AN ANALYSIS OF THE ACCURACY OF EFFICIENCY MEASUREMENTS OF HANDSET ANTENNAS USING FARFIELD RADIATION PATTERNS

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ABSTRACT

Radiation efficiency is an inherent property of an antenna that relates the net power accepted by an antenna to the total radiated power. It is especially useful for handset antennas where the radiation patterns are often of less use for comparing competing antennas. Radiation patterns though not as useful for direct comparisons, still provide one method by which efficiency can be calculated. To accurately calculate the efficiency from patterns, it becomes necessary to obtain multiple pattern measurements (cuts). A larger number of cuts whilst yielding more accurate efficiency results, significantly increase measurement time. Thus an antenna designer is often forced to trade off accuracy against measurement time since both quick and accurate measurements are desired. The focus of this paper is to quantify this trade off, in order to provide guidelines on the number of pattern measurements required for accurate efficiency results. Simulated and measured far-field radiation patterns are used and various numbers of cuts are utilized to quantify the loss in accuracy with a reduced number of cuts. The techniques outlined are geared primarily towards cellular handset antennas.

Keywords: Antennas, Pattern Measurement, Low Directivity, CTIA, Wireless, Cellular communications

1. Introduction

One of the primary drivers for the design of low directivity antennas has been the cellular communications industry. The high volume nature of this industry has resulted in the need for fast design turn around. The compression of the design cycle time thus necessitates reduction of the time overhead required for antenna measurements. This must be done without a corresponding loss in accuracy of performance results. Accurate performance characterization for low directivity antennas is however not straight forward since most of the energy is not directed away from the antenna under test (AUT) into a narrow test zone. A number of measurement methods have to be implemented (see [1] for a survey of techniques for measuring low directivity antennas).

The focus of this paper is to analyze these techniques with a view to streamlining measurement methodologies.

2. Methodology

Simulation and measurement have been used to determine how the patterns of three common handsets types should be sampled. As the handset itself contributes significantly to the way the device radiates, a common bar phone, a slider phone and a clamshell phone have been evaluated so that separate conclusions can be drawn for each type.

Patterns have been measured using Antenova's rectangular far-field anechoic chambers. The chambers were used to make planar cuts of the antenna under test. For this paper, 8 cuts, each spaced 22.5 degrees apart in the phi or azimuth plane have been taken to measure the phones. For the purposes of this paper a cut is defined as a two dimensional gain pattern that consists of data for both co and cross-polarizations summed together.

To complement the measurements done, EM simulation has been used to generate pattern results for the same set of phone types. Pattern data was generated using Ansoft HFSS and then analyzed using the same techniques as for the measured data. Very dense sampling of the simulated pattern is relatively straightforward, but would have required a great deal of measurement time. For that reason the effect of taking more than 8 pattern cuts has only been analyzed on simulated data.

Each of these phone types has been simulated over a combination of frequency bands covering the GSM800, GSM900, GSM1800 (DCS), PCS and W-CDMA bands. For ease of understanding the five bands are sub-grouped into two major frequency bands from 824 MHz to 960 MHz and 1710 MHz to 2170 MHz henceforth referred to low band and high band respectively

Table 1 shows the antennas that have been evaluated, the type of phone to which they are attached and the frequency bands in which they operate.

	GSM 850	GSM 900	DCS	PCS	WCDMA
Generic Bar phone	SIM and MEAS	SIM and MEAS	SIM and MEAS	SIM and MEAS	SIM and MEAS
Commercial slider		MEAS	MEAS	MEAS	
Generic slider	SIM	SIM	SIM	SIM	SIM
Generic clam-shell	SIM and MEAS	SIM and MEAS	SIM and MEAS	SIM and MEAS	

Table 1: Summary of measured and simulated phones

3. The "Great Circle" Method

The Cellular Telecommunications & Internet Association (CTIA) has specified minimum acceptable standards [2] for the measuring of handset antennas. One of the approved methods is often known as the "great circle" method. It involves the use of an azimuth positioner and rotation of the AUT perpendicular to the azimuth positioner. In this way it is possible to measure 360^0 over all ϕ angles with all the cuts intersecting at the poles of the second axis of rotation. Figure 1 shows the principle of operation.

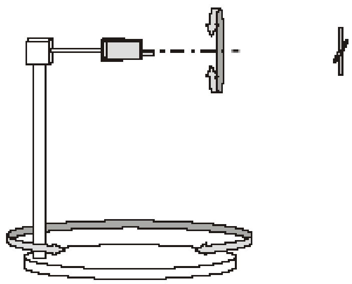

Figure 1: Roll over Azimuth measurement system [2]

Measurement of the radiation pattern using this methodology yields cuts that are oriented as shown in Figure 2. The orientation of the great circles defines two poles, similar to lines of longitude on a globe. Also shown in this figure is the AUT. The orientation of the AUT relative to the great circle is important in that the choice of orientation can place the pattern nulls or peaks at the "poles" of the great circle.

In this paper we shall consider two methods based on great circles. Method A is shown in Figure 2, the poles are in line with the ends of the handset. Method B is shown in Figure 3, here the poles of the great circles lie at the sides of the handset.

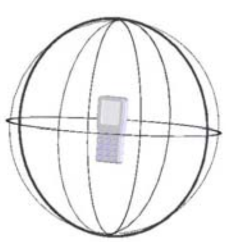

Figure 2: Great circle cuts as for Method A

Figure 3: Great circle cuts as for Method B

Although not explored in this paper the material composition of the test stand for low directivity antennas is a major contributor to any measurements done. To negate the effect of the test stand changing the dielectric loading, the arm of the test stand connecting the AUT to the azimuth positioner is made as much as possible of low dielectric materials such as polystyrene.

4. Simulated Efficiency Results

As highlighted earlier an EM simulator can be used to generate a dense sphere of points over the radiation pattern, relatively quickly. This is because the fields are calculated at each individual point specified over the radiation sphere. The gain data obtained for each sampling point can then be evaluated to calculate efficiency. It is important to note that the efficiency from the simulated data has been evaluated by using gain values obtained from the simulator. The efficiency calculation feature in HFSS has not been used, as this would not be a direct comparison with measured data.

The simulated models consisted of the phone PCB with feed and the antenna itself. The antenna simulated is a hybrid dielectric antenna developed by Antenova Ltd. It displays radiation characteristics similar to a conventional PIFA. Figure 4 shows a picture of a simulation setup for a generic penta-band bar phone.

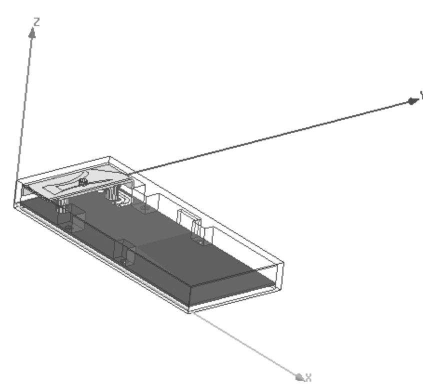

Figure 4: Penta-band bar phone simulation

The radiation patterns obtained for the phone at 824 MHz and at 1710 MHz are shown in Figures 5 and 6 respectively. The plots are shown on a linear scale. The phone is placed as per Method A.

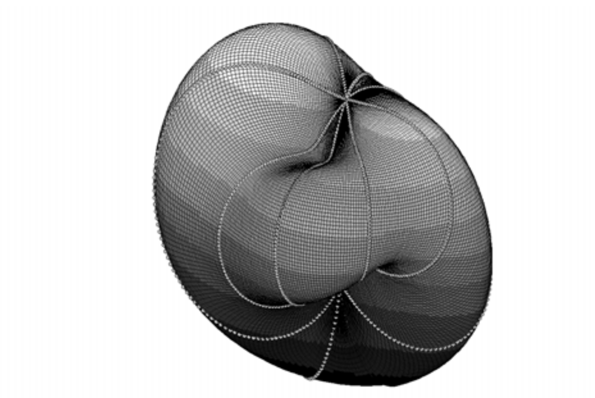

Figure 5: Radiation pattern at 824 MHz

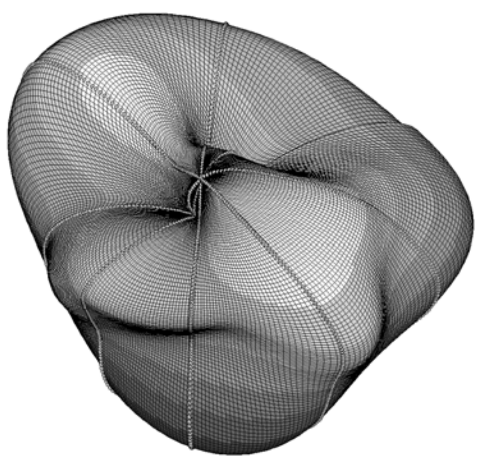

Figure 6: Radiation patterns at 1710 MHz

Highlighted on the radiation patterns in Figures 5 and 6 are 4 great circle cuts. These have been created using a pattern analysis tool. The details of the working of the tool are further elaborated in Appendix A. All the simulations are done using Method A. These cuts define sampling regions over the radiation pattern. A radiation efficiency is then estimated from the sets of cuts taken.

The analysis yields some interesting results on the effect of the number of cuts on the accuracy of efficiency calculations. This can be seen by examining Figures 7 to 12. The plots show the efficiencies across the frequency band in question. Each frequency point sampled is shown as a separate line. The lower line shows the lowest efficiency result estimated for that number of cuts, similarly the high line shows the highest result. The gap between the two lines gives an estimate of the likely error incurred by using that number of cuts. The efficiencies have all been normalized to the efficiency calculated when the entire radiation pattern is sampled, for clarity of illustration. A semi-log scale has been used to show the number of cuts from 2 through to 128, which corresponds to sampling every point of the data set. The data points for a single cut are not shown.

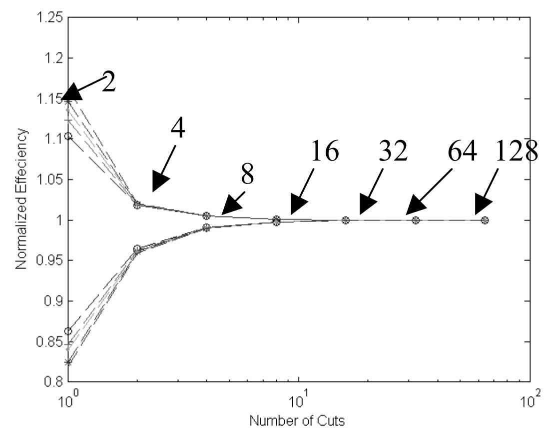

Figure 7: Bar phone over GSM 800 and GSM 900

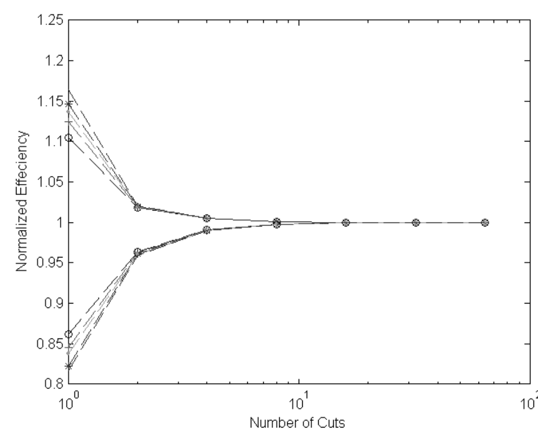

Figure 8: Bar phone over PCS, DCS and W-CDMA

The funnel shape of the plots is as expected. However an interesting result seen is that, the efficiency calculations can be made with relatively little error with as few as 16 cuts. The results also show that for the bar phone simulation, the error spread when under sampling is relatively constant in both the high and low bands.

Applying this analysis to a clamshell style phone resulted in the graphs shown in Figure 9 and 10. The simulations are performed only for the clamshell open as the results for a closed clamshell are quite similar to that of a bar phone.

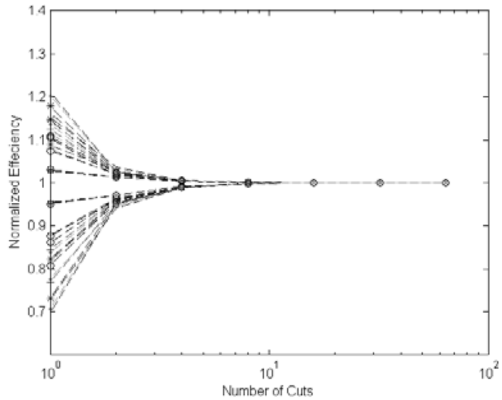

Figure 9: Clamshell phone open position – GSM800/900

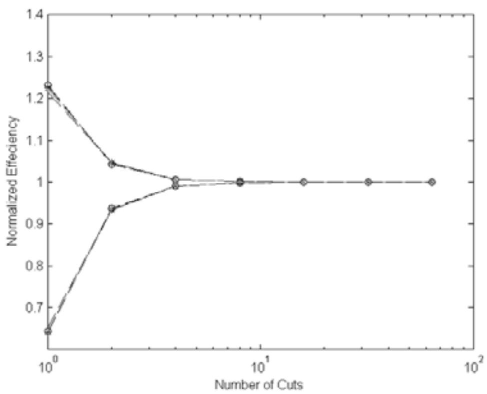

Figure 10: Clamshell phone open position – PCS, DCS

As per the bar phone it is very clear that the efficiency results can be confidently determined with as few as 16 cuts. However for the simulated clamshell, it can be seen that there is a much larger variation in the error introduced by under-sampling the data, when comparing high and low band. In the low band there is much more dependence of the flare of the funnel on frequency. However the average spread will be much closer due to the presence of frequency points with a very tight flare angle, which would end up dominating the mean efficiency. This phenomenon is not observed in the high band.

Finally analyzing slider type phones yields the results shown in Figures 11 and 12. As per the clamshell phone the simulations were only done for the open position.

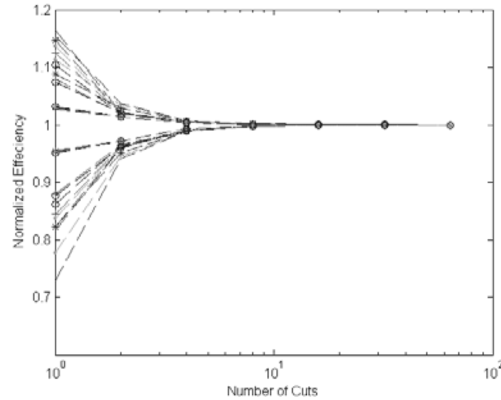

Figure 11: Slider phone open position – GSM 900

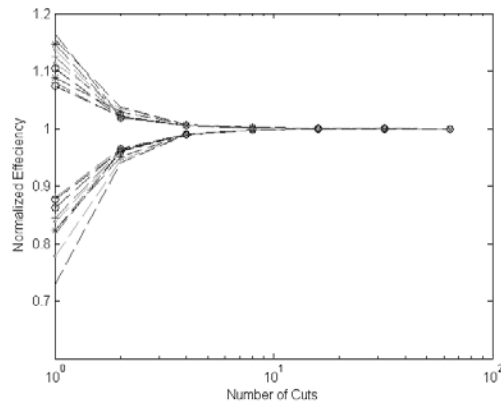

Figure 12: Slider phone open position - PCS and DCS

The slider phone is like the clamshell phone in that the minimum number of cuts required is also very frequency dependant. As per the clamshell phone the average spread is much smaller for the low band than for the high band.

5. Measured Efficiency Measurements

As for the simulations bar, clamshell and slider handsets were measured. All three were measured using method A, the bar handset was also measured using method B. For each measurement eight cuts were taken around the handset, each cut equally spaced in angle by 22.5 degrees. At each angle, measurements were separately taken in both horizontal and vertical polarizations.

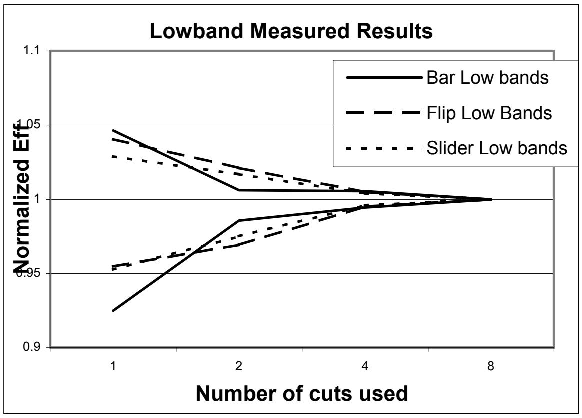

Figure 13:Measured results low band

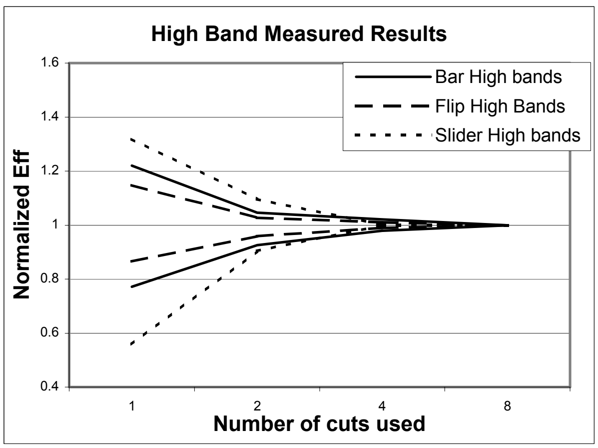

Figure 14:Measured results high band

The measured data presents mean efficiencies across the entire band, as opposed to the simulated data, which shows efficiencies for each frequency sampled. Figure 13 and 14 shows the result of estimating efficiencies from various numbers of cuts. The charts are grouped together for ease of comparison across frequency and phone type. As for the simulated plots the lower line shows the lowest efficiency result estimated for that number of cuts, similarly the high line shows the highest result and the gap is an estimate of the likely error incurred by using that number of cuts. A linear scale is used here since the number of cuts only varies from 1 to 8.

Comparing the bar phone it can be seen that measurements indicate that there is less error incurred by taking a smaller number of cuts across the low band than the high band. This is also the case with the slider phone and the clamshell phone. The results in Figure 13 illustrate that a reasonable estimate of the efficiency can be made with only a few cuts. An estimate based on four cuts will be little different to one based on eight. Figure 13 gives a similar result to the simulated results in Figure 7 to 12. Both also show that there is more complexity in the patterns seen in the high bands than those seen in the low bands. This in turn means that the number of cuts required cannot be readily reduced without introducing error into the calculation for efficiency.

When comparing across phone types the largest error resulting from the use of the fewer cuts is for the high-band measurement of the slider handset. This is mainly because this handset has more complex patterns than the others and therefore requires a denser sampling.

6. Shifting the Poles

Figure 15 shows the measurements of the bar handset taken using method B. Many more cuts are needed for the graph to converge using this method rather than method A as was utilized for the results shown earlier.

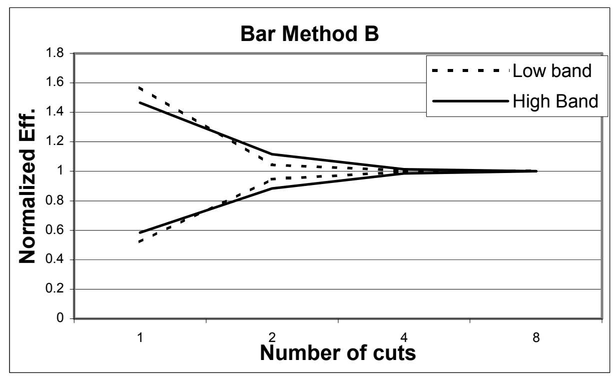

Figure 15: Low and High band meas. results using Method B

It's clear that time can be saved if the number of cuts required for a type of measurement is studied. Using method A, it is easier to reduce measurement time than using method B. There is less gain in speed to be had in the high band than the low band.

Method B has an advantage though. It is normal to connect a cable to a handset by bringing the cable out from the side, this method produces the least disturbance of the antenna's frequency response [3]. This means using Method B it is possible to route the cable away from the handset in exactly the same way for every measurement. This makes it relatively simple to rotate the antenna automatically. It may also have repeatability advantages, but this is not addressed further here.

7. Effect of Polarization on Efficiency Measurements

An interesting side study developed due to the need to measure each polarization when measuring the AUT. The study involved the investigation of the contribution of each polarization to the total radiated power of the antenna.

The polarization is referenced using the polarization of the range antenna. Figure 16 shows the amount of power measured with the range antenna cross polarized to the AUT. The result shown is for the bar handset.

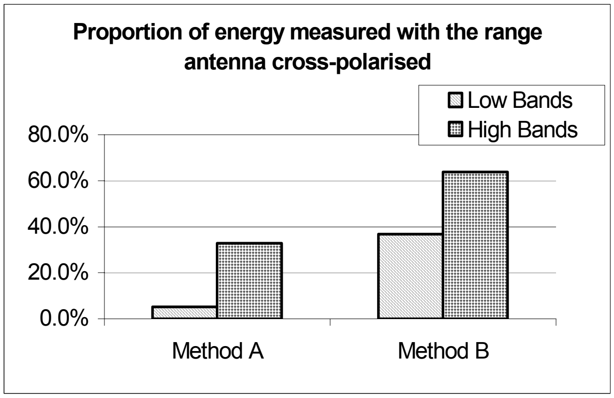

Figure 16: Radiated power in different polarizations

Figure 16 shows that relatively little energy is measured from the cross-polarization, especially in the low-band. This proportion although not shown here was also seen for the clamshell and slider handsets. The slider handset was found to produce the largest amount of power in the cross polarization, 15% of the total using method A.

This means that for the purpose of quick testing of an antenna design the cross polarization measurements may be skipped for the lower bands. There is likely to be little error in doing this and the error will always underestimate the result. However the same cannot be said about measurements in the high band where it becomes necessary to measure both polarizations in order to get an accurate result for the radiation efficiency.

Significantly, it can also be seen that changing the orientation of the antenna with respect to the poles of the cuts will make such a conclusion invalid. This can be seen when the antenna is re-measured using method B. In this case once again it become absolutely necessary to measure both polarizations in order to obtain the right efficiency results. This is because the cross polarization contains a relatively high percentage of the radiated power.

8. Conclusions

Using the funnel charts shown in this paper the number of cuts needed to measure a handset can be minimized. To take quick measurements a number of approximations can be made – such as taking fewer cuts and ignoring cross-polar power while measuring in some bands. For greater accuracy the number of cuts can then be increased as desired. The funnel plots can be used by a handset antenna designer as a guide to the relative error introduced by reducing the number of cuts and thus improving the time required for measurements.

It is important to note that good anechoic chambers have only a gain accuracy of about ±0.5dB, when measuring low directivity antennas. In the case of an efficiency of 50% this produces an error in efficiency of ±5%. This means that for a reasonable number of cuts this error will be larger than the error from sampling of the pattern.

Of further interest would be similar studies done with a phone measured in the presence of a phantom head.

Appendix A

The radiation pattern analysis tool was written in MATLAB. The analysis involves cutting the 3D pattern varying the number of cuts from 1 through to 128. A set of combinations of cuts is then obtained by varying the start angle at which the first cut is taken e.g. for 2 cuts, there are a possible 64 ways of cutting the pattern depending on where the first cut is taken and that the two cuts are orthogonal. The sampling points are always sine weighted [2], as there is a larger density of sampling points at the poles of the pattern, see Figure 2 and 3. The efficiency calculated from each combination is then grouped and the maximum and minimum efficiencies calculated are recorded. This analysis is applied to all frequency points.

9. REFERENCES

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