Correlation between OATS, Fully Anechoic Room and GTEM Radiated Emissions

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Introduction:

Just a few words about myself. My name is Steve Clay and I work for Nokia Mobile Phones, and it is my job to measure our phones which are designed in England.

Radiated Emissions for AMPS Mobile Phone

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In this presentation, I shall briefly describe the experiments that I've done with a mobile phone which will show how the different radiated emissions measurements work in practice.

From an EMC point of view, an AMPS Analogue phone has advantage of continuous RF signal with some interesting radiation patterns - easy to measure because it is very small and can be measured with no connecting leads which can upset repeatability:

This has enabled me to avoid the usual statistical comparison techniques which are very unconvincing.

SPECIFICATIONS

- FCC CFR47 Part 22
  – Transmitter Power (at 850 MHz, +28dBm)
  – Transmitter Harmonics (<-13 dBm)
  – Receive Band (-80 dBm)
- ANSI C63.4

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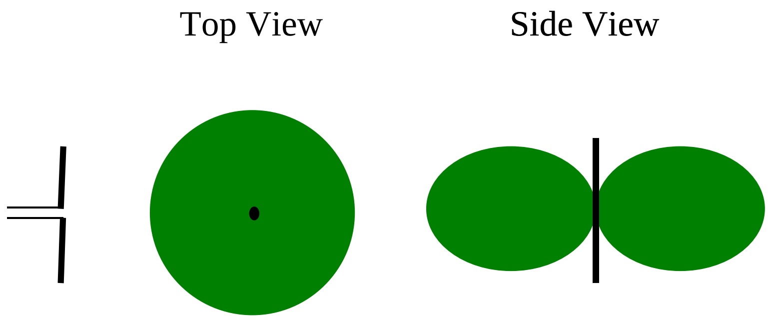
I work in a very fast moving business, and for AMPS phones, we need to FCC approval. As we cannot afford to delay a product launch, it is my jo to ensure that we do not fail by checking the performance during development in our lab.

Just a quick look at one of the specifications we have to meet.

The specifications usually use a 3metre OATS

RADIATION PATTERNS

Half Wave Resonant Dipole

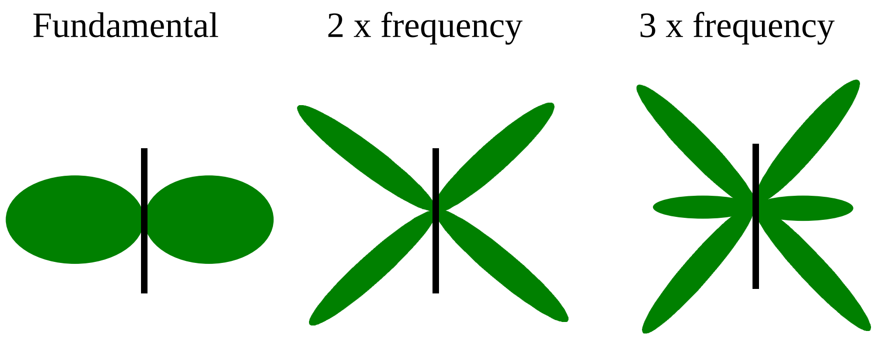


First let us look at some of the patterns we could be measuring.

Here is the familiar picture of the radiation pattern of a vertical half wave dipole; it is omnidirectional from above, and doughnut shaped from the side - approximately.

Elemental dipole gives similar shapes

RADIATION PATTERNS



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However, if we increase the frequency, we get an increased number of lobes, something like this.

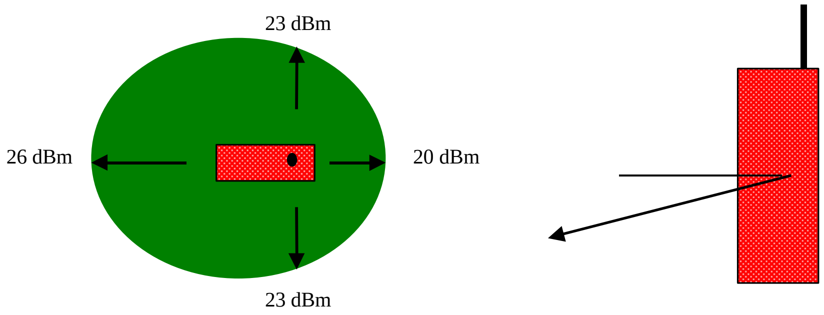
For the case of a mobile phone, non linearities in the Power Amplifier generate 3rd harmonic signals which leak through the duplex filter and can give a similar pattern to that shown.

This assumes a perfect dipole and no radiation from the case.

RADIATION PATTERNS

Mobile Phone fundamental

Top View — Side View



Another cause of directivity was found due to the relative positioning of the antenna and the phone case, and the p.c.b. layout.

This gave greater radiation away from the antenna corner, and also the radiation was also slightly tilted downwards.

I should just strees that this is not a paper about mobile phones, but I do need to explain these patterns to show how the results vary if we choose different methods, and this will now be looked at.

TEST SITES

- FCC TEST HOUSE
  - 3 m OATS
- NOKIA CAMBERLEY
  - Fully Anechoic Room
  - Small GTEM
  - Large GTEM

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I should just explain that this work came about because of differences that we got between our FCC Test House which uses a 3m OATS, and our own facilities which due to lack of space could only house a couple of GTEMs, and an Screened Room which could only be used Fully Anechoic; it wasn't big enough to be Semi Anechoic.

SIMPLIFIED GTEM THEORY

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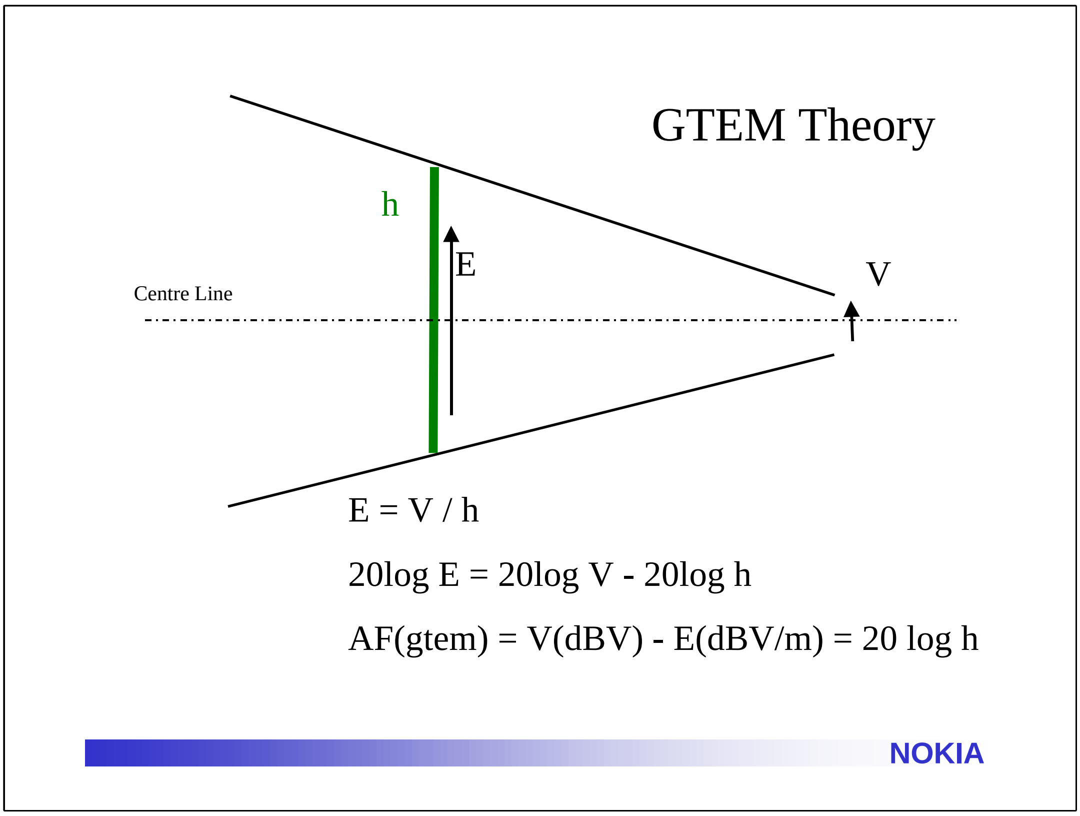
Before describing this, I would just like to describe the simplified method that I have used to derive the GTEM equations.

I should say that anybody who likes pages of equations had better turn away now!

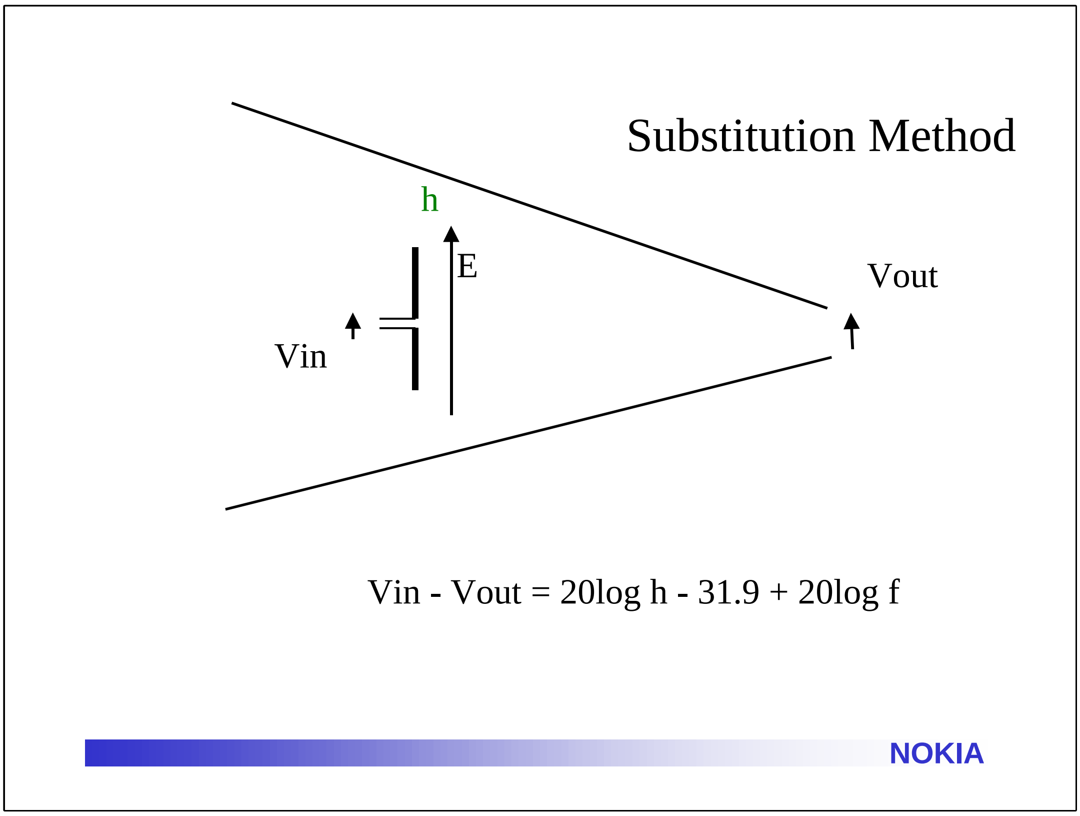


I think it's fair to say that this can be done on the back of a cigarette packet:

For an EUT placed on the centre line, a GTEM is sensitive to vertically polarized radiation in the direction of the apex as shown.

Mathematically, the field at any point is determined simply by the ratio of the voltage and septum height.

If we express this in dBs as an Antenna Factor, the difference between terminal voltage (in dBuV) and field (in dBuV/m)is 20logh.



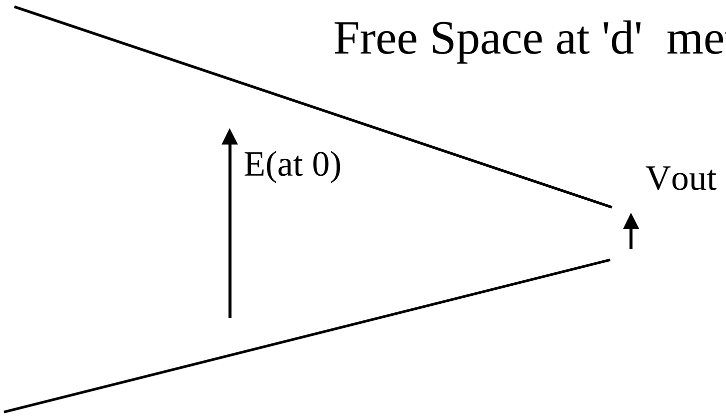
Now, mobile phones are usually specified in terms of achieving the power that would be fed to a half wave dipole substituted in place of the EUT.

My computer used to have the full IEC1000-4-20 equations to give the field and then worked backwards to give the dipole power, although I couldn't understand the theory at all.

I had one of those bathtub thoughts where I wondered "What happens if you just add the GTEM and dipole Antenna Factors together?"

Answer: Exactly the same as for the complicated method!! Not even a need for any correction factor, and it was simply verified using a Signal Generator and Spectrum Analyser.

Free Space at 'd' metres



E(at d) = Vout + 20log h - (32 + 20 log d - 20 log f)

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In a similar simple way, it is possible to extrapolate to the equivalent field at say 10 metres by correcting the GTEM Antenna Factor by the Free Space Normalised Site Transmission Loss.

All of these assume a far field situation of course.

From this we can imagine a GTEM as the limit case of an EUT placed opposite to a Horn antenna with the distance 'd' =0.

IEC1000-4-20 Correlation Algorithm

- Free Space Electric Field
- Resultant Voltage

$$V_{res} = \sqrt{(V_x^2 + V_y^2 + V_z^2)}$$

- Ground Reflection Simulation

Approx. +5dB

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For interest, should you wish the full IEC equations, they can be obtained by using the resultant voltage for 3 orthogonal measurements in the previous equation, and adding a composite V & H ground reflection simulation.

As we shall see, I don't use these equations because they make assumptions that there is no directionality in the EUT, and my mobile phone does not meet this criteria.

OATS

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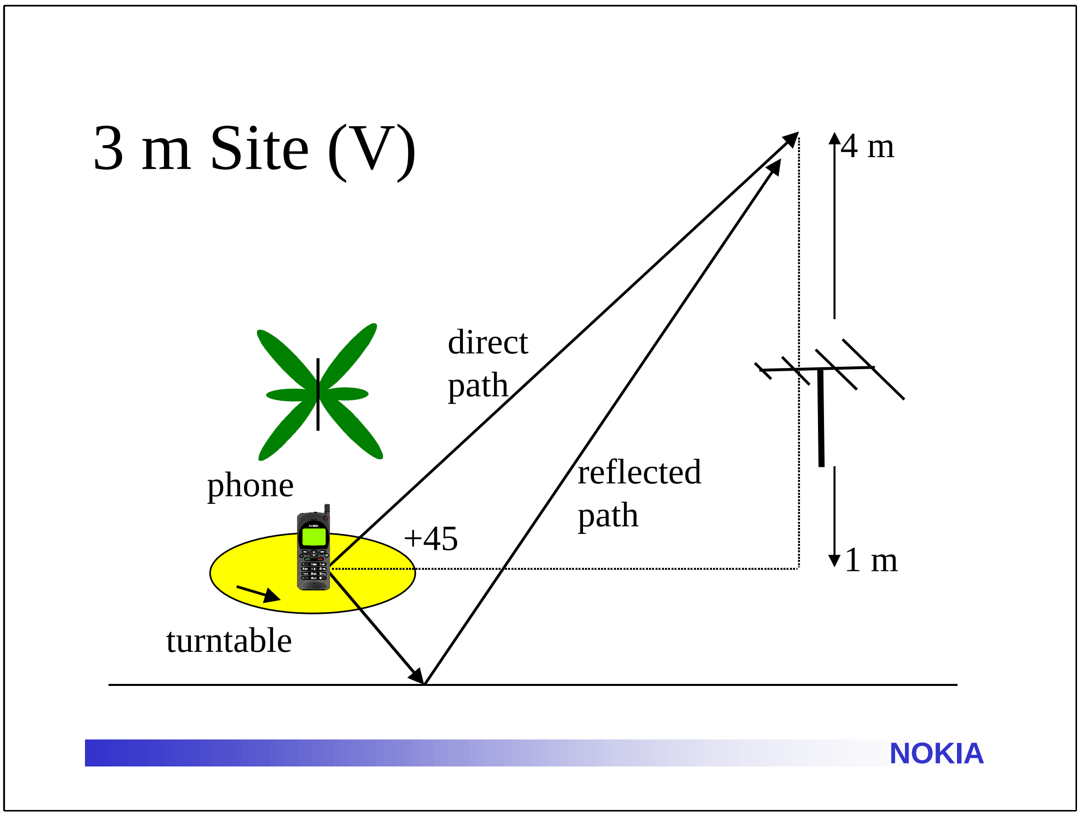
Consider a radiation source with directional characteristics on an OATS.



Picture shows a 3m OATS measuring a 3rd harmonic signal, for example.

Surely there is an ambiguity here.

1. Are we measuring the radiation pattern on a sphere of up to +45?
2. Or are we optimizing the direct and reflected rays?

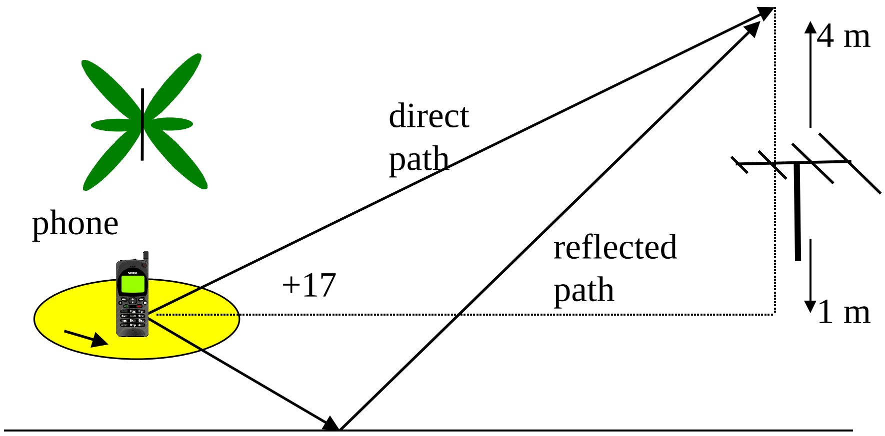
It is actually a mixture.

We could look at the lobe coming out at +45 as antenna moved up and down.

Or the lobe coming out horizontally, as antenna moved up and down.

I challenge anybody to work out exactly what we will get.

10 m Site (V)



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Now not only is the OATS measurement ambiguous, it is also inconsistent between sites - Here's a 10m site

Again, looking at the 3rd harmonic.

It is

1. Distance dependent - a 10m site measures up to +17degrees instead.
2. Antenna directivity dependent - the amount of signal for the direct and reflected paths may not be equal etc.
3. It is very tilt dependent - tilting to an angle half way between the 2 may not give the same gain on the 2 paths and nulls could affect the results.

It is a fundamental assumption that there is no directionality using the OATS, and this si not necessarily be the case.

Universal Specification

"The maximum field strength allowed at a specified distance from the EUT, at a specified frequency, at all angles in an azimuthal plane for both horizontal and vertical polarization"

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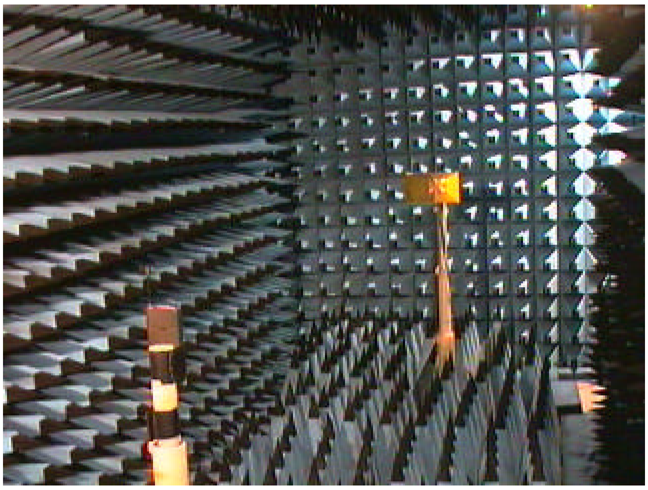
In an attempt to define what is the purpose of the OATS where the omnidirectional criteria is not met, I am suggesting this as a definition

Reading the specifications, it seems that the idea behind the OATS is to measure the radiation from an EUT in the horizontal plane.

Could argue this is undertesting. What about radiation vertically upwards etc.

Or could say overtesting. Shouldn't we only measure a few faces so we don't miss any time varying signals.

Fully Anechoic Room



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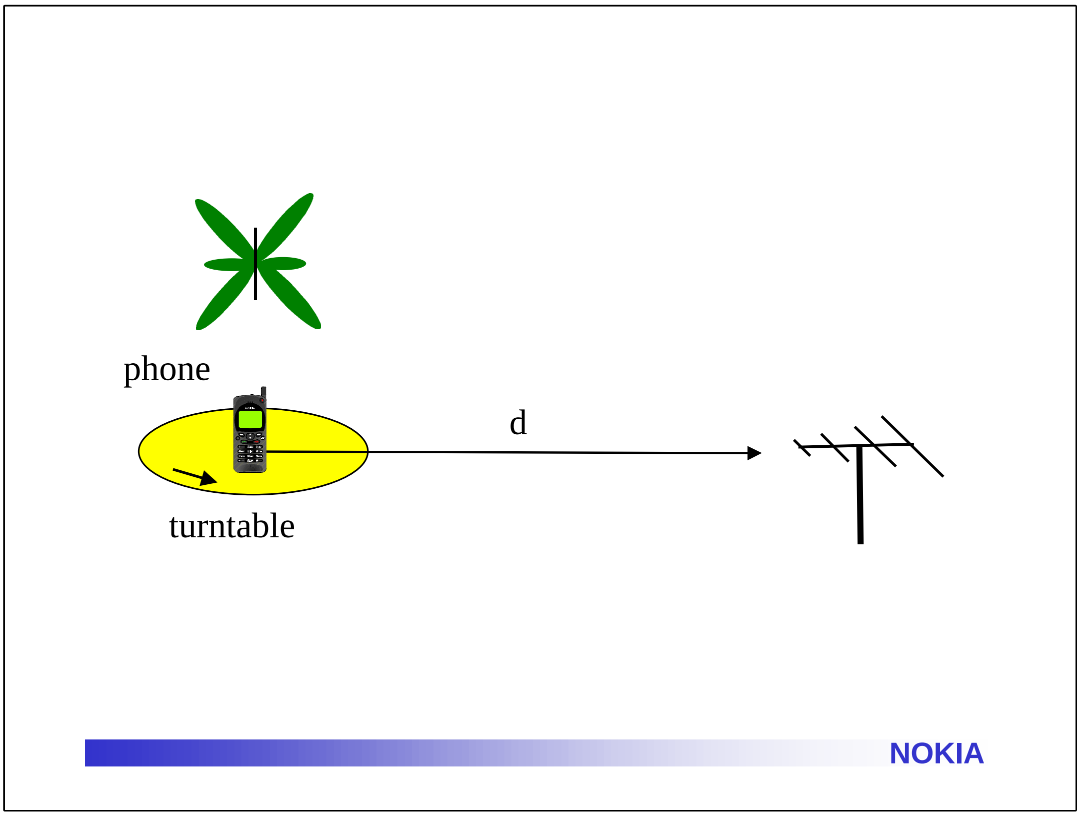
Here is a photograph of our Fully Anechoic Room used to simulate free space.



This is actually a simple case because there is no ground plane, and consequently no height search - the main disadvantage is cost, as it's a case of "The bigger the better" with the best absorber to minimise reflections.

Here, the distance is not critical.

In the 3rd harmonic case shown, there is no ambiguity; we are simply measuring the horizontal lobes and ignoring the angled lobes.

Small GTEM

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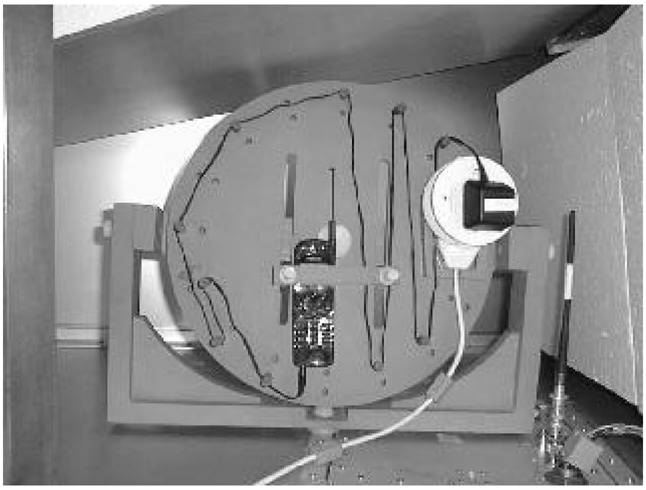
And now for the GTEMs.

Here's a rather old picture of our Small GTEM and its equipment rack.

Phone mounted inside



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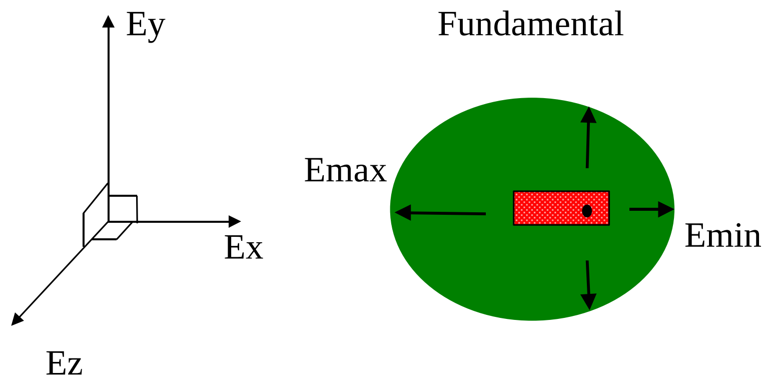
And another picture of a phone mounted on the turntable/ manipulator.

The leads and charger are removed for the measurements.

The turntable need to be improved to make it more electromagnetically transparent.

3 Axis Method (IEC1000-4-20)



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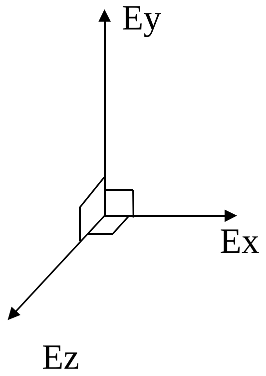
If we look at the specified IEC method with 3 orthogonal measurements, at the fundamental frequency for a phone.

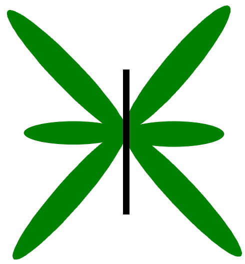
We see that in the horizontal plane, only if E max aligns with Ez, the direction of maximum sensitivity of the GTEM towards the APEX, will we measure the maximum. As the positioning in any plane is arbitrary, Emin could be in the direction of maximum sensitivity instead giving a result which is too low.

The other axes do not couple significantly to the GTEM, and so make little difference to the result.

3 Axis Method (IEC1000-4-20)



3 x frequency



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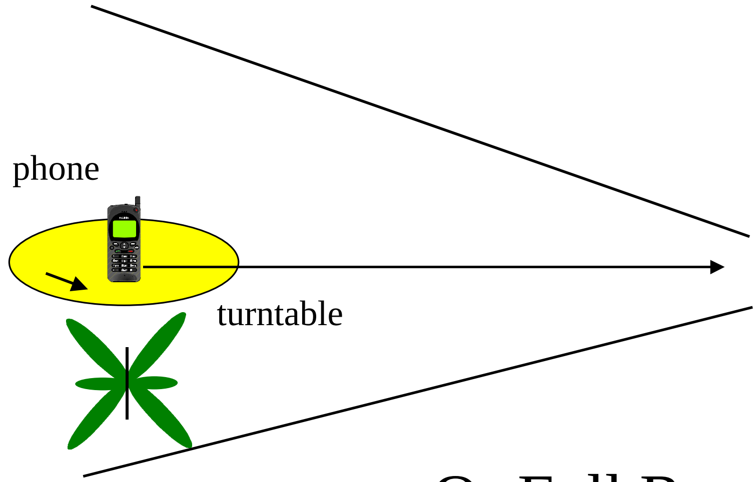
With the 3rd harmonic, it is also possible to measure a maximum lobe which is not in the horizontal plane when the EUT is oriented with the horizontal plane in the Ex or Ey planes instead of Ez.

This can give a result which is too high.

As with OATS , the standard IEC makes assumptions about lack of EUT directivity which is not satisfactory.

Defies common sense to measure in more than one direction at once.

4 Faces Method (V)



Or Full Rotation

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For this work, I then tried measuring 4 faces for vertical polarization and plotting the maximum for all frequencies.

Basically, this method can be considered to be similar to the anechoic room method with no distance between the EUT and the antenna, except that the turntable was rotated by 90degrees to give horizontal polarization instead of the GTEM.

A full rotation was not possible because of the absence of an an automated turntable -the manipulator was just moved by hand. Such a method is dependent on the radiation not varying significantly over a 90degree arc.

EXPERIMENTAL RESULTS USING A MOBILE PHONE

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Now to my actual results.

	(a) OATS	(b) FAR		(c) GTEM 5305		(d) GTEM 5305		(d) GTEM 5311	
AMPS Ch799 S/N 059	V&H max	Vert	Horiz	max	min	Vert	Horiz	Vert	Horiz
TX fund 849MHz	24	25 ±0.5	12 ±1	25	17	25	16	26	12
TX 2nd harm 1.7GHz	-35	-36 ±3	-39 ±1	-33	-40	-37	-44	-35	-40
TX 3rd harm 2.55GHz	-34	-30 ±5	-31 ±5	-22	-31	-26	-29	-31	-33
TX 4th harm 3.4GHz	-42	-42 ±2	-42 ±3	-41	<-48	-46	-44	<-45	-43
TX 5th harm 4.25GHz	-33	-30 ±4	-33 ±3	-30	-38	-28	-32	-29	-41
TX 6th harm 5.1GHz	-25	-29 ±4	-23 ±0	-27	-35	-30	-26	-30	-25
TX 7th harm 5.95GHz	-20	-20 ±5	-22 ±5	-26	-33	-30	-20	-28	-30
RX Band 878MHz		-73	-83	-74	-85	-76	-94	-77	-87
RX Band 887MHz		-75	-84	-77	-85	-81	-95	-77	-88

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FAR: This method is closest to the universal specification.

OATS Surprisingly, the OATS results are fairly comparable with the other methods.

This is partly due to the lack of ground reflections at higher frequencies, and no antenna tilting was employed.

It is noticeable that the transmitter power wasn't approximately doubled as expected, and the large 3rd harmonic angled lobe was not measured.

Hence, the results were comparable because the full OATS method had not or could not be followed.

GTEM 3 axis algorithm, for the transmitter, we get an arbitrary range of results, even getting 17dBm instead of the 25dBm of the other methods which is not acceptable.

GTEM 4faces, although not fill rotation, reasonably comparable.

With more work, I hope to improve the agreement particularly at the higher frequencies.

CONCLUSIONS

- Both OATS and GTEM 3 Axis Correlation Algorithm Methods have directional ambiguities.
- For consistent results, the directions to be measured must be specified.

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The first obvious point is that the OATS and GTEM 3 axis and other methods are unsuitable for EUTs with directional characteristics, and the users of these methods should prove that their EUT is not directional before accepting any results. It is particularly disturbing when methods which give arbitrary or inconsistent are mandatory.

Secondly, what we have managed to do is to specify different directions for OATS, for Antioch Room, and for GTEMs.

I find it almost embarrassing to stand here and say something so obvious, but is important to measure the specified and consistent directions.

FURTHER WORK

- Effect of EUT size
- Effect of leads
- Lower frequency and Higher frequency limitations

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One of the things I hope this paper will do is to stimulate people to look at the consequences of this work, and some examples are shown on the slide.

The first 2 depend on antenna beamwidth.

How far down in frequency can you go before worrying about near field effects / ground reflections?

Improved tilted and electromagnetically transparent turntables for GTEMs would be useful.

Images in GTEMs

Field direction in GTEM off centre line is not towards the apex.

SPECIFICATIONS

- Remove ambiguities - cannot assume no directionality
- Reciprocity between Emissions and Immunity

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A final shot if I may:

1. Specifications need some overhaul.

In particular, the OATS method has problems below 1GHz.

2. Relationship between an EUT and its environment must be reciprocal.

Going from immunity to emissions just just involve removing an amplifier and connecting a spectrum analyzer.

This applies to:

4 face FARs for immunity vs full rotation OATS for emissions.

RF Common Mode CDNs vs Conducted Emissions LISNs

etc.