Selecting antenna/power amplifier combinations for the coming new RF immunity standards

Though far from certain, it looks as if 6 GHz is a strong candidate for the upper frequency for consumer products.

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TESTING PRODUCTS FOR SUSCEPTIBILity to radiated fields above 1 GHz is on the horizon. The new medical standard now stipulates testing to 2.5 GHz, and this upper frequency may be adopted in the coming standard for fire detection products. Though far from certain, it looks as if 6 GHz is a strong candidate for the upper frequency for consumer products. When test facilities test products for compliance to these new RF immunity standards, which antenna/amplifier combination will prove the most effective at producing the necessary volts per meter over the new band? What is the cost-benefit trade-off? This article presents practical combinations using existing technology and highlights the inevitable trade-offs faced during the selection process.

Antennas and power amplifiers of various frequency bands and power capabilities are readily available within the EMC marketplace. Ideally, you would simply select an antenna covering 1 GHz to 6 GHz, combine it with a power amplifier covering 1 GHz to 6 GHz, and 'hey presto', you have the solution. Life, as we all know, is never that simple. Antennas covering this frequency band (and wider) that can handle the necessary input power are indeed available from many excellent manufacturers. In fact, antennas covering 25 MHz to 7 GHz exist, possibly allowing coverage of the old and new frequency in an uninterrupted sweep. Unfortunately, a power amplifier covering 1 GHz to 6 GHz and capable of delivering the necessary power level does not exist. The band will need to be covered by at least two amplifiers so that a switch is required to connect the antenna to the appropriate amplifier during the immunity test. Or, if preferable, two amplifiers and two antennas could be used. Clearly, the scene is set for the evaluation of a selection of mix-and-match permutations.

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FIRST CONSIDERATIONS

RF immunity testing is done under the control of an automatic test system (ATE). A button is pressed, and the product is subjected to a specific RF field strength (say 10 volts per meter) for a fixed dwell time and over a series of predetermined spot frequencies. The ATE software program steps the system through the frequencies, and the product is monitored for susceptibility to the applied RF field. Figure 1 shows the antenna/amplifier combination used to generate the necessary RF field. Also shown at a fixed distance from the antenna is the imaginary measurement plane. The field strength is measured at points across a section of this plane as part of the system calibration.

The selection of suitable antenna/amplifier combinations is part of the ATE design

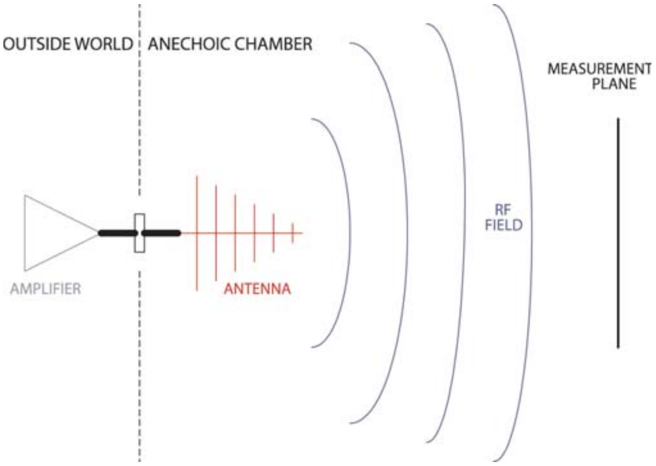

Figure 1. *RF field generation.*

process. The steps in this process are:

1. Establish what is required of this part of the ATE system
2. Identify possible solutions
3. Assess and compare the solutions
4. Select the best solution

Any impact on the time taken to complete the testing of the product is important, and the solution should represent good value in terms of performance, reliability, and cost.

THE REQUIREMENTS

The fundamental requirement is that the antenna/amplifier combination generates the necessary RF field strength over the specified frequency range. A field strength of 10 V/m at a distance of 1 meter will be used in this example. (The exercise can be repeated for different field strengths and distances as required). Sufficient power margin must be built in to cover:

- System losses

  These include dissipative (heat) loss in the cable feed to the antenna, dissipative loss in the antenna itself, and any power reflected back by the antenna. These losses affect the net power utilized by the antenna to generate the RF field.
- Modulation of the RF signal

  The test signal is amplitude modulated at 1 kHz to a depth of 80%. This modulation results in signal peaks that require 3.3 times more power than the un-modulated signal. Also, waveform integrity must be maintained as flattened waveform peaks caused by amplifier compression could cast doubt on the validity of the test. In the frequency domain, flattened peaks will show up as harmonic noise. Note: the upcoming standard is likely to stipulate 'modulation on' at the calibration stage.
- Field variation

  An allowance must be made for field variation at different points on the calibration measurement plane caused by the peculiarities of the chamber, *e.g.*, inconsistent damping of reflected signals and the effect of locating the antenna in close proximity to the chamber walls.

There is a size constraint on the antenna since it must fit within an allotted space in the chamber if the product is to be positioned at the prescribed distance from the antenna. Fortunately, at frequencies above 1 GHz, antenna dimensions are small compared to Sub-1-GHz broadband antennas so this should be a non-issue.

POSSIBLE SOLUTIONS—ANTENNAS

For the 1-GHz to 6-GHz frequency range, the main antenna options are microwave horn and log periodic since they exhibit excellent performance over this band and are physically small. The parameters of interest are input VSWR, radiation pattern, power handling capability, and the input power required to generate 10 V/m at 1 meter. The required input power provides the most useful information in terms of assessing suitability so this data will be utilized most frequently, and the other data will be used to confirm the selection.

Figure 2 shows samples of each type of antenna. For this exercise, the microwave horn (SAS-571) will be compared with log periodic antenna model (SAS-510-7). The dimensions (L ´ W ´ H) of the microwave horn are 8.2 ´ 5.6 ´ 9.5 inches and the dimensions (L ´ W) for the log periodic are 24.9 ´ 20.1 inches.

Table 1 and Table 2 show the power budget for each antenna. The figures in the "Watts Required" column are actual measured data of the power required at the antenna connector to generate 10 V/m at 1 meter. Parameters such as power reflected back from the antenna and antenna dissipation are already factored in. The cable loss is for nine-feet cable length and uses manufacturers' data readily available on the Web. Notice that cable loss increases with frequency. The "Peak Modulation Power" is calculated by multiplying by 3.3 (adding 5.2 dB). The "Total Power Required" adds 3 dB (doubles the power) to allow for field variation. The figures have been rounded where appropriate. The microwave horn can handle 300 watts input power, and the log periodic can handle 1000 watts so the power levels shown

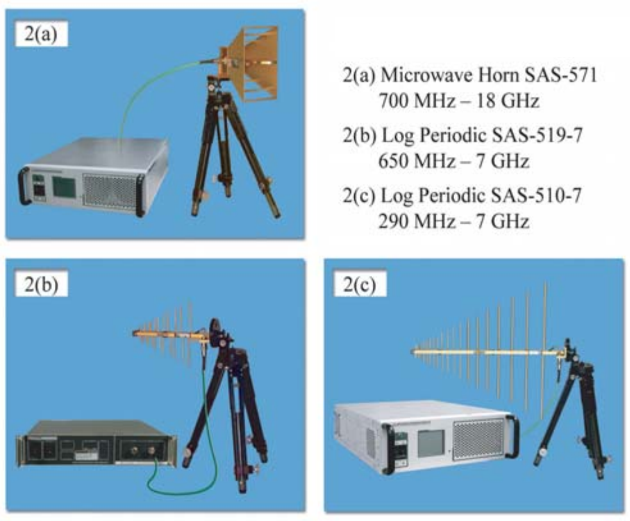

Figure 2. *Antenna types.*

Frequency	Watts Required	Cable Loss	Power with Cable Loss (W)	Peak Modulation Power (W)	Total Power Required (W)
1000 MHz	0.7	1.0 dB	0.88	2.9	5.8
1500 MHz	0.4	1.15 dB	0.52	1.7	3.4
2000 MHz	0.6	1.3 dB	0.81	2.7	5.4
2500 MHz	0.5	1.45 dB	0.70	2.3	4.6
3000 MHz	0.4	1.6 dB	0.58	1.9	3.8
3500 MHz	0.3	1.75 dB	0.45	1.5	3.0
4000 MHz	0.4	1.9 dB	0.62	2.0	4.0
4500 MHz	0.3	2.05 dB	0.48	1.6	3.2
5000 MHz	0.4	2.2 dB	0.66	2.2	2.4
5500 MHz	0.4	2.35 dB	0.69	2.3	4.6
6000 MHz	0.4	2.5 dB	0.71	2.3	4.6

Table 1. *Microwave horn SAS-571, total required power for 10 V/m at 1 meter.*

Frequency	Watts Required	Cable Loss	Power with Cable Loss (W)	Peak Modulation Power (W)	Total Power Required (W)
1000 MHz	0.8	1.0 dB	1.0	3.3	6.6
1500 MHz	1.0	1.15 dB	1.3	4.3	8.6
2000 MHz	0.7	1.3 dB	0.94	3.1	6.2
2500 MHz	0.7	1.45 dB	0.98	3.2	6.4
3000 MHz	0.8	1.6 dB	1.15	3.8	7.6
3500 MHz	0.8	1.75 dB	1.19	3.9	7.8
4000 MHz	0.8	1.9 dB	1.23	4.0	8.0
4500 MHz	0.8	2.05 dB	1.27	4.2	8.4
5000 MHz	0.8	2.2 dB	1.32	4.4	8.8
5500 MHz	0.7	2.35 dB	1.76	5.8	11.6
6000 MHz	1.1	2.5 dB	1.95	6.4	12.8

Table 2. *Log periodic SAS-510-7, total required power for 10 V/m at 1 meter.*

are well within the capability of the antennas. The dimensions of both antenna types are small so interaction with the chamber will be minimal.

POSSIBLE SOLUTIONS—AMPLIFIERS

The amplifier options are solid-state (GaAsFET) and traveling wave tube (TWT). Today, solid-state is the preferred technology up to 4 GHz, but it still has a long way to go to beat the price/performance capability of high-power octave band TWT amplifiers above 4 GHz. An octave represents a doubling of the frequency. The 4-GHz to 6-GHz power modules in the dual-band solid-state amplifiers referred to in this exercise are half an octave.

Three amplifier frequency band permutations that cover or exceed the 1- to 6-GHz requirement are shown in Figure 3. Option A and Option C are all solid-state. Option B uses solid-state and TWT technologies.

The power budget tables show that the necessary linear power is 5.8 watts for the microwave horn and 12.8 watts for the log periodic antenna. Linear power is required to prevent distortion of the modulated waveform. For the purposes of this exercise, Option A (all solid-state) will be combined with the microwave horn and Option B (solid-state/TWT) will be combined with the log periodic antenna. Rules of thumb for linear versus saturated power require backing off 1 dB from saturated for GaAsFET amplifiers and 3 dB for TWT amplifiers. This adjustment equates to 7.3-W saturated power for Option A and 16.2-W/25.6-W saturated power for the Option B solid-state/TWTA combination.

Band-switching is needed irrespective of which option is decided upon. The next section discusses how this is implemented.

BAND-SWITCHING

There are two basic approaches to switching the feed to the antenna. The first is through an external band-switch box as shown in Figure 4. External cables are used to connect the amplifiers to the band-switch box. With both relays in the position shown (normal), Band 1 feeds the antenna. With both relays operated, Band 2 feeds the antenna.

The second approach is for the amplifier manufacturer to put both amplifiers in one chassis and switch the bands internally. A schematic of this method is shown in Figure 5. The principle of operation is the same, but there are major space and cost savings since many of the key components are shared. These include the power supply, the cooling system, control circuits, and of course, the chassis itself.

Sharing components is possible since only one amplifier is running at a time. Therefore only one power supply is needed, and the cooling components need to dissipate the heat from only one amplifier. Also, the internal RF cable

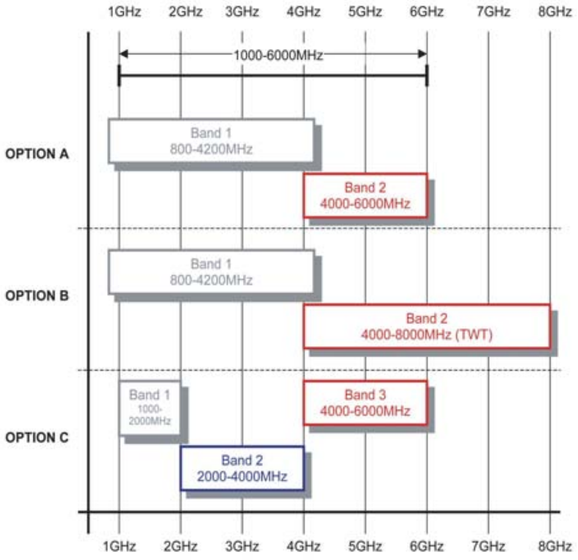

Figure 3*. Amplifier frequency band permutations.*

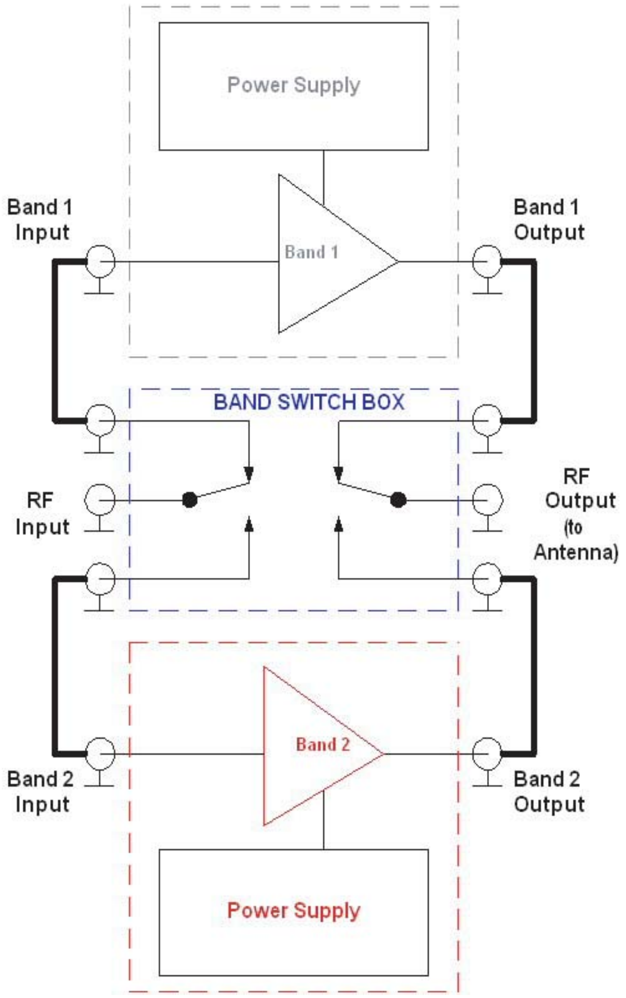

Figure 4. *External band-switching.*

runs can be shorter (compared to externally run cables) resulting in reduced cable loss. As the power budget tables indicate, cable loss can be significant, especially at 6 GHz. Once the main chassis design of a dual-band product is complete, it is relatively easy to substitute RF modules with different frequency bands and/or power levels. Unfortunately, this shared component approach cannot be used with solid-state/TWT combinations since the power supplies and cooling arrangements are radically different.

The ATE software provides the switching signal at the appropriate place in the test run. The time for the relays to switch is about one-tenth of a second so the impact on the overall test time is negligible. In fact, for RF Immunity applications, a single-band solution requiring no switching is a feature with little benefit and can actually be detrimental to the harmonic noise performance of the system.

Cold-switching should be employed with both band-switching methods. That is, the switching sequence should be:

1. Remove the RF input signal
2. Switch over the band
3. Apply the RF input signal.

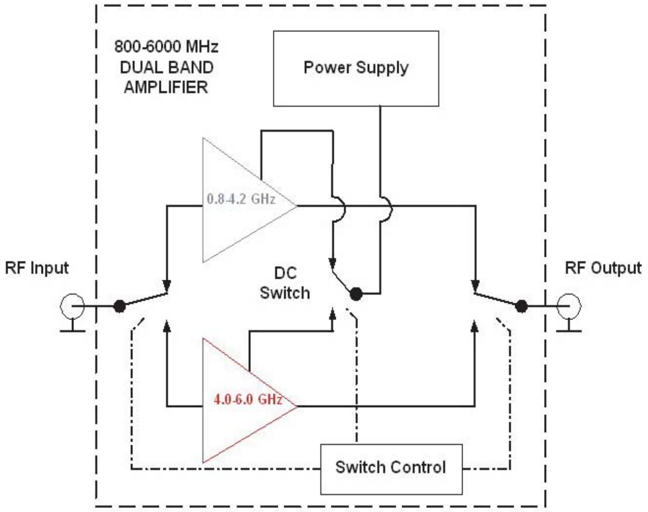

Figure 5. *Internal band-switching.*

Alternatively, cold-switching circuits that disable the power supply during relay switchover can be implemented easily with internally switched amplifiers. This feature is included in the dual-band amplifiers described in this article. RF relays suitable for band-switching are available on the open market with a loss of less than 0.1 dB at 6 GHz so the insertion loss of the relays has not been factored into the calculations here.

COPING WITH REFLECTED POWER

The system losses included in the power calculations reduce the amount of reflected power the amplifier has to handle. The factors reducing the reflected power seen by the amplifier are:

1. The power leaving the amplifier is attenuated by the cable loss in the forward direction and is attenuated again in the reverse direction. At 1 GHz, these losses represent at least 2 dB total path loss in the cable alone. At 6 GHz, the return path loss is 5 dB.
2. The antenna does not transmit a pencil beam (unlike a laser). Instead, the beam spreads and bathes the measurement plane calibration area and its surroundings. Even with the device under test in place, the absorptive tiles on the walls of the chamber absorb much of the forward power; and because of the angle of reflection, much of the reflected power from the device under test as well. Even in the worst case of high reflection from the device under test, only a small part of the forward power is returned via the antenna.

The TWTA is operating in a backed-off condition and is delivering a fraction of its forward power capability. This condition, together with the system losses described above, means that the ratio of reflected power to forward power capability is small. Also, GaAsFET amplifiers use an internal power combining method that safely deflects reflected power away from the output transistors. Collectively, these factors indicate that reflected power via the antenna is not a crucial issue.

SUITABLE AMPLIFIER MODELS

The Option A power requirement can be met by a dual-band internally switched 0.8- to 6.0-GHz power amplifier such as the BBS3Q9ACD. This contains a 0.8- to 4.2-GHz 15 watt amplifier and a 4.0- to 6.0-GHz 10-watt amplifier providing 12 watts and 8 watts of linear power, respectively. Model BBS3Q9ACD is shown in Figure 2(a).

The Option B power requirement can be met with models BBS3Q7EEL a 0.8- to 4.2-GHz 25 W GaAsFET amplifier, and model TWTA-7A8GFE, a 4.0- to 8.0-GHz 30 watt TWT amplifier. These provide 20 watts and 15 watts (over 4.2 to 6.0 GHz) of linear power, respectively. TWTA amplifiers produce significantly more power away from the band edges so 15 watts of linear power is conservative at 6.0 GHz. External band switching using a band-switch box is suitable for this option. Model TWTA-7A8GFE is shown in Figure 2(b).

So far, both antenna/amplifier combinations appear well suited for generating the necessary field strength for the upcoming standard, with Option A seemingly providing the best value. However, there is a major consideration that needs to be factored into the selection criteria—integration with the existing test setup.

INTEGRATION WITH THE EXISTING TEST SETUP

If the sub-1-GHz test procedure and the above-1-GHz test procedure are performed as separate events, then it is merely a matter of manually replacing one test set-up with the other. Under these circumstances, the microwave horn antenna/dual-band amplifier combination is a good match. If the intention is to integrate the two tests and, if possible, share test components, then other solutions need to be considered.

These include:

- Using a single antenna for the entire frequency sweep.
- Mounting antennas side by side.
- Manually substituting another antenna part way through the sweep, but capitalizing on the available antenna characteristics to optimize the system performance.

Note: converting the test chamber to make it suitable for above-1-GHz testing is beyond the scope of this article.

SINGLE ANTENNA COVERING THE EXISTING AND NEW FREQUENCY BANDS.

In 1994, the University of York and Chase EMC collaborated on a hybrid biconical/log periodic antenna intended for use in broadband emissions testing. The antenna exhibited poor performance below 100 MHz, but this problem was corrected relatively inexpensively by boosting the signal from the antenna with a low power amplifier. Also, the poor match into 50 ohms at low frequencies was corrected by inserting an in-line attenuator. Never intended for RF immunity testing, the antenna would need a very expensive high-power amplifier to generate RF immunity fields below 100 MHz. As regards immunity testing, a biconical antenna is far superior below 100 MHz needing only around 70 watts of RF input power to produce 10 V/m at one meter. The hybrid antenna would need around 900 watts to produce the same field.

More recent attempts to create a single antenna to monitor RF emissions below 80 MHz and up to several GHz are unwieldy in size (of the order of ten feet across and six feet long) and have a poor match into 50 ohms at the lower band edge. The size means there is a risk of interaction with the chamber and with the device under test (except in the largest of chambers), and the poor match of up to 10:1 VSWR below 80 MHz means high power is required to generate the required field strengths. Using one of these antennas for field generation makes for an expensive antenna/amplifier combination as compared to using a biconical antenna covering 20 MHz to 300 MHz (Model SAS-543) followed by a log periodic antenna covering 290 MHz to 7 GHz (Model SAS-510-7). Also, antennas designed for frequencies above 1 GHz are comparatively small, and it would be a shame to lose this valuable feature. Very large ultra-broadband antennas are intended for use in open area test sites, and that is where they should stay.

MOUNTING ANTENNAS SIDE BY SIDE

Antennas covering different bands can be co-located without cross interference occurring. Therefore, it is feasible to place a biconical antenna next to a log periodic and to switch amplifiers to the antennas at the appropriate time during the test sweep. Mounting the antennas and maneuvering them between vertical and horizontal polarization could prove a challenge; but as long as each antenna adequately illuminates the calibration plane, there is no fundamental reason this approach cannot be used. As with all the approaches mentioned in this article, the feed to the high-frequency antenna should be as short as possible. Most amplifiers are available with remote control and monitoring facilities, and there is no written rule that the high-frequency amplifier cannot be mounted up close to the chamber to minimize cable length. A schematic of the switching arrangement is shown in Figure 6.

MANUAL SUBSTITUTION PART WAY THROUGH THE SWEEP

With this approach, the biconical antenna is used from 20 MHz to 300 MHz and is then manually substituted for the log periodic to complete the rest of the test from 300 MHz to 6 GHz. The 20- to 1000-MHz amplifier feeds both antennas up to 1000 MHz, and then the 1- to 6-GHz dual-band amplifier feeds the log periodic antenna up to 6 GHz. This method has the disadvantage of a break in the test run. The break should be kept in context. Only one component is changed in the test setup, and this adjustment takes a fraction of the time necessary to tear down and to install a completely new test setup. The automatic switching of the amplifiers to the antenna feed is retained.

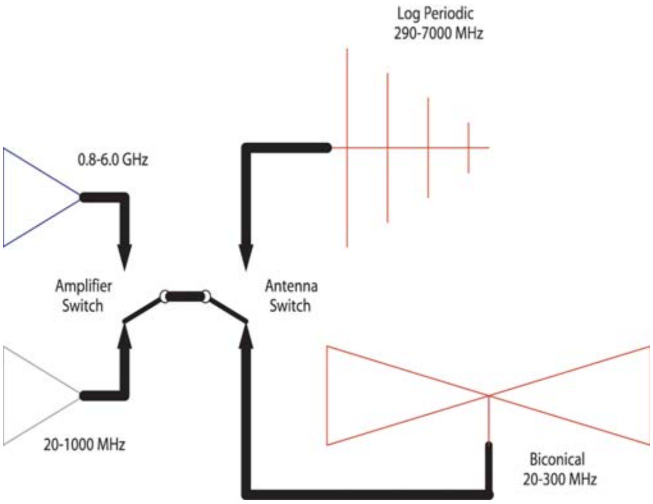

***Figure 6**. Side-by-side antenna switching.*

A FURTHER RAMIFICATION OF THE NEW STANDARD

There is a high probability that the new standard will require modulation to be applied during calibration. For the old test standard, many test houses were sold antenna/amplifier combinations that included a 30-watt amplifier and a log periodic antenna. A 30-watt amplifier will produce a guaranteed minimum linear power of about 20 watts. At 80 MHz, log periodic antennas require about 5 watts to produce 10 V/m at 1 meter. Multiply this power by the modulation factor of 3.3, then add the allowances for system losses and chamber peculiarities, and the performance of this antenna/amplifier combination may prove to be marginal at best for this field strength and distance. As shown, it does not take "rocket science" to determine field strength and design within a sensible margin. It is never wise to accept and to pay for goods blindly, and 'one size fits all' with no guaranteed margin could be construed as a prime example of this folly.

CONCLUSION

The anticipated RF immunity standard brings challenges and opportunities. Although somewhat dependent upon the existing test setup, there are many approaches to upgrading a test facility in readiness for the new standard. This article lists pragmatic guidelines allowing independent determination of how to meet the new requirement. This independence may help test houses disregard marketing ploys that try to convince buyers that there is only one viable solution.

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