A Trade Study on Quasi Far-Field Accuracies and Measurements

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***Abstract*— Recent papers have addressed making far-field measurements at much less than the traditional far-field distance, particularly for 5G MIMO test articles. These papers have focused on main beam measurements only, such as Total Radiated Power (TRP) and have stated that other normal antenna pattern metrics, such side lobe level measurements are not appropriate for this shortened distance. These papers have addressed fixed error levels acceptable for this quasi far-field technique. This paper will present main beam error from two other perspectives, looking at agreement with the previous efforts. In addition, the paper will present a trade study in terms of chamber size, measurement durations and measurement methods between the quasi far-field, compact range, and spherical near-field approaches. This trade study will cover five representative test articles in the C, Ka, and V frequency bands for 5G applications.**

I. INTRODUCTION

5G Base Stations (BS) and handsets require testing for Total Radiated Power (TRP), Total Isotropic Sensitivity (TIS) and Effective Isotropic Radiated Power (EIRP). These metrics require measurement of the AUT over a complete sphere at required sampling intervals and the result is an integration of the individual results at each sample point. 3G and 4G base stations were also tested for these metrics at coarser sampling intervals due to the lower frequencies. These metrics are evaluated in the far-field. Traditional methods are a true far-field range, a compact antenna test range (CATR) and spherical near-field (SNF) collection with transformation to the far-field. For many years, the test community has sought a method where these tests could be performed in the quasi far-field. Research on 3G base stations began [1][2] over 15 years ago and more recent work [3][4][5][6][7][8] has been performed in the sub-6 GHz bands for 5G. The references [3] through [8] established a range distance criterion that bound the error of the quasi far-field measurement to a reasonable, though fixed, value.

This paper will look at two other methods of arriving at the desired quasi far-field distance that allow the tester to find a different quasi far-field distance for different error bounds.

In addition, this paper will perform a trade study on measurement techniques for three base stations, one in the FR1 band, one in the lower end of the FR2 band, and the last in the upper end of the FR2 band and two handsets, one in the FR1 band and one in the FR2 band.

II. ERROR EVALUATIONS

A. *Quasi Far-Field Criterion*

The authors of [3] through [8] are in a development group at Rohde & Schwarz. The work developed the following equation [4] for the quasi far-field distance that kept the error in the top 10 dB of the main beam within +/-0.5 dB.

$$r_{qff} = \lambda\left(\frac{\pi D}{\lambda}\right)^{0.8633}\left[0.1673\left(\frac{\pi D}{\lambda}\right)^{0.8633} + 0.1632\right] \tag{1}$$

D is the diameter of the AUT aperture and λ is the wavelength. This equation has become known as the Derat Criterion, after the lead author in most of the references [3] through [8]. The caveats for this equation are that it is only valid for the top 10 dB of the main beam, and the error is fixed at ± 0.5 dB. No accuracy of side lobe measurement is claimed. However, these caveats work well for the metrics of TRP, EIRP and TIS. Comparing this criterion to other approaches to quasi far-field error provides a comparison and hopefully, an approach to using other error levels. Figure 1 is Figure 40 from [11] with the Derat Criterion added for comparison.

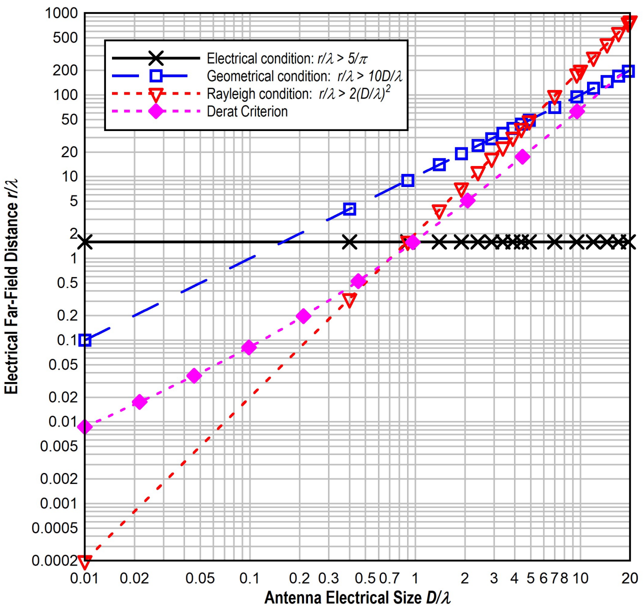

Figure 1. The Derat Criterion added to the Standard Far-Field Definitions

The +/- 0.5 dB error is in addition to other range errors. As a point of comparison, [11] references [12] for calculating the quiet zone taper error in a compact range as follows:

$$AUT\ Taper\ Error = 0.1\ dB * \left[\frac{QZ\ Taper * \frac{AUT\ D}{QZ\ Width}}{0.25\ dB} \right] \quad (2)$$

For example, given a 70 cm AUT in an 80 cm CATR quiet zone, which has a taper specification of 0.5 dB across the entire quiet zone, the taper error for the AUT is 0.175 dB. This is a one-sided error in that amplitude taper is a parabolic curve in a CATR.

B. Power Density versus Range

Several of the referenced papers [4],[6] show power versus distance. Therefore, using the well-known power density curves versus distance [9][10] is attractive. The Fraunhofer estimate for power density in the far-field or greater is:

$$Power\ Density\ @\ R = \left({}^{EIRP}/_{4\pi R^2} \right) \quad (3)$$

Figure 2 shows normalized power density on the y-axis where 1 = far-field distance value of (3) and the x-axis is the normalized range where 1 = the far-field distance.

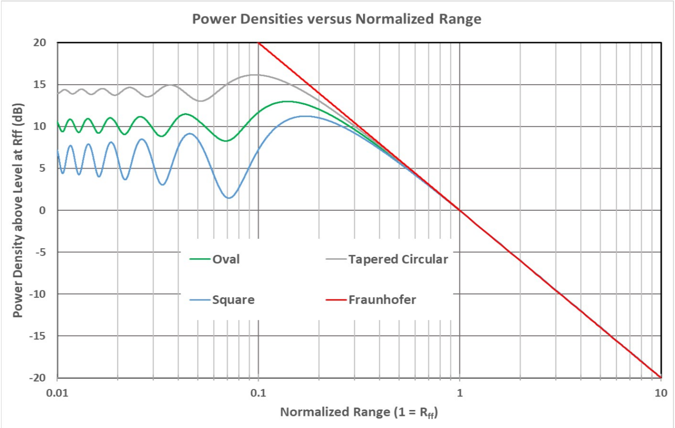

Figure 2. Power Density vs. Range for Aperture Shapes

However, the red line in Figure 2 computes a Fraunhofer value back toward the aperture. The power density of this line could be considered the far-field value at that distance. The curves for the aperture shapes show the oscillation in the near-field region and then asymptotically approaching the Fraunhofer slope. Collecting quasi far-field data in the oscillatory region will not be accurate. This problem is illustrated in Figures 3 and 4 of [7]. Note that the different aperture shapes approach the Fraunhofer line at different rates. The circular aperture, with the most area for its diameter, approaches the line the fastest. The square or rectangular aperture approaches the slowest, as it is the most inefficient area for its diameter. The oval or hexagonal shape is in the middle. Its curve will vary with its major to minor axes ratio, either toward the circular aperture curve or the square aperture curve. Figure 3 shows the aperture curve distances from the Fraunhofer line versus distance. From [4] through [8], the Derat distance for a small rectangular handset, a square array, a standard gain horn and a MIMO base station of unknown aperture shape are included. Note that since the power density error is single sided, the rms of the +/- 0.5 dB Derat error is used, 0.707 dB.

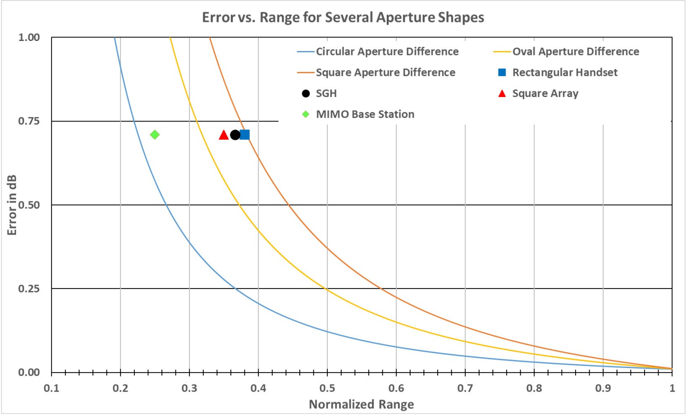

Figure 3. Error vs. Range for the Aperture Shapes

C. *SNF Transform Range Method*

The SNF transform can produced a pattern output at a specified distance, from infinity down to just outside the measurement sphere. A hexagonal array operating at 5.4 GHz with major axis length of 86 cm and minor axis length of 71 cm was measured in a spherical near field range. Figure 4 shows a plot of the AUT far-field main beam computed at ranges that are several fractional values of the far-field range, which is approximately 29 m. The directivity increases as the computed range gets shorter since the distance is approaching the broader pattern in the near-field and the transform interprets that as more energy in its field of view.

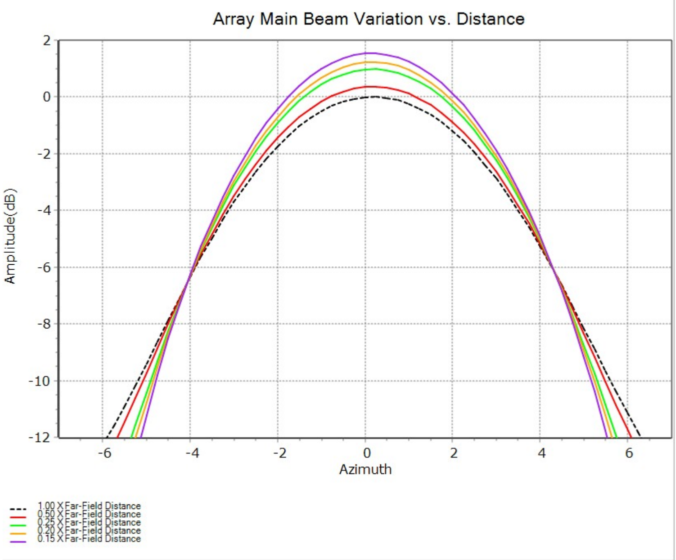

Figure 4. Transformed Main Beam at Several Distances

Figure 5 shows the single sided error for directivity and 10 dB beamwidth at the various distances. The power density error curve for an oval/hexagonal shape is also shown. The Derat criterion distance and single sided error for this AUT is shown for comparison.

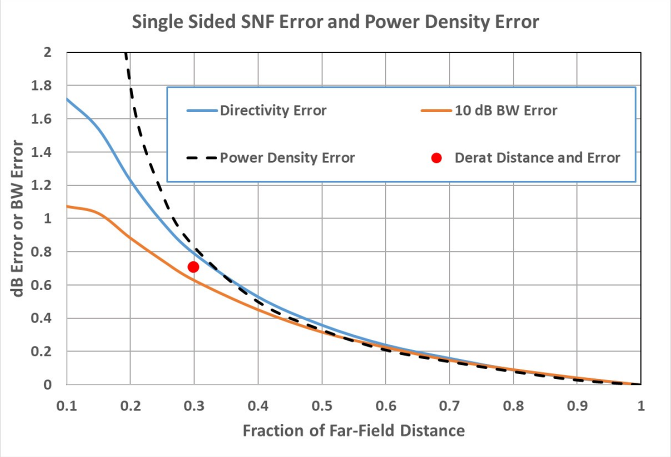

Figure 5. Directivity, Beam Width and Power Density Errors vs. Range

D. *Comparison*

Both the power density error and SNF distance error agree well with the Derat criterion. In fact, the results in Figure 4 indicate that the MIMO base station is probably a circular aperture. The results show that the power density error is more conservative than the Derat criterion, while the SNF error with range is very comparable for the single case tested. Either of these two methods can indicate a reasonable quasi far-field distance for other error bounds, instead of having to re-derive the Derat criterion for different error limits. For example, looking at the power density error curves in Figure 3, if the user would like a single sided error of 0.25 dB, the quasi far-field distance is 0.37 to 0.58 of the far-field distance, depending on aperture shape.

III. TRADE STUDY

Several test articles will be used to compare chamber size, quantity of measurements required and the impact of multiple frequency bands for the possible choices of quasi far-field, compact antenna test range and spherical near-field. The tester is urged to make this trade study for their AUT or class of AUT's to determine the most cost effective approach to 5G measurements.

A. *Test Articles*

The following three base station test articles will be used, a 70 cm circular aperture @ 6 GHz in 5G band FR1, a 50 cm circular aperture @ 26 GHz in band FR2 and a 30 cm circular aperture @ 50 GHz in band FR2. Two handsets, one in FR1 and the other in FR2 will also be analyzed for comparison. Table I shows the various parameters for the test articles.

TABLE I. TEST ARTICLES

Parameter	FR1 BS	FR2 BS #1	FR2 BS #2	FR1 Handset	FR2 Handset
Aperture	Circ	Circ	Circ	Rect.	Rect.
Diameter (cm)	70	50	30	7 x 15	7 x 15
Frequency (GHz)	4.8	28	50	4.8	28
Far Field (m)	15.7	46.7	30	0.9	5.1
Derat Ratio	0.33	0.21	0.21	0.54	0.30
Derat Distance (m)	5.1	10.0	6.3	0.5	1.5

B. *Chamber Size*

A far-field chamber is generally a rectangular shape. However, for these type AUT's, the length of the range for quasi far-field and the required width and height form a room that is very narrow. When this happens, the stray signals from the side walls, ceiling and floor will be high since the signal from the range antenna or the AUT hits the side walls at a shallow angle, resulting in low reflectivity for the absorber. Therefore, for this type of range, the optimum size is square with the range axis along the diagonal. This is also the most compact space for an SNF configuration. An illustrative chamber arrangement is shown in Figure 6.

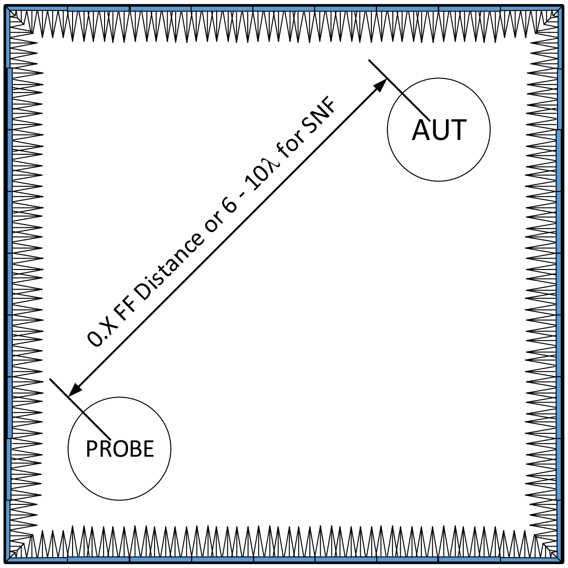

Figure 6. Generic Diagonally Oriented Range

Table II shows the chamber sizes needed for the test articles for quasi far-field measurements. A standard height of 2.5 m (normal building room height) is used. This provides sufficient separation of the AUT zone from the ceiling and floor for the largest test article. It is assumed that the AUT positioner space is 1.25 times the AUT sphere. The space allowed behind the probe aperture and behind the back of the AUT positioner is set at 1 m for both. This allows working room around the two locations and separates the antennas from the absorber enough to avoid mutual coupling.

TABLE II. COMPARISON OF QUASI FAR-FIELD CHAMBER SIZES

Parameter	FR1 BS	FR2 BS #1	FR2 BS #2	FR1 Handset	FR2 Handset
Aperture Separation (m)	5.1	10.0	6.3	0.5	1.5
Room Diagonal (m)	7.6	12.5	8.8	3	4
Footprint (m)	6 x 6	9 x 9	7 x 7	3 x 3	3 x 3
Room Height (m)	2.5	2.5	2.5	2.5	2.5
Absorber surfaces (m^2)	132	252	168	48	48
Absorber Pieces ($0.36\ m^2$ each)	367	700	467	134	134
Volume (m^3)	90	202	122	22	22

Figure 7 shows an elevation view of a moveable chamber with a compact range reflector that provides an 80 cm cylindrical quiet zone from 4 to 75 GHz. Its dimensions can support any of the test articles.

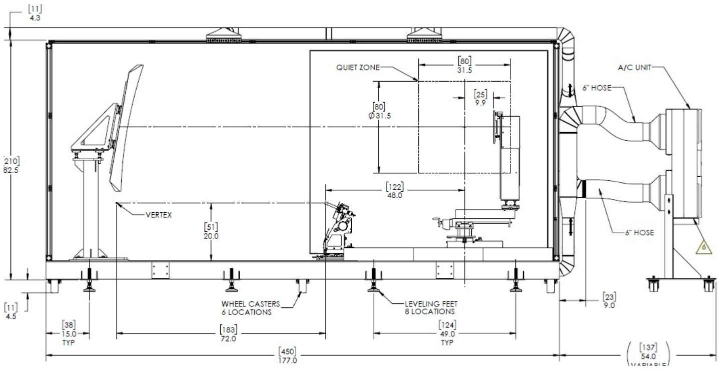

Figure 7. Elevation View of a Mobile CATR

TABLE III. SIZE PARAMETERS FOR THE CATR

Parameter	Compact Range
Focal Length (m)	1.8
Length (m)	4.5
Width (m)	2.1
Height (m)	2.5
Absorber surfaces (m^2)	52
Absorber Pieces ($0.36\ m^2$ each)	145
Volume (m^3)	24

A spherical near-field range will be like the quasi far-field range except that the aperture to aperture separation of 10 λ will be used. The rule of thumb is that probe correction in SNF is not necessary with a minimum of 10 λ separation. This leads to the following table:

TABLE IV. SNF CHAMBER SIZES

Parameter	FR1 BS	FR2 BS #1	FR2 BS #2	FR1 Handset	FR2 Handset
Aperture Separation (m)	0.6	0.1	0.1	0.6	0.1
Room Diagonal (m)	3.1	2.6	2.6	3.1	2.6
Footprint (m)	3 x 3	2 x 2	2 x 2	3 x 3	2 x 2
Room Height (m)	2.5	2.5	2.5	2.5	2.5
Absorber surfaces (m^2)	48	28	28	48	28
Absorber Pieces ($0.36\ m^2$ each)	134	78	78	134	78
Volume (m^3)	22	10	10	22	10

Chamber manufacturers use volume as their first approximation for the cost of a chamber. Comparing volumes shows that the quasi far-field chambers have the largest volume for base station testing, with the compact range second and the SNF chambers the smallest. Quasi far-field and SNF chambers for the handsets are both small and relatively equivalent in volume. Handset testing could be conducted in a compact range but is not normally done.

C. Number of Measurements

In the quasi far-field and CATR cases, the number of samples is set by the testing standards. A complete sphere of data around the AUT is required. That can be accomplished by either elevation over azimuth (yoke style) or roll over azimuth positioners. One axis must cover 180 degrees and the orthogonal axis must cover 360 degrees. The sampling interval for handsets are 15 degrees in both dimensions [13]. 5G base stations have multiple options for sampling, but the most stringent (most accurate) is the reference sampling interval in [14]. Assuming a spherical AUT with no projections of radiating elements, the reference sampling interval is:

$$\Delta\phi_{ref} = \Delta\theta_{ref} = MIN\left[\frac{180}{\pi} * \frac{\lambda}{D}, 15\right] \qquad (4)$$

For SNF, the sampling interval in both dimensions is the Nyquist value of the arc on the surface of the minimum sphere. This can be larger or smaller than the 5G standards values, depending on the frequency and minimum sphere diameter. The table below compares the number of samples needed for quasi far-field/CATR measurements versus SNF.

TABLE V. MEASUREMENT POINTS

Parameter	**FR1 BS**	**FR2 BS #1**	**FR2 BS #2**	**FR1 Handset**	**FR2 Handset**
Quasi Far-Field or CATR Sampling					
Δϕ and Δθ (degrees)	5	1.2	1	15	15
Total Points	2664	45300	65160	312	312
Spherical Near-Field Sampling					
Δϕ and Δθ (degrees)	3.75	1	1	7.5	2.5
Total Points	4704	65160	65160	1200	7320
Ratio of SNF to FF/QFF	1.76	1.44	1	3.85	1.44

The ratio of SNF total points to quasi far-field or CATR points is high for the handsets, but the relatively small number of points makes that less significant. For the higher bands and larger apertures, the difference between SNF and far-field are less, but the difference for the base station in the lower part of the FR2 band is large, leading to a point differential of almost 20,000 points.

D. Multiple Frequency Bands and Techniques in the Same Chamber

For a quasi far-field chamber, large AUT's at higher frequencies lead to larger chambers. For a given size chamber set up for quasi far-field, any AUT with a Derat criterion distance that fits in the chamber can be evaluated. The compact range can operate with any AUT that fits in the quiet zone and is above the lowest frequency supported by the compact range optics. Spherical near-field chambers can evaluate any AUT whose minimum sphere diameter plus 4 to 6 wavelengths is within the measurement sphere.

The positioners in any of the range types that can provide full sphere coverage of the AUT can also be used for SNF measurements. Therefore, the quasi far-field range can make SNF measurements and the SNF range can make quasi far-field measurements if enough aperture to aperture separation is available to provide the Derat criterion distance. A floor slide in the spherical or quasi far-field chamber can provide more flexibility for measurements. Spherical measurements can be made in the CATR if the distance from the feed aperture to the center of the reflector is used as the measurement radius.

IV. SUMMARY

This paper has shown that the power density evaluation of main beam errors and the SNF distance error evaluation are comparable to Derat distance calculations and can provide an estimate of the distance needed for different error bounds other than the standard ±0.5 dB. Note that both the power density evaluation and SNF beam error evaluation are single sided error limits.

Quasi far-field chambers tend to be larger than small CATR's and SNF chambers. SNF chambers are smaller than the equivalent CATR.

Quasi far-field and CATR systems require fewer measurement points than SNF systems in most cases. However, in several cases, the number of measurement points is equivalent.

Quasi far-field and SNF chambers are best suited for R&D environments or when few AUT's need to be evaluated. An R&D facility that also requires pattern measurements should use an SNF approach or a CATR. The CATR is best for production efficiency and covering multiple AUT's in different frequency bands and sizes in a single chamber.

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