitor approach provides the most versatility since it allows for both manual and automated operation. While many tests will eventually run in an automated fashion, the ability to operate manually can be extremely useful when initially setting up the test and in the event of a system malfunction. A manual mode also allows for the occasional unique test that is not covered by the system software and when it is expedient to simply do a quick spot check rather than reconfiguring the system to look at a suspect frequency. The system software can also interface with the RF monitor providing complete flexibility as well of offering more interface options.

When RF testing is intended to be totally automated, RF field probes can be connected directly to a computer via one of many interfaces. Most battery operated probes use a small fiber optic to RS-232 adapter, while the newer laser power probes offer a variety of computer interfaces including GPIB (IEEE-488), USB, RS-232 and Fiber-optic Serial. This approach requires field monitoring software usually supplied by the probe manufacturer, a third party software vendor, or user created custom software.

In either case, the monitor and software need to be user friendly and intuitive to use.

AR's Probe Solution

AR worldwide has developed a comprehensive family of RF field probes that utilize the latest technologies in order to provide an incredibly durable and accurate device that the industry has been in need of for years. The following lists some of the key features that set AR probes apart:

AR's Starprobe™ FL7000 series

- Laser powered so there is absolutely no concern of ever running out of battery power in the middle of that all important test
- Small size permits the use of these probes in small spaces like TEM cells and the reduced size is less disruptive to the RF field

- Spherical housing yields a uniform interaction with the RF field resulting in an improvement in the isotropic response
- User friendly interfaces with the FM7004 field monitor and/or VM7000 virtual monitor software
- Four levels of unequaled laser safety in order to meet laser safety regulations and fully protect the user from injury
- Rugged design to withstand the rigors of the typical EMC test facility
- Multiple computer interface options: USB, IEEE-488 (GPIB), RS-232 (serial), Fiber-Optic Serial
- Automatic Temperature compensation

AR's Battery Power Probes FP7000 & FH7000 series
- User changeable batteries
- Standard size type AA rechargeable batteries
- User friendly interfaces with the FM7004 field monitor and VM7000 virtual monitor software
- Rugged design to withstand the rigors of the typical EMC test facility

AR's Field Monitor FM7004
- Simplified, user friendly interface
- Many control options: USB, IEEE-488 (GPIB), Ethernet, RS-232 (serial)
- Durable, long lasting color screen will not fade or burnout
- Max/min function readings
- Rugged design to withstand the rigors of the typical EMC test facility
- No need to zero probes before use since this function is automatically performed by each probe

AR's Virtual Monitor Software VM7000
- Intuitive, user friendly interface
- Provides readings from field probes directly through an RS-232 to fiber optic converter (IF7000, FL7000 series does not need the serial converter) or through the FM7004

AR RF/Microwave Instrumentation's most complete line of RF probes

Model #	Power	Type	Frequency Response		Sensitivity	Linearity	Overload Level	Data Return	Acc Grp
FL7030	Laser FI7000	Isotropic diode E-field	5kHz-30MHz	±2.0 dB	1.5V/m-300V/m	±0.5dB ±0.9V/m	1000V/m CW and 10,000 V/m peak	X,Y,Z, & Composite	1
FL7006	Laser FI7000	Isotropic diode E-field	100kHz-6GHz	±2.0 dB	0.5V/m-800V/m	±0.5dB ±0.3V/m	1000V/m CW and 10,000 V/m peak	X,Y,Z, & Composite	1
FL7018	Laser FI7000	Isotropic diode E-field	3MHz-18GHz	±1.8 dB	1V/m-1000V/ m	±0.5dB ±0.3V/m	1600 V/m CW and 16,000 V/m peak	X,Y,Z, & Composite	1
FP7003	2-AA NiMH Batteries Rechargeable	Isotropic diode E-field	100kHz-3GHz	±1.4 dB	0.4V/m-660V/m	±3 dB (0.4–1.25 V/m) ± 1 dB (1.25–2.5 V/m) ± 0.5 dB (2.5–400 V/m) ± 0.7 dB (400–800 V/m)	1600 V/m CW and 16,000 V/m peak	X,Y,Z, & Composite	2
FP7018	2-AA NiMH Batteries Rechargeable	Isotropic diode E-field	3MHz-18GHz	±1.8 dB	0.6V/m-1000V/m	± 3 dB (0.6–1.65 V/m) ± 1 dB (1.65–3.3 V/m) ± 0.5 dB (3.3–300 V/m) ± 0.7 dB (300–1000V/m)	1600 V/m CW and 16,000 V/m peak	X,Y,Z, & Composite	2
FP7050	2-AA NiMH Batteries Rechargeable	Isotropic Thermo-couple E-field	300MHz-50GHz		8V/m-614V/m	+ 0.5dB (39 to 614 V/m)	1500 V/m CW and 27.5K V pulse	Composite	2
FP7060	2-AA NiMH Batteries Rechargeable	Isotropic diode E-field	27MHz-60GHz	±1.0 dB	0.7V/m -300V/m	+ 2/-3 dB (1.0–2.0 V/m) ± 1 dB (2–250 V/m)	1600 V/m CW and 16,000 V/m peak	Composite	2
FH7103	2-AA NiMH Batteries Rechargeable	Isotropic diode H-field	300kHz-30MHz	±0.5 dB	0.012A/m -17A/m	± 3 dB (0.0017–0.033 A/m) ± 1 dB (0.033–0.066 A/m) ± 0.5 dB (0.066–3 A/m) ± 1 dB (3–17 A/m)	> 35 A/m, CW, 350 A/m pulse	Composite	2
FH7110	2-AA NiMH Batteries Rechargeable	Isotropic diode H-field	27MHz-1GHz	±1.2 dB	0.025A/m -16A/m	± 3 dB (0.025–0.05 A/m) ± 1 dB (0.05–0.1 A/m) ± 0.5 dB (0.1–3 A/m) ± 1 dB (3–16 A/m)	20 A/m CW, 200 A/m pulse	Composite	2

Accessory groups (Acc Grp) – the following accessories match up to the listed probes

1. FI7000 (Laser-driver), FM7004 (field monitor), VM7000 (virtual monitor software), FC7000 series (fiber cables), MA7000 (mating adaptor for FC7000 series), PS2000 (probe stand), and BC2000 (probe clamp for PS2000)

2. FM7004 (field monitor), VM7000 (virtual monitor software), FC2000 series (fiber cables), FT2000 (bulkhead feed through for FC2000 series), BC7000 (extra battery charger), PS2000 (probe stand), and BC2000 (probe clamp for PS2000)