Practical Radiated RF Immunity System Design Considerations
## Relevant Standards

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Designing a System

- Determining what Power Amplifier to select depends on
  - The test level required by the standard
  - The type of modulation required
  - The antenna efficiency (Gain)
  - The test environment
  - Cable and other component losses
Usable Amplifier Power

• Saturated Power (Psat) Vs Linear Power (P1dB)

• Definitions
  – Psat – Highest power that the amplifier can generate
  – P1dB – Highest power where Pin Vs Pout curve is considered to be straight
Power $\Box$ Voltage$^2$

$1.8^2 = 3.24$
80% AM with Peak Conservation

CW

AM (80%) With Peak Conservation
Effect of Saturation on Modulation

80% AM With Peak Conservation
Pulse Modulation

CW (unmodulated signal) | Pulse Modulation

Period

Pulse Duration
Pulse Modulation

CW (unmodulated signal)

100% Amplitude Modulation

Period

Pulse Duration
Effect of Saturation on Modulation

O/P Modulation Matches the Input
Harmonics

- Unwanted signals produced at multiples of the required fundamental frequency
- Specified as dBc
  - Difference (in dB) between the level of the harmonic and the level of the intended signal or ‘Carrier’.
What Happens to the Harmonics at and above P1dB
Output Power vs. Input Power

- 1dB Compressed
- Amplifier Starts to Compress

Graph showing the relationship between output power and input power with two curves indicating 1dB compression and 0dB compression.
**Output Power**

- **2dB Compressed**
- **1dB Compressed**

**Amplifier Starts to Compress**

**Graph:**
- **Time:** 0 to 4
- **Signal:**
  - 0 dB compression
  - 2 dB compression

**Axes:**
- **Output Power** vs. **Input Power**
Maximum Compression (Saturated)

2 dB Compressed

1 dB Compressed

Amplifier Starts to Compress

Output Power

Input Power

0 dB compression

6 dB compression

0 1 2 3 4
time

-1 -0.5 0 0.5 1

0 dB compression

6 dB compression
Harmonics of a Square Wave

- Relative Level
- Harmonic Number

Bar chart showing the relative level of harmonics for a square wave, with harmonic numbers from 1 to 13.
Radiated Immunity

- Power required depends on the test level and the selected antenna
  - Trade of between efficiency and size at low frequency
  - Larger antenna are more efficient, if they will fit in the chamber
Basic Radiated Field/Power Calculation

Power required to generate a field of $E$ V/m at a distance $d$ metres from the antenna

$$\text{Power (watts)} = \frac{(E^2 \cdot d^2)}{(30 \cdot g)}$$

$g = 10^{(G/10)}$ \quad \{g = \text{ratio gain, } G = \text{gain (dBi)} \}$
Additional Factors to Consider

- Antenna gain varies with the separation distance between the antenna and the measuring device.
- Close to the antenna the presence of the antenna itself effects the parameters of the environment.
- Some antenna suppliers show gain figures at various distances:
  - Always use the correct values if available or make allowance if not.
  - Around 3dB gain reduction between 3 and 1 metre values is typical.
Loss in Cables and components

- Typical example

Test Rack to Antenna
- 1.5m rack to penetration (Loss 0.25 dB @ 1GHz)
- 5m penetration to floor panel (underfloor cable) (Loss 0.8 dB @ 1GHz)
- 3m floor panel to antenna (Loss 0.5 dB @ 1GHz)

Internal to rack
- 0.4m RF switch output – rack bulkhead (Loss 0.1 dB @ 1GHz)
- 0.4m Directional Coupler output – RF switch input (Loss 0.1 dB @ 1GHz)
- Werlatone C5982 Directional Coupler (Loss 0.1 dB @1GHz)
- RF Switch – 2 Way N type (Loss 0.1 dB @ 1 GHz)

- TOTAL LOSS 1.95 dB @ 1 GHz
- Would be lower at 80MHz but much higher at 3GHz
Additional Factors to be included

- Some standards require the EUT to be placed above a metal ground plane on a table at the height of the centre of the antenna.
- This ground plane can add as much as another 3dB to the power required.
Automotive Radar Pulse
Many establishments use radar systems designed to scan at ground level.

This is used at airports to control aircraft during taxi and take off.

Such systems are also used for security at airports and military establishments.

This represents a severe threat to a vehicle when the high fields impact on safety critical electronic components for example; airbags, ABS, collision avoidance systems.

Field strengths can be very high but the duration of the interference is short.

- Radar is a made up of a series of very short pulses.
- As the radar antenna rotates the beam will only hit a vehicle for a short time.
Typical Radar Pulse Modulation

Period = 3.333 ms (300 Hz)

50 pulses = 1/6 s = 0.166 s

Pulse Duration = 3 μs
Automotive Radar Pulse Test

- Standards bodies and automotive manufacturers have defined the test conditions
- Frequencies usually in two bands 1.2-1.4GHz and 2.7-3.1GHz (3.2GHz)
- Test levels 300 or 600V/m
- Typically amplifier power in the region of 500 – 1000 Watts is required depending on test level and the antenna selected
- Whole vehicle testing requires different antenna and much higher power amplifiers
  - Please contact your local Ametek CTS sales office for further information on the available high power amplifiers
Antenna selection

- Horn antenna tend to be the most efficient antenna in these frequency ranges
- It is possible to source either a single wide band horn 1GHz - 4GHz or a pair of narrow band horns 1GHz-2GHz and 2GHz-4GHz
  - Narrow band horns will be more efficient than broadband but are less convenient to use as they need to be constantly exchanged
- Because the specified test distance is 1 metre the EUT will be in the ‘near field’ and so the normal field Vs gain calculation will not always be valid
  - Focusing devices can be used but care should be taken as they tend to reduce the beam width of the antenna
Three Techniques

- In most radiated immunity tests an isotropic field probe is used to measure the field during the calibration phase.
- Normal Isotropic field probes cannot react fast enough to measure the short duration pulses for the radar pulse test.
- Different techniques are required for the system calibration and these depend on the type of amplifier used.
- There are benefits and disadvantages to each technique.
Three Amplifier Types

- **CW amplifier** (are able to output maximum power continuously)

- **Pulse Amplifier** (can output full power pulses but no CW)

- **Pulse/CW amplifier** (can output reduced power continuously or full power pulses)
CW amplifier
(can output maximum power continuously)

Advantages

- Tests can be run in a similar manner to all other RI tests
  - Calibrate at the specified test level and then during the test apply the required modulation
  - Can use all of the available power from the amplifier (in some cases even at saturation)
  - Standard Isotropic field probe can be used

Disadvantages

- Amplifier is bigger
- Amplifier is more expensive
Pulse Amplifier
(can output full power pulses but no CW)

Advantages
  - Lowest cost

Disadvantages
  - Calibration requires use of a calibrated receive antenna and spectrum analyser
  - Antenna can integrate field over larger area resulting in potentially inaccurate measurement
  - Close coupling of the transmit and receive antenna could give less accurate readings
  - Pulse measuring field probes are available but are expensive and cannot be used for other applications
Pulse/CW amplifier
(can output reduced power continuously or full power pulses)

Advantages

- Lower cost
- Can use isotropic field probe for calibration
- Calibrate at low CW level and scale power to achieve required level in pulse

Disadvantages

- Must rely on linearity of amplifier
- Not possible to know if you are driving the amplifier into saturation
- Near saturation linearity of amplifier cannot be used to calculate field
Amplifiers available from Ametek CTS

- AS0104R-280/150
  - Dual band CW
  - Saturated power 1.2-1.4GHz 280 watts, 2.7-3.1GHz 150 watts
  - Saturated power 1-2GHz 200 watts, 2-4GHz 100 watts

- AS0104R-280/300
  - Dual band CW
  - Saturated power 1.2-1.4GHz 280 watts, 2.7-3.1GHz 300 watts
  - Saturated power 1-2GHz 200 watts, 2-4GHz 220 watts

- AS0104R-500/300
  - Dual band CW
  - Saturated power 1.2-1.4GHz 500 watts, 2.7-3.1GHz 300 watts
  - Saturated power 1-2GHz 400 watts, 2-4GHz 200 watts
Amplifiers available from Ametek CTS

- **AS0104R-800/400 (New Product)**
  - Dual band CW
  - **Saturated power 1.2-1.4GHz 800 watts, 2.7-3.1GHz 400 watts**
  - Saturated power 1-2GHz 500 watts, 2-4GHz 350 watts

- **AS0102R-1500**
  - Single band CW
  - **Saturated power 1.2-1.4GHz 1500 watts**
  - Saturated power 1-2GHz 1000 watts

- **S31-500-900P (New Product)**
  - Single band CW/Pulse
  - 0.8 - 3.1GHz
  - 500 watts CW
  - 900 watts Pulsed
S31-500-900P
What is it that normally prevents us from using all the power that the amplifier can provide?

- i.e. running the amplifier at saturation

There are two main reasons:

- Distortion of Amplitude Modulated (AM) signal
- High Harmonic levels
Modulation

- When using Amplitude modulation the peak of the modulation envelope must be at or below the P1dB to ensure correct reproduction of the modulation envelop.
- With pulse modulation the signal is either on or off and so the amplifier could be operated at saturation without affecting the modulated signal.
Harmonics

- When an amplifier is saturated the power devices produce high levels of harmonics but in order for these to be delivered to the amplifier output the tuning components must be able to transmit these frequencies.
- A broadband amplifier covering 1-6GHz or more would be able to produce these harmonics
  - Harmonics of 1.2GHz = 2.4, 3.6, 4.8GHz which are all in band for a 1-6GHz amplifier
  - Harmonics of 1.4GHz = 2.8, 4.2, 5.6GHz which are all in band for a 1-6GHz amplifier
- However a dual band amplifier with each band covering an octave (1-2GHz and 2-4GHz) or less would not produce high levels of harmonics as the harmonics would be out of band
- Therefore this type of amplifier can be used at saturation
- IMPORTANT NOTE
  - This only applies if system is calibrated CW at the full test level
  - Calibrating at a low CW level and scaling is not acceptable since the test level is above the linear region
What limits the Bandwidth of an Amplifier

- Amplifier designs require chokes and transformers
- The lower the frequency the larger they need to be
- At higher frequencies they start to become capacitive
- The larger they are the more capacitive they become
- So the lower and upper frequency is limited by the selection of the magnetic components
Bandwidth Limited by the magnetic components

- Low Frequencies limited by reducing Inductance of the Magnetic Components
- High Frequencies attenuated by capacitance of the Magnetic Components

Specified Operating Frequency Range

Gain (dB) vs. Frequency
Maximum Usable Power

Extrapolation
Conditions for Use at saturation

- If the amplifier can produce enough power so that the field is calibrated CW at the full test level
  - Then there is no extrapolation and so any non linearity in the I/P-O/P curve has no effect
- If it can be shown that the harmonics at saturation are better than -20dBc
  - The harmonics will not effect the test

Then the amplifier can be used at saturation

IMPORTANT NOTE

- This only applies if system is calibrated at the full test level
- Calibrating at a low CW level and scaling is not acceptable since the test level is above the linear region
Conclusion

- Amplifier selection will depend on a number of items
  - Antenna selection
    - Two narrow band antenna are more efficient and require less power but less convenient to use
    - Wideband horn does not require changing during test but are less efficient
    - Wideband horn with focusing lens more efficient but EUT size can be limited
  - Calibration method
    - Use of isotropic field probe more convenient but requires either
      - An amplifier capable of producing required power CW
      - A combined CW/pulse amplifier and scaling of results
    - Use of receive antenna and spectrum analyser
      - Can use pulse only amplifier but less convenient

- Whatever your choice, Ametek CTS have a solution for you