Application Note #38A
Automotive 600V/m Radar Pulse Test Solution

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There are many hazardous electrical events in the environment that can have adverse effects on the systems of a vehicle, causing potentially unsafe situations. These events can be generated by "off-vehicle" as well as "on-vehicle" sources and can either be natural or man-made. To protect against these events automobile manufacturers have developed ElectroMagnetic Compatibility (EMC) standards to test electronic components and whole vehicles. One known manmade event is the Radar Pulse used by military and airports to track aircraft. This high intensity RF field is directed up into the sky but sometimes can be detected on the surface where it could possibly affect the electronics of an automobile.

Test Specifications

Both General Motors (GM) and Ford auto manufacturers have developed test specifications to test automobile components against the Radar Pulse. Both specs are not identical but they are very similar.

Manufacturer Spec	Band	Frequency	Field Level		Pulse modulation
GM GMW3097		1.2 – 1.4 GHz		600V/m	300Hz Pulse Repetition Rate (PRR)
FORD	6	1.2 – 1.4 GHz	300V/m[1]	600V/m[2]	3µs Pulse Duration (PD)[3]
ES-XW7T-1A278-AC	7	2.7 – 3.1 GHz			Dwell time 1 sec

1 Level for most electronic equipment
2 Level for selected components associated with supplemental restraints including frontal crash
3 6µs Pulse duration used when testing in a Reverberation Chamber

Table 1: Test Level for Radar Pulse

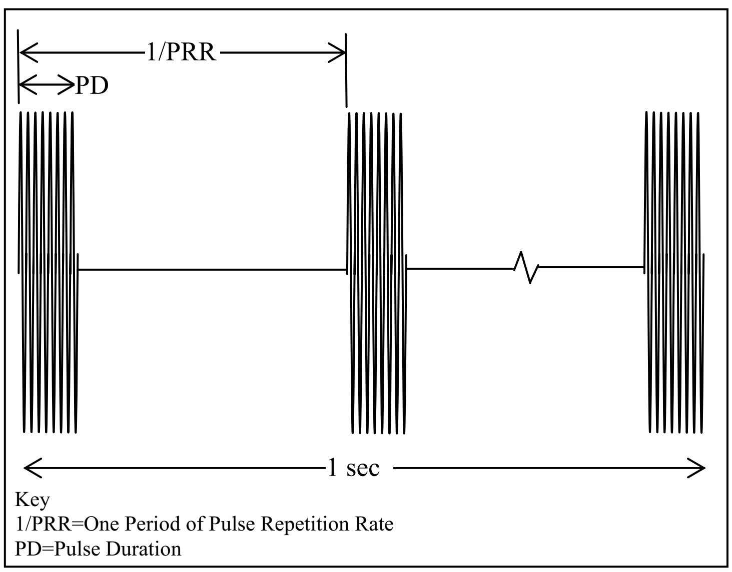

Figure 1: Automotive high field strength RF pulse timing diagram

This test can be performed either in an Absorber Lined Shielded Enclosure (ALSE) or a Mode tuned Reverberation chamber. In this Application Note, we will mainly focus on the ALSE method.

Recently, Ford Motor Company has issued a specification change testing the 2 frequency bands listed in table 1. This application note will be based on the Ford update of January 30^{th} 2006.

Basic changes from original ES-XW7T-1A278-AC standard

- New 300 V/m level for most electronics the FMC EMC department will make the decision if 600 V/m is applicable for your component. This will be checked when the test plan is submission.
- New continuous pulsed field (no more 50 pulse bursts per second)
- New 1 second dwell time
- Changes to ALSE method
  - No ground plane used
  - New dielectric table requirement (wood is not acceptable)
  - New 1000 mm table top height
  - Field MUST be calibrated at peak signal levels
  - Changes to RF field probe calibration method
    - Calibration with a Continuous Wave (CW) amplifier only
    - Probe must be calibrated at 2 frequency points by a calibration lab.
    - Probe has special positioning constraints that allow the user to read only the probe axis that is parallel to the RF field.
  - Added receiving antenna and spectrum analyzer calibration method
    - Calibrate with either CW or Pulsed amplifier
- No changes to reverberation setup

Note: GM has stated that with their up-coming specification release/update they will follow Ford's new test setup requirements. They are **not** planning to lower the requirements to 300 V/m as Ford has done. Please refer to the appropriate standards for clarification.

Reasons for Change

It has been found that vastly different results have been submitted from different test labs while all were found to be following correct testing practices. Error at this high a test field (600 V/m) can have a large affect on the actual fields. An error of 2 dB could change the actual fields by hundreds of V/m. In order to reduce error Ford has streamlined the test setup also.

The largest change to the setup was the removal of the ground plane. This removed any reflection off the surface and from grounding connections/straps, which improves the uniformity of the field. Any and all reflection can change the results so therefore measures should be taken to remove all reflecting materials that are not required. Since the ground plane is not required the test table becomes a larger factor in the test. This is why Ford is now requiring a low dielectric material. It is becoming a more of a requirement in the Radiated Immunity testing world where wood tables can no longer be used for testing above 1 GHz. Wood does contain some amount of moisture and will not be 100% permeable to microwaves. A suggested material would be rigid polystyrene.

There are now two ways that field calibrations can be performed, ether with an RF field probe or with a receiving antenna and spectrum analyzer. Due to the limitations of diode type RF field probes, a pulsed field can not be measured accurately so only CW signals can be calibrated. Another economical solution to perform this test is to use a pulsed amplifier. But this can not be calibrated with a common diode RF probe. To use a pulsed amplifier a receiving antenna and spectrum analyzer will be needed, it has the ability to respond to the fast pulses of the radar pulse. Limitations of each device need to be taken into account to minimize error.

The new field probe calibration and positioning requirements are a major change in this update. When the field probe is sent out for calibration, 2 specific frequencies 1.3 and 2.9 GHz are required to have calibration factors and will be needed for each associated frequency band. The probe will have to be positioned so that the probes axis line up parallel with the field. This means for vertical field calibration the z axis of the probe needs to be positioned vertically and for horizontal field calibration the x axis of the probe is positioned horizontal (probe is positioned once so both axis are aligned at the same time). A positioning jig might be a good idea so the probe is positioned correctly each time a calibration is run.

The use of a receiving antenna is now allowed since the removal of the ground plane. The proximity to the ground plane would have affected the antenna's readings. The positioning and polarization of the antenna needs to be carefully aligned. Making a jig to help position the antenna correctly on the table top would be a good idea to help with repeatability. Ford does call out specific receiving antennas to be used in order to keep the antennas similar in size and have a minimal effect on the field. These antennas are very common and most labs will have them already in their inventory.

One of the problems associated with this test is the equipment needed to create such a large RF field. The specification states that the calibration is to be performed at full or peak signal strength in order to eliminate any non-linearity issues with setup or antenna. Ford believes that when using such high field strengths, VSWR of the antenna may increase as the power increases. This would result in the output field from the antenna not being linear with respect to input. AR RF/Microwave Instrumentation does not feel this to be true; if an antenna is correctly specified there should be no change in VSWR over the power range.

The Solution

To determine type and size of the equipment needed for the antenna and amplifier, it is best to start with the selection of the antenna. You will want to choose an antenna with a narrow beam width and high RF compression characteristic, in the different frequency ranges in question. This is key in determining the size of the RF amplifier that is needed. Amplifier requirements for 600 V/m can range from 500 Watts to 1000 Watts. The next issue that will affect the size of the amplifier is the effects of the room and test setup. With the update it is now easier to predict the power needs for this test, but with a quick experiment a test lab can estimate the required power with confidence. This will be useful for an EMC lab that already has some capability in these frequency ranges but just don't have the required power.

1) Setup the test as per the standard with the intended antenna, cabling, and field measurement selection (Receiving antenna or field probe). The only difference will be the lower powered amplifier. Perform a calibration but at 200 V/m (or a field you have the capability to reach). Perform this calibration for both horizontal and vertical polarization and at each calibration frequency. You should generate tables with frequency and forward power (Watts) levels needed to meet the 200 V/m level.

2) Multiply each of the forward power levels by a factor of 9 (if using the 200 V/m level). The result will give you the minimum power required to reach 600 V/m for each frequency step and polarization. (see Appendix A for derivation of the factor to scale from other field strengths other then 200 V/m)

You can now use this new power level as a guide to select an amplifier. With the new amplifier the calibration now must be rerun at the required level.

If you are having trouble reaching this goal with a reasonable amount of power or would like to try to reduce this power more, here are some helpful test setup hints:

- Reduce the length of cabling from the amplifier to the antenna to reduce any losses
  - May have to physically move the amplifier closer.
- Reduce any adaptors or connectors as much as possible in the cabling
  - These losses always must be kept to a minimum
- Try a different antenna

Remember the key factors that may affect the required power level needed to achieve this test are the test setup and, of course, antenna selection.

Reverberation Chamber

The above method can be applied if testing in a reverberation chamber. The main differences would be that you would use the setup and calibration methods for the Reverberation chamber to find the levels needed for a 200 V/m. Antenna selection will not make much difference since this test is producing a field in a volume and not at a spot. Multiply your found level by a factor of 9 to determine the power needed to reach a 600 V/m field. You can then select the amplifier.

Amplifier Differences

Now that the required amplifier size has been found there are different amplifier technologies that can be selected. Each one will have some advantages and disadvantages.

Traveling Wave Tube Amplifier (TWTA)

TWTAs are an economical solution for high power in the microwave frequency range. They have been until recent years the only solution for such testing. Their unique properties also allow them to be used in a pulsed mode that can lower the total required power reducing cost further. However, TWTAs do produce high harmonics. Some advanced TWTAs combine multiple tubes together to reduce harmonic content. Another easy solution to meet this harmonic requirement is to use filters on the amplifier output. There are always losses associated with filters which must be taken into account for amplifier power requirements.

Pulsed TWTA

Pulsed amplifiers designed for this purpose will not require the "full power" as a CW amplifier since it usually has a max duty cycle of about 4%. So the net output power is only 4% of a CW amplifier. Since these 2 frequency bands are spread apart 2 TWTAs usually are required but due to the properties to our TWT we can cover this with one amplifier.

CW TWTA

CW TWTAs offer a solution for performing this testing and can reach full level in CW not just in pulsed which allows this amplifier to be used for other applications not just pulsed fields. This will also allow the use of the RF field probe for calibration. To cover this range however 2 TWTAs are needed.

Solid-State Amplifier

Solid-State amplifiers are now readily available in the microwave frequency range. Solid-state adds many benefits over TWTAs. They are more modular, not relying on one tube but many transistors. This allows the amplifier to be much more reliable, with a longer life and lower total cost of ownership. There are many performance benefits over TWTAs, such as an excellent harmonic content, wider frequency coverage, and improved output linearity. All of these benefits add up to a much more versatile instrument to meet today and tomorrow's requirements.

Other Non-Compliant Solutions

The use of a pulsed RF Amplifier can be used to achieve this level. Pulsed amplifiers can be a cost effective solution since the same energy is not required as it is to produce a CW signal. The Ford spec does define and allow the calibration of a pulsed amplifier as stated above. Below are some different ways to perform this task.

2 different ways to reach the required level:

1) Perform the calibration at 200 V/m CW, multiply this value by 9 and apply this as your peak forward power to reach 600 V/m. Scaling up the power is not allowed by Ford as described above.
2) Use a thermocouple field probe for calibration which has the ability to read true Root Mean Squared (RMS) levels. This means a 600 V/m pulsed field with a 4% duty cycle will give an RMS reading of 120 V/m ($= 600 * \sqrt{.04}$) with a thermocouple field probe. Due to the dynamic range of the field probe the Radar pulse in these standards are difficult to sense the 0.1% duty cycle to get an output of 19 V/m which is below the thermocouples probes sensitivity. Therefore for calibration you could increase the duty cycle to fit into the dynamic range of the thermocouple probe you are using. This way you would have an isotropic way of reading pulsed fields. This method also relies on the fact the duty cycle is know. The duty cycle should be verified with a spectrum analyzer at the forward power sampling port of the directional coupler.

The 2 methods listed above are acceptable ways of reading and performing pulsed radar field. Keep in mind that they are not accepted by Ford Motor Company EMC.

AR RF/Microwave Instrumentation's Solution

The selections below are broken down into both 300 V/m solutions and 600 V/m solutions. In addition, different antenna selections are also given.

300 V/m

<table>
<tr><th rowspan="2">Frequency range</th><th rowspan="2">Antenna</th><th colspan="3">Amplifier, direction coupler (DC), filter if needed (TF)</th></tr>
<tr><th>Solid State</th><th>TWTA</th><th>Pulsed TWTA</th></tr>
<tr><td>1.2 – 1.4 GHz</td><td rowspan="2">AT4510</td><td rowspan="2">200S1G4A^{+}
DC7144A</td><td>250T1G3
DC7144A
TF1002*</td><td rowspan="2">1000TP1G3
or
750TP1G3/200T
DC7154A
TF1005*</td></tr>
<tr><td>2.7 – 3.1 GHz</td><td>200T2G4
DC7144A
TF1001*</td></tr>
</table>

600 V/m

<table>
<tr><th rowspan="2">Frequency range</th><th rowspan="2">Antenna</th><th colspan="3">Amplifier, direction coupler (DC), filter if needed (TF)</th></tr>
<tr><th>Solid State</th><th>TWTA</th><th>Pulsed TWTA</th></tr>
<tr><td>1.2 – 1.4 GHz</td><td rowspan="2">AT4510</td><td rowspan="2">540S1G4^{+}
DC7164</td><td>500T1G2
DC7128A
TF1002*</td><td rowspan="2">1000TP1G3
or
750TP1G3/200T
DC7154A
TF1005*</td></tr>
<tr><td>2.7 – 3.1 GHz</td><td>300T2G8
DC7280A
TF1001*</td></tr>
</table>

$^{+}$ Please refer to Application Note # 40 Expandable Power, which explains the ability of these amplifiers to be combined to increase power and/or separated to use sections in different locations of the facility.
* RF filters are needed for TWTAs to meet ISO 11452-1 requirement for a better then -6 dBc harmonic content.

CW Calibration:
E-Field Probe that can be used to meet the specification and can read individual Isotropic axis readings:
FP7018/Kit Isotropic "E" Field diode probe, 3 MHz-18 GHz, 0.6-1000 V/m CW
FM7004 Field monitoring kit can except up to 4 probes.
CW or Pulsed calibration:
Use spectrum analyzer and calibrated receive antenna as specified in Ford's update.

AR RF/Microwave Instrumentation also carries accessories for completing the test setup such as directional couplers, cables, and power meters. Please call an applications engineer at 800-933-8181 today to put together a package for you.

Appendix A

Why multiply by 9?

Begin with the standard gain equation:

$$E = \frac{\sqrt{30PG_n}}{D}$$

E = field intensity in V/m,
P = power in watts
G_n = numerical antenna gain.
D = Distance

This equation is then used to express two field strength and power conditions as a ratio:

$$\frac{E_1}{E_2} = \frac{\frac{\sqrt{30P_1G_n}}{D}}{\frac{\sqrt{30P_2G_n}}{D}}$$

Canceling like terms gives:

$$\frac{(E_1)^2}{(E_2)^2} = \frac{P_1}{P_2}$$

Solving for P_2, the power required to achieve 600 V/m:

$$P_2 = \frac{(P_1)(E_2)^2}{(E_1)^2}$$

Substituting known values for E_1 (200 V/m) and E_2 (600 V/m):

$$P_2 = 9P_1$$

If working with different field levels you can substitute these into the equation for E_1 and E_2 to find your unique multiplier.