Radiated Spurious Emission Testing

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What is RSE?

- RSE = radiated spurious emission
- Radiated → chamber
- Emission → EMI
- Spurious → intentional radiator
Spurious, all emissions but the fundamental (carrier)
Spurious can be harmonics, oscillations, mixing terms
Spurious Domain
Receiver vs. Spectrum analyzer

- Spurious Emission measurements differ from EMI measurements mainly in that BW’s matching the useful signal have to be set on the receiver instead of the typical EMC bandwidths (e.g. 200 Hz, 9 kHz, 120 kHz).

- Also EMC BW’s are referred to the 6 dB points of the IF filters, whereas the BW’s for spurious emission measurements are referred to the 3 dB points.

- In spurious emission measurements, the peak detector takes the place of the QP detector.

- All these differences make it necessary that for spurious emission measurements a spectrum analyzer or test receiver with spectrum analyzer functionality to be used rather than a pure EMC test receiver.
Typical RSE Standards

- **FCC 15C/22/24/ (90)**
  - Per 2.2.12 and 2.2.17 of TIA-603-C/D

- **3GPP standards define RSE for cellular technologies, such as**
  - **3GPP.51.010 for GSM** (same std as EN 400 367-1)

- **ETSI EN 300 328 defines RSE for 2.4 GHz ISM band using spread spectrum modulation, up to 24 GHz**

- **ETSI EN 300 440 even defines RSE for equipments used to 40GHz, spurious measured to 100GHz**

- **Limit lines are given in dBm, not dBuV**
  - This implies EIRP measurement
    - EIRP not function of test distance
    - So, substitution calibration is required
Semi Anechoic Chamber

3m Test Distance

1 to 4 m scan high

0.8m high
FCC Chamber

FCC does not deviate from general ANSI C63.4 spec when measuring the RSE, but simply reinforces the use of “typical” 3-meter EMC chamber.
Noise Floor in FCC 3 meter chamber

- 3m distance
- Short cable
- Receive antenna 10dB horn with built-in preamp
ETSI Chamber

The above mentioned standards (ETSI 300-328, ETSI 300-440) clearly define the *Reflectivity* of absorber and chamber size, not chamber performance.
ETSI Chamber
FCC

Intentional Emitters:

- f < 10 GHz: to the tenth harmonic of the highest fundamental frequency or to 40 GHz, whichever is lower.
- In some cases the emissions from an intentional radiator must be measured to beyond the tenth harmonic of the highest fundamental frequency designed to be emitted by the intentional radiator because of the incorporation of a digital device.

FCC Rules Part 22 and 24 requirement for radiated spurious emissions is as follows:

- The ERP limit is \(-13\text{dBm} \ [\text{derived from } 43 + 10\log(P)]\)
### FCC RBW/Limits

<table>
<thead>
<tr>
<th>Rules FCC</th>
<th>Frequency /Resolution Bandwidth</th>
<th>Power Limit (Ave.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>22.917 (850)</td>
<td>$f_{low} - 1$MHz ( &lt; f &lt; f_{low} ) &amp; ( f_{up} &lt; f &lt; f_{up} + 1 )MHz;</td>
<td>$\geq 100$ kHz</td>
</tr>
<tr>
<td>24.238 (PCS) ; 27.53(g) (AWS)</td>
<td>$f \leq f_{low} - 1$MHz &amp; $f \geq f_{up} + 1$MHz</td>
<td>$\geq 1$M Hz</td>
</tr>
<tr>
<td></td>
<td>RBW $\geq 1%$ of BW</td>
<td>$-13$ dBm</td>
</tr>
</tbody>
</table>
FCC Spurious Testing, Handset Example

1. Connect the equipment with the EUT's antenna in a horizontal orientation.
   - If antenna element can be loaded with 50 ohm dummy load please do so or else take care not to overload the receiver/spectrum analyzer.

2. Adjust the settings of the Radio Communication Tester to set the EUT to its maximum power at the required channel. NOTE, Requires communication antenna to maintain the link!

3. Set the spectrum analyzer to measure peak hold.

4. Place the measurement antenna in a horizontal orientation. Raise the measurement from 1m up to 4 meters in steps and rotate the EUT 360 degrees at each height to maximize all emissions. Measure and record all spurious emissions (LVL) up to the tenth harmonic of the carrier frequency.

5. Replace the EUT with a horizontally polarized half wave dipole or known gain antenna. The center of the antenna should be at the same location as the center of the EUT's antenna.
   - Step is typically performed prior to testing and LOSS is recorded by test software
FCC Spurious Testing, Handset Example

6. Connect the antenna to a signal generator with known output power and record the path loss in dB (LOSS). LOSS = Generator Output Power (dBm) - Analyzer reading (dBm).
   - Step is typically performed prior to testing and LOSS is recorded by test software.

7. Determine the level of spurious emissions using the following equation: Spurious (dBm) = LVL (dBm) + LOSS (dB):

8. Repeat steps 4, 5 and 6 with all antennas vertically polarized.

9. Measurements are to be performed with the EUT set to the low, middle and high channel of each frequency band.
FCC 22.917 Emission limitations for cellular equipment

The rules in this section govern the spectral characteristics of emissions in the Cellular Radiotelephone Service.

(a) Out of band emissions. The power of any emission outside of the authorized operating frequency ranges must be attenuated below the transmitting power (P) by a factor of at least $43 + 10 \log(P)$ dB.

(b) Measurement procedure. Compliance with these provisions is based on the use of measurement instrumentation employing a resolution bandwidth of 100 kHz or greater. In the 1 MHz bands immediately outside and adjacent to the frequency block a resolution bandwidth of at least one percent of the emission bandwidth of the fundamental emission of the transmitter may be employed. A narrower resolution bandwidth is permitted in all cases to improve measurement accuracy provided the measured power is integrated over the full required measurement bandwidth (i.e. 100 kHz of 1 percent of emission bandwidth, as specified). The emission bandwidth is defined as the width of the signal between two points, one below the carrier center frequency and one above the carrier center frequency, outside of which all emissions are attenuated at least 26 dB below the transmitter power.
FCC 24.238 Emission limitations for Broadband PCS equipment.

The rules in this section govern the spectral characteristics of emissions in the Broadband Personal Communications Service.

(a) *Out of band emissions*. The power of any emission outside of the authorized operating frequency ranges must be attenuated below the transmitting power (P) by a factor of at least $43 + 10 \log(P)$ dB.

(b) *Measurement procedure*. Compliance with these provisions is based on the use of measurement instrumentation employing a resolution bandwidth of 1 MHz or greater. However, in the 1 MHz bands immediately outside and adjacent to the frequency block a resolution bandwidth of at least one percent of the emission bandwidth of the fundamental emission of the transmitter may be employed. A narrower resolution bandwidth is permitted in all cases to improve measurement accuracy provided the measured power is integrated over the full required measurement bandwidth (*i.e.* 100 kHz of 1 percent of emission bandwidth, as specified). The emission bandwidth is defined as the width of the signal between two points, one below the carrier center frequency and one above the carrier center frequency, outside of which all emissions are attenuated at least 26 dB below the transmitter power.
Example of FCC Spurious Test

Uplink Signal
ETSI Standard Basics

- EMI measured from 30MHz to 12.75GHz
- The receiving device is spectrum analyzer (3dB BW RBW), not EMI receiver (6dB BW RBW).
- No defined chamber performance test
- Only absorber requirement
- And suggested chamber size (10m x 5m x 5m)
Here is one example.

<table>
<thead>
<tr>
<th>fL/fH</th>
<th>GSM850 (CH190)</th>
<th>GSM900 (CH62)</th>
<th>GSM1800 (CH700)</th>
<th>GSM1900 (CH661)</th>
</tr>
</thead>
<tbody>
<tr>
<td>fo</td>
<td>824</td>
<td>849</td>
<td>880 915</td>
<td>1710 1785</td>
</tr>
<tr>
<td></td>
<td>836.6</td>
<td>902.4</td>
<td>1747.8</td>
<td>1880</td>
</tr>
<tr>
<td>RBW</td>
<td>fstart</td>
<td>fstop</td>
<td>fstart</td>
<td>fstop</td>
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<tr>
<td>10k</td>
<td>30</td>
<td>50</td>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td>100k</td>
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<td>50</td>
<td>500</td>
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<td>3MHz</td>
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<td>794</td>
<td>500</td>
<td>850</td>
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<td>1MHz</td>
<td>794</td>
<td>804</td>
<td>850</td>
<td>860</td>
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<tr>
<td>300k</td>
<td>804</td>
<td>814</td>
<td>860</td>
<td>870</td>
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<tr>
<td>100k</td>
<td>814</td>
<td>824</td>
<td>870</td>
<td>880</td>
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<tr>
<td>30k</td>
<td>830.6</td>
<td>834.8</td>
<td>896.4</td>
<td>900.6</td>
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<tr>
<td>30k</td>
<td>834.8</td>
<td>838.4</td>
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<tr>
<td>100k</td>
<td>842.6</td>
<td>834.8</td>
<td>904.2</td>
<td>908.4</td>
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<tr>
<td>100k</td>
<td>842.6</td>
<td>849</td>
<td>908.4</td>
<td>915</td>
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<tr>
<td>300k</td>
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<td>859</td>
<td>915</td>
<td>925</td>
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<tr>
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<td>935</td>
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<td>1MHz</td>
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<td>879</td>
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<td>945</td>
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<tr>
<td>3MHz</td>
<td>879</td>
<td>4000</td>
<td>945</td>
<td>4000</td>
</tr>
</tbody>
</table>
ETSI Limits

Harmonics are mostly limited to -30dBm (in dBi), or -27.85dBm (in dBi) \[\text{dBd} = \text{dBi} - 2.15\]

<table>
<thead>
<tr>
<th>Freq. Range (MHz)</th>
<th>Limit (ERP, dBm)</th>
<th>RBW (kHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 – 1000</td>
<td>-36</td>
<td>100</td>
</tr>
<tr>
<td>1000-12.750</td>
<td>-30</td>
<td>1000</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Freq. Range</th>
<th>GSM 850/900/1900 and GSM 400/700 (ERP in dBd)</th>
<th>GSM1800 (ERP in dBd)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30-1000 MHz</td>
<td>-36 dBM</td>
<td>-36 dBM</td>
</tr>
<tr>
<td>1000-4000 MHz</td>
<td>-30 dBM</td>
<td>(see separate limits)</td>
</tr>
<tr>
<td>1000-1710 MHz</td>
<td>-30 dBM</td>
<td>-30 dBM</td>
</tr>
<tr>
<td>1710-1785 MHz</td>
<td>-36 dBM</td>
<td>-36 dBM</td>
</tr>
<tr>
<td>1785-4000 MHz</td>
<td>-30 dBM</td>
<td>-30 dBM</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Freq. Range</th>
<th>CDMA (Cell and PCS Bands)</th>
<th>TD-SCDMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 ≤f&lt;1000 MHz</td>
<td>-36 dBM</td>
<td>2013.4-2021.4 MHz</td>
</tr>
<tr>
<td>1 ≤f&lt;12.75 GHz</td>
<td>-30 dBM</td>
<td>-36 dBM</td>
</tr>
<tr>
<td>Exclusive Band</td>
<td>near fc to be exempt</td>
<td>-30 dBM</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Freq. Range</th>
<th>WiFi ISM Band and Bluetooth (EIRP limit)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>30 ≤f&lt;1000 MHz</td>
<td>-36 dBM</td>
<td></td>
</tr>
<tr>
<td>1 ≤f&lt;12.75 GHz</td>
<td>-30 dBM</td>
<td></td>
</tr>
<tr>
<td>1.8-1.9 GHz and</td>
<td>-47 dBM</td>
<td></td>
</tr>
<tr>
<td>5.15-5.3 GHz</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Basic ETSI RSE System Diagram

- 3D positioner for 3D measurement
- Notch Filter to remove fundamental carrier
- Preamp to increase dynamic range
Filters for Wireless

Compliant EMC Solution

- For Measurement of the radiation and sensitivity of wireless devices under different signal protocols and frequency.
- Main carrier frequencies used are:
  - 800MHz, 900MHz, 1.2GHz, 2.4GHz ....
- When measuring broadband responses these carrier frequencies need to be included in the measurement path.

Pre Compliant MAPS Solution

- Pre compliant solution (above 200/700 MHz only)
- Upper frequencies only
Filters for EMC and Wireless

Basic RSE System Diagram

<table>
<thead>
<tr>
<th>Freq (MHz)</th>
<th>Air Loss (dB)</th>
<th>(1x6) Switch Insertion loss (dB) *2</th>
<th>(1x2) Switch Insertion loss (dB) *1</th>
<th>Approximated Cable loss (dB)</th>
<th>Filter Pass band Loss (dB)</th>
<th>Antenna Gain (dB)</th>
<th>Preamp Gain (dB)</th>
<th>Link Budget</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>11.52662237</td>
<td>0.36</td>
<td>0.25</td>
<td>7</td>
<td>0.5</td>
<td>2</td>
<td>47</td>
<td>28.50337763</td>
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<tr>
<td>100</td>
<td>21.98419728</td>
<td>0.36</td>
<td>0.25</td>
<td>7</td>
<td>0.5</td>
<td>2</td>
<td>47</td>
<td>18.04580272</td>
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<td>500</td>
<td>35.96359737</td>
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<td>0.25</td>
<td>7</td>
<td>0.5</td>
<td>5</td>
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<td>7.066402633</td>
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<tr>
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<td>41.98419728</td>
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<td>0.25</td>
<td>7</td>
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<td>5</td>
<td>47</td>
<td>2.472023462</td>
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<td>1500</td>
<td>45.50602248</td>
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<td>0.25</td>
<td>7</td>
<td>0.5</td>
<td>5</td>
<td>47</td>
<td>2.574797194</td>
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<td>2000</td>
<td>48.00479719</td>
<td>0.36</td>
<td>0.25</td>
<td>7</td>
<td>0.5</td>
<td>7</td>
<td>47</td>
<td>2.574797194</td>
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<tr>
<td>2500</td>
<td>49.94297945</td>
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<td>0.25</td>
<td>7</td>
<td>0.5</td>
<td>7</td>
<td>47</td>
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<td>3000</td>
<td>51.52662237</td>
<td>0.36</td>
<td>0.25</td>
<td>7</td>
<td>0.5</td>
<td>7</td>
<td>47</td>
<td>-6.496622375</td>
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<tr>
<td>3500</td>
<td>52.86555817</td>
<td>0.36</td>
<td>0.25</td>
<td>7</td>
<td>0.5</td>
<td>7</td>
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<td>-7.835558167</td>
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<tr>
<td>4000</td>
<td>54.02539711</td>
<td>0.36</td>
<td>0.25</td>
<td>7</td>
<td>0.5</td>
<td>8</td>
<td>47</td>
<td>-7.995397107</td>
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<tr>
<td>4500</td>
<td>55.04844756</td>
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<td>0.25</td>
<td>7</td>
<td>0.5</td>
<td>8</td>
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<tr>
<td>5000</td>
<td>55.96359737</td>
<td>0.36</td>
<td>0.25</td>
<td>7</td>
<td>0.5</td>
<td>10</td>
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<tr>
<td>5500</td>
<td>56.79145107</td>
<td>0.36</td>
<td>0.25</td>
<td>7</td>
<td>0.5</td>
<td>10</td>
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<tr>
<td>6000</td>
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<td>0.25</td>
<td>7</td>
<td>0.5</td>
<td>10</td>
<td>47</td>
<td>-9.517223288</td>
</tr>
</tbody>
</table>
Filters for Wireless
Typical Notch Filter

- Very sharp rejection band - 50dB rejections in 200kHz bandwidth
- To notch out the fundament which is strong enough to saturate receiver
Preamp

- Preamp is essentially LNA (low noise amp) to boost up weak spurious to become detectable.
- Carefully select preamp to have enough dynamic range.
- Preamp is connected right after next to the receive antenna, after the notch filter, in good compliant RSE system.
Filters for EMC

- EMC Solution for 2.7GHz or 6 GHz to 18 GHz

HPF filter used in series with Pre amplifier

Protects preamp from overload.
Filters for EMC

- EMC Solution for 2.7GHz or 6GHz to 18 GHz
Measured Graph

- Limit line for GSM900 steps at 1GHz
- Fundamental TX carrier is strong.
Exclusion Band

The fundament of 902.4MHz is taken out by the BW of 3.6MHz.
Table picks up peaks.

<table>
<thead>
<tr>
<th>Peak Points</th>
<th>Final Frequency (MHz)</th>
<th>Response (dB)</th>
<th>Peak Points Frequency (MHz)</th>
<th>Peak Cut</th>
<th>Secondary Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>945.519</td>
<td>-26.53</td>
<td>945.519</td>
<td>1</td>
<td>180</td>
</tr>
<tr>
<td></td>
<td>943.876</td>
<td>-26.89</td>
<td>943.876</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>897.804</td>
<td>-29.60</td>
<td>897.804</td>
<td>1</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>943.016</td>
<td>-29.67</td>
<td>943.016</td>
<td>3</td>
<td>180</td>
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<tr>
<td></td>
<td>946.556</td>
<td>-30.35</td>
<td>946.556</td>
<td>2</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>938.801</td>
<td>-31.79</td>
<td>938.801</td>
<td>3</td>
<td>180</td>
</tr>
</tbody>
</table>
The FCC has received several inquiries regarding the acceptance of an adjunct methodology, whereby a signal generator is used to radiate a signal that is swept over a pertinent frequency range, and then recorded at a single point in space at a distance corresponding to the measurement distance required for compliance testing. A table of data collected from this site “pre-calibration” is then to be used to replace specific substitution procedures as described in Sections 2.2.12 (j) through (l) and/or 2.2.17 (c) and (d) of the TIA-603-C standard.
Pre Test Calibration Methodology

- FCC Released a KDB 449343 (https://apps.fcc.gov/oetcf/kdb/forms/FTSSearchResultPage.cfm?id=47471&switch=P) recognizing that there are labs using this method and prior to it being recognized by any industry standard or officially by FCC it is not acceptable at this point.

- There was a response submitted to try to get this methodology included as part of the FCC approved methodologies for this test.
Pre Test Calibration Methodology

EMC test labs have technically justified and used pre-test site calibrations to evaluate the field strength of radiated emissions in lieu of individual substitution measurements for each emission for many years.
Pre Test Calibration Methodology

Procedure

Reference Field Strength

The related regulatory compliance limit [e.g. -13 dBm / -20 dBm] should be used as the reference field strength for the pre-test site calibration.

However, as long the system sensitivity of the measurement system is adequate, labs are able to define their own reference field strength.

Labs should be capable of justifying their decision of reference field strength.
Pre Test Calibration, Procedure

- Measurement instruments used for path loss calibration do not need to be the same as ultimately used for measuring EUT radiated power
  - Swept frequency measurement under consideration
  - Network analyzer → Speed.

- It is very important that antenna locations, measurement antenna and related measurement cables to be the same for both the path loss calibration and EUT measurements.
  - If any of these elements change, then site calibration shall be verified before continuing with EUT testing

- A preamplifier can be utilized for testing even if it was not part of the path loss measurement.

- Correction Factor (CF) determined on the exact frequencies of the EUT emission testing or calculated using linear interpolation between site calibration frequencies
Pre Test Calibration, Procedure

Set up the substitution measurement with the ref. point of the substitution antenna located in the position where the closest periphery of the EUT will be located during EUT measurements.

The height of the substitution antenna should be at approximately the same height as where center of the transmitter to be tested would be located.

Set the test receiver settings and receive path parameters exactly as they will be used during emissions measurements.

Connect a signal generator to the substitution antenna and set the level according

\[ P_{\text{gen}} = P_{\text{ref}} + \text{Cable Loss} - \text{Antenna Gain [dBd]} \]

Where

- \( P_{\text{gen}} \) = signal generator setting [dBm]
- \( P_{\text{ref}} \) = Reference Field Strength
- Antenna Gain [dBd] = Antenna Gain [dBi] - 2.15
- Antenna Gain [dBi] = 10*Log (Num Gain)

Scan antenna 1m to 4m to determine the height of the maximum received level.
Pre Test Calibration, Procedure

- Record the level of the received power [Prec] at the Receiver in dBm for that frequency and polarization.
- Perform the leveling of the signal generator power for each frequency with the receive antenna oriented in both the polarizations as described above.
- Calculate the system correction factor for each frequency in dB using the following equation:
  
  \[
  \text{Correction Factor \[CF\] = \text{Pref \[dBm\] – Prec \[dBm\]}}
  \]

  For example:
  
  At 4800 MHz for a frequency / polarization
  
  \[
  \text{Prec = -34.8 dBm for a -13 dBm limit}
  \]
  
  \[
  \text{CF = -13 dBm – [-34.8 dBm] = 21.8 dB}
  \]

- Using Pre-Test Site Calibration Correction Factor to Determine EUT Emission Power

- EUT emission powers are calculated using the following equation:
  
  \[
  \text{Emission Power = EPrec dBm + CF}
  \]
  
  Where EPrec is the power of the emission measured at the test receiver during EUT measurements as defined in TIA 603C/D section 2.2.12.2 a - 2.2.12.2 g.

- This is the level to be compared against the regulatory limit as it is the emission power referenced back to the EUT on the test site.
Pre Test Calibration

Concerns

- Multitude of Correction Factors for variety of different EUT sizes, diameter, height and cable orientations.
  - Needs to be careful that right files are used or use methodology to reduce the error by performing a series of tests (or volumetric) for different path loss measurements and do 1/r distance correction to reduce the chamber associated ripple.
    - Maybe you can live then with one Correction Factor for the center and then just reduce the correction factor based on the radius of the EUT.

- How sensitive the calibration factor determination is for set-up.
  - Do labs start taking short cuts if the set-up is “close enough” for the calibration factors already existing.
    - How to audit?