

# ANAMET REPORT

ANAMET Report 012

December 1997

Destination Unknown:  
A journey into the repeatability of  
WG25 measurements on an ANA

J P Ide

ANAMET reports are produced by, and for, the members of ANAMET. They are intended for fast dissemination of technical information for discussion purposes and do not necessarily represent an official viewpoint. No responsibility is accepted by the author(s) or ANAMET for any use made of the information contained in this report.

For further information about ANAMET and its activities contact:

internet:        **<http://www.npl.co.uk/npl/collaboration/clubs/anamet/index.html>**  
e-mail:         **[anamet@npl.co.uk](mailto:anamet@npl.co.uk)**

Comments on this report should be sent to:

mail:            **ANAMET  
Building 72  
National Physical Laboratory  
Queens Road  
Teddington  
Middlesex  
TW11 0LW**

fax:             **0181 943 7176 (UK)  
+44 181 943 7176 (elsewhere)**

Extracts from this report may be reproduced  
provided that the source is acknowledged.

*This report has been approved by the ANAMET Steering Committee.*

Destination Unknown: A journey into the repeatability of WG25 measurements on an ANA.

<sup>1</sup> J P Ide, DERA, St Andrews Road, Malvern, WR14 3PS.

### **Author's comment**

During an investigation on a WG25 extension to an HP8510C ANA I decided to examine in detail some aspects of the repeatability of the measurements. This report is an entire personal view and although it is presented in a light-hearted manner, the problems looked at are not trivial. It is, by no means, an exhaustive examination and the route taken was determined by the results as it progressed. The results are not conclusive in any sense but I hope that this record adds to the general body of knowledge (or confusion) on the subject and possibly provokes others to take up where this work leaves off.

### **Abstract**

This report is mainly a pictorial record of an examination into the repeatability of the measurement of voltage reflection coefficient of a 1-port WG25 (WR15, R620, V-band) device. The report looks at the repeatability in terms of magnitude and phase and real and imaginary components and the correlation between the parts. Some comments are made showing the reasoning behind the selection of the forms of presentation as the process developed but generally the plots are presented in such a way that each reader can and should draw their own conclusions.

### **Data Collection**

A single 1-port calibration of a WG25 extension was performed over the frequency range 50 - 75 GHz at 0.1 GHz steps using a short-circuit, an offset short-circuit, a load and an offset load as calibration items. A device, consisting of a nominal 10 dB attenuator with a short-circuit at one end, was attached to the measurement port and error corrected measurement data was taken and stored using <sup>2</sup>SoftPlot. The device was disconnected and inverted before re-connection and re-measurement. This process was repeated until a total of six measurements had been performed consisting of three conventional connections and three inversions. The waveguide flanges are not sexed in any sense so the descriptions 'conventional' and 'inverted' are not absolute, only relative to the orientation of the first measurement. This seems better nomenclature than 'non-inverted' and 'inverted'. If the waveguide orifices of both test port and device are rectangular and symmetrical with the alignment pins then there should be no difference between the conventional and inverted measurements. However, if there are significant differences between the two connection positions then this might indicate a mechanical or manufacturing fault requiring further investigation. The data consisting of six sets of real and imaginary components at 251 frequency points comprises the entire data set for this analysis and all the subsequent plots derive from this data or a subset of it.

---

<sup>1</sup>The author was on loan to the National Physical Laboratory, Teddington, UK. at the time that this evaluation was performed.

<sup>2</sup> SoftPlot Measurement Presentation Package. P & H Technology Consultants, 10 Teversham Road, Fulbourn, Cambridge, UK, CB1 5EB.

**Plot 1:** The magnitude of the VRC for the six connections shown against frequency.

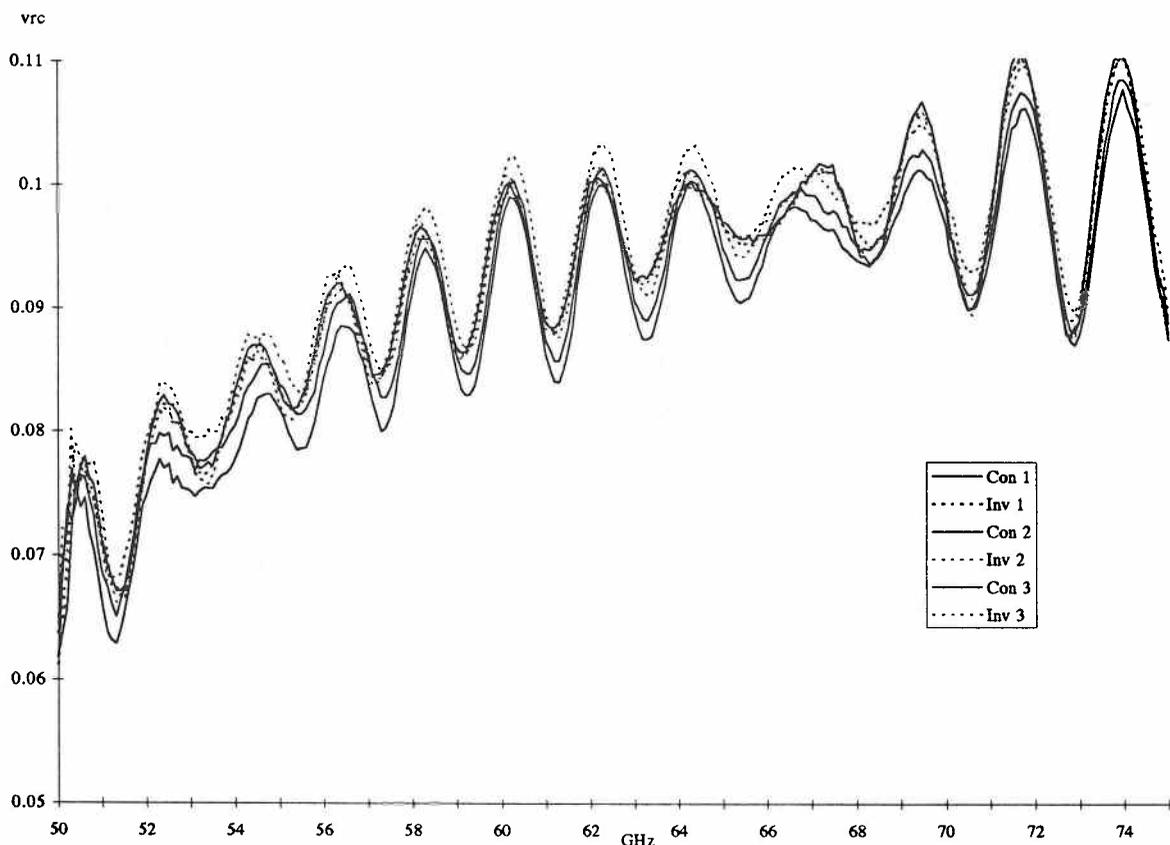
The 'conventional' and 'inverted' connections are shown using solid and dotted lines respectively. The plot shows considerable ripple implying at least two reflections beating with each other. As the device consists of a waveguide attenuator terminated with a plain short-circuit, it is not unreasonable to speculate that the major components are the attenuated short-circuit and the reflection from the front face of the attenuator. The spacing of the peaks should align with the electrical length of the attenuator. The attenuator is about 60 mm long which gives a 'there and back' path length of 120 mm.

First check electrical length:

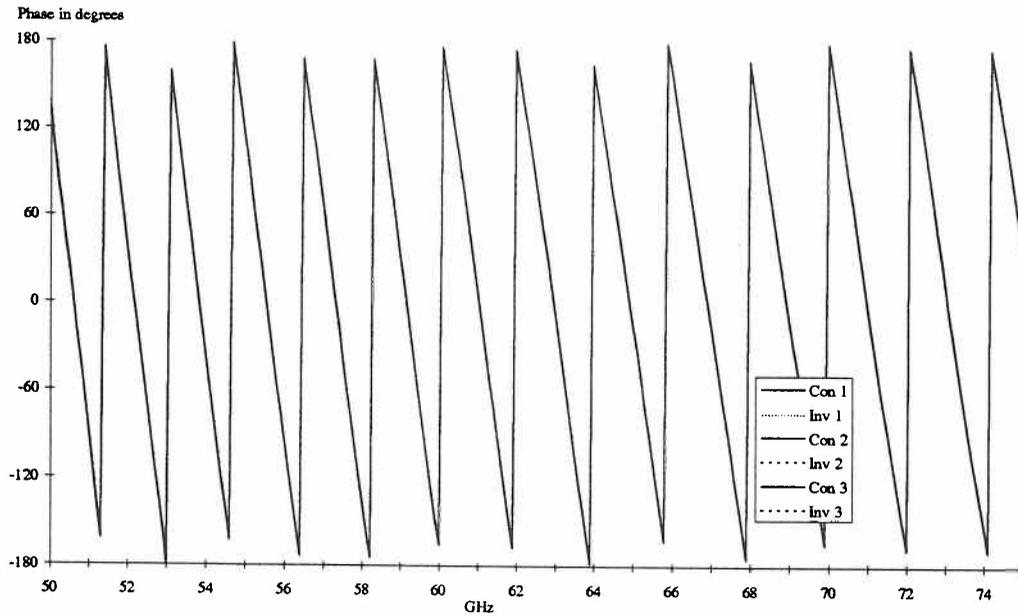
The plot shows (among over things) adjacent peaks at 62.3 GHz and 64.3 GHz. I don't have values for the guide wavelength at exactly these frequencies but I have a reference table with values that are fairly close; i.e. 62.5 GHz and 64.5GHz so I will use those instead.

At 62.5 GHz  $\lambda_g = 6.229$  mm and at 64.5 GHz  $\lambda_g = 5.914$  mm. If there are  $n$  complete cycles in length  $\ell$  at 62.5 GHz then there will be  $n+1$  complete cycles at 64.5 GHz, because the peaks are adjacent  $\therefore n/(n+1) = 5.914/6.229 = 0.94933$ .  $\therefore n \approx 19$  and  $\ell = 19 \cdot 6.229 \approx 118.4$  mm. This agrees well with the nominal mechanical length of the attenuator above thus confirming the source of the ripples.

As a preliminary observation the solid lines look to be less well grouped than the dotted ones, this might imply poorer repeatability for one orientation than the other. I will have to see if the same effect is noticeable in the phase measurements.

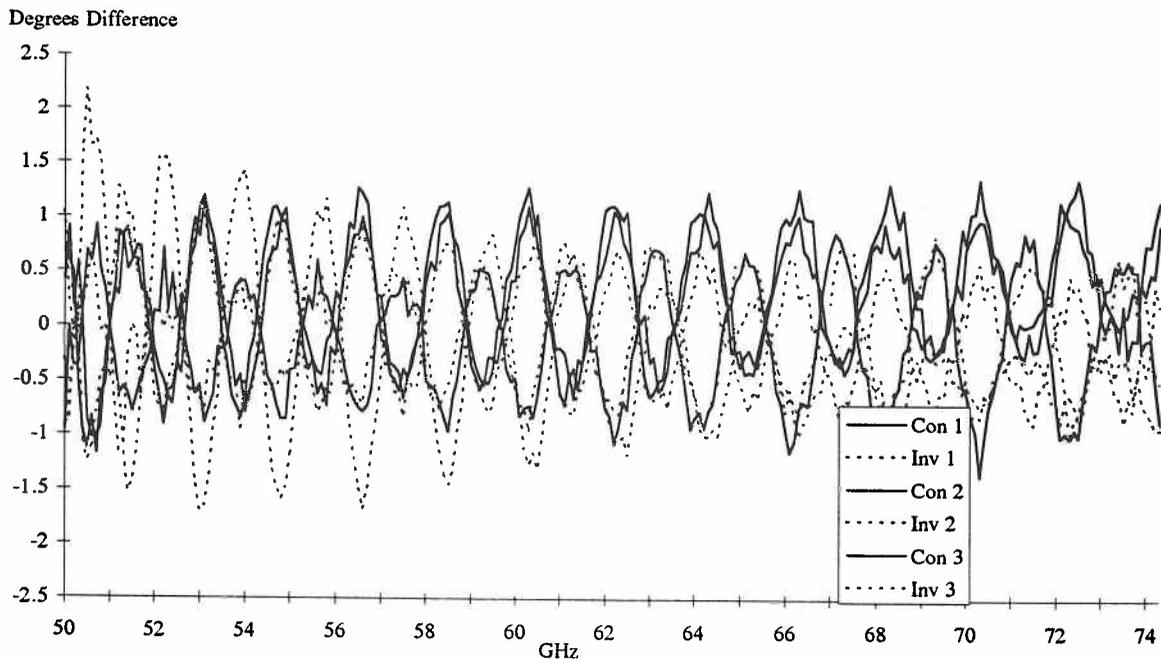


**Plot 2:** The phase of the VRC for the six connections shown against frequency.



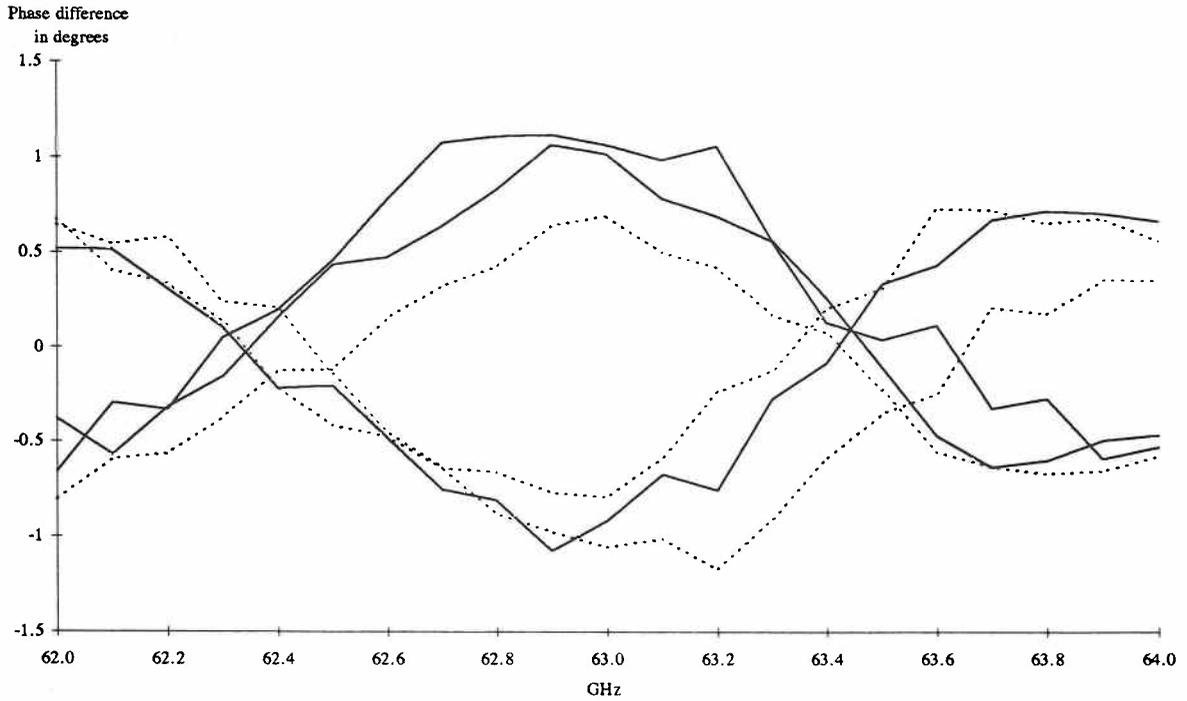
This doesn't show anything useful at all. I will have to find the mean value (I bet NMR would use the Median!) and display the differences from the mean instead.

**Plot 3:** The differences from the mean phase of the VRC for the six connections shown against frequency.



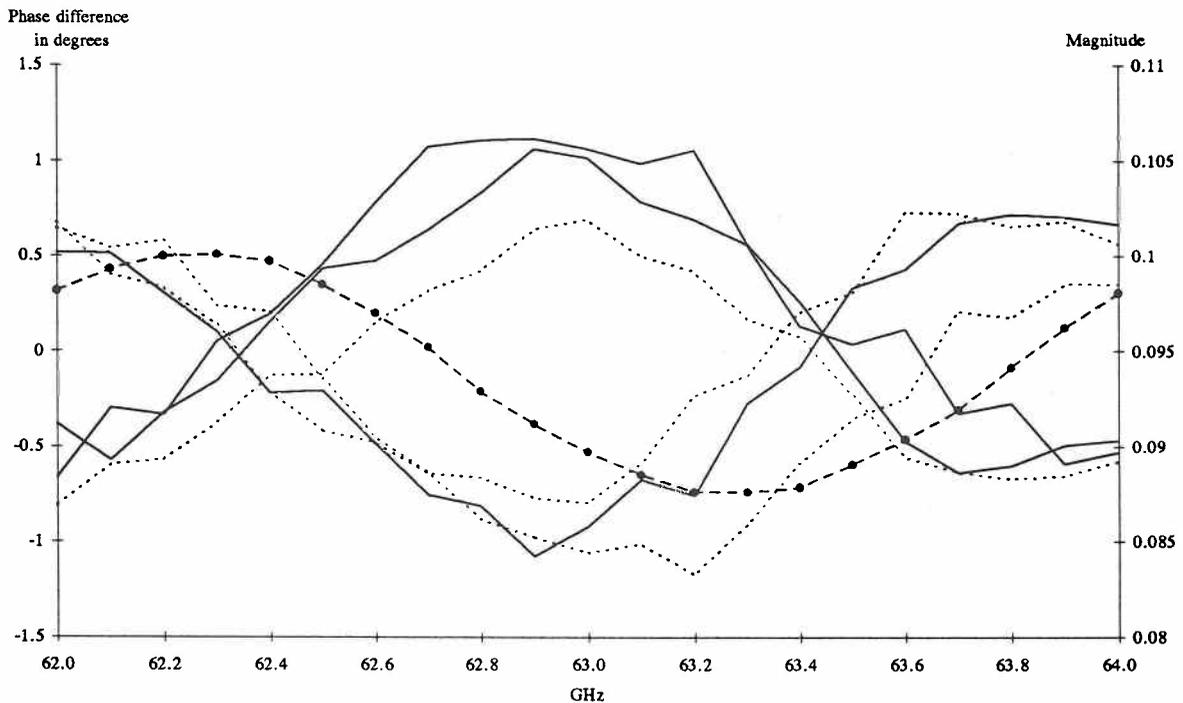
Wow! Lots of structure, i.e. patterns. Why should the phase differences become very small at regular spaced frequencies? What is special about some of the frequencies and how far apart are the special frequencies? To answer some of these questions I will examine just a small part of the frequency range and expand it. I will use the same solid or dashed line convention but dispense with the key on the plot because it tends to obscure vital detail and distract the eye.

**Plot 4:** The differences from the mean phase of the VRC for the six connections shown over the frequency range 62 to 64 GHz.



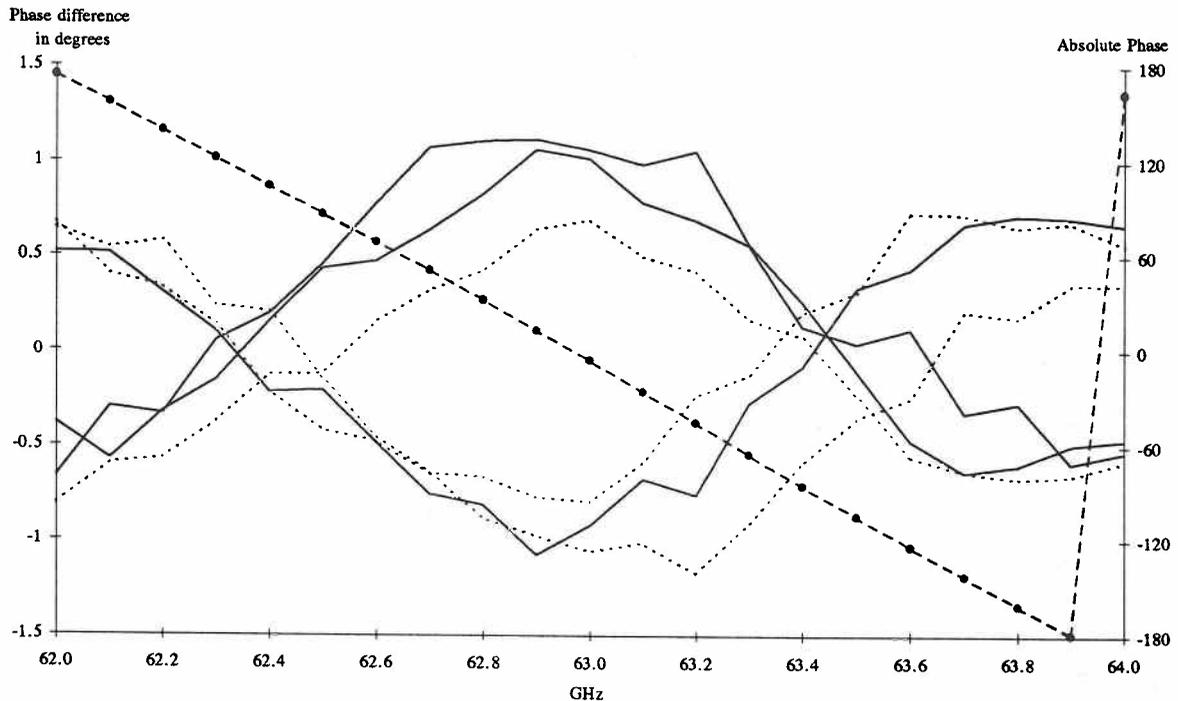
This is more like it. There is obviously something going on at 62.4 GHz and 63.4 GHz, i.e. every 2 GHz. This also shows that for phase measurement there does not appear to be any difference in the repeatability between the two orientations. If there is a difference, then it is being swamped by something else. So far I have discovered that the item has a magnitude ripple every 2 GHz and the phase uncertainty goes through a minimum every 1 GHz. All I need to do now is plot the magnitude ripple and phase unrepeatability on the same axis to determine the relationship.

**Plot 5:** The differences from the mean phase of the VRC for the six connections shown over the frequency range 62 to 64 GHz with the magnitude shown (as a dashed line with dots on it).



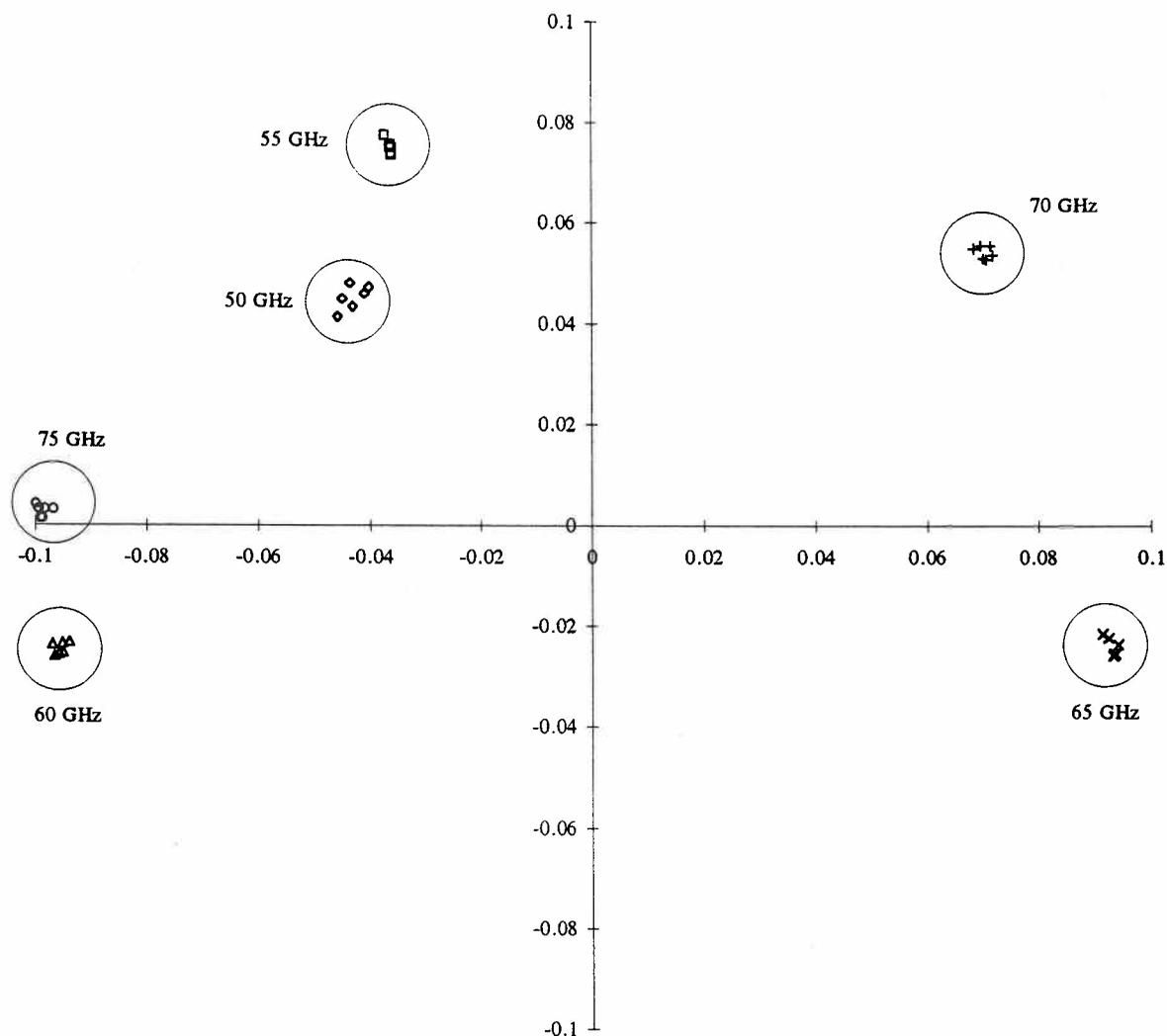
The previous plot showed that the maximum phase unrepeatability occurs at a frequency slightly higher than the frequency at which the magnitude is changing most rapidly with frequency, and the minimum unrepeatability at a slightly higher frequency than the frequency at which the magnitude is changing most slowly with frequency. This frequency shift might be significant or it might be that each of the six traces would be offset by a slightly different amount. For completeness I will also plot the phase variation vs the phase of the reflection coefficient to see if there is better correlation.

**Plot 6:** The differences from the mean phase of the VRC for the six connections shown over the frequency range 62 to 64 GHz with the absolute phase shown (as a dashed line with dots on it).



At last! Something definite. It is clear that there is no correlation between the phase repeatability and the absolute phase of the reflection coefficient. OK, so I've got some connection between the variation in phase repeatability and the position in the cycle of the ripple in the magnitude but I haven't yet resolved if the orientation of the waveguide makes a difference. One way to do this is to plot the results spatially, ie as positions in the complex plane. This should show if there are two camps (using the word as a form of short-hand or jargon to describe distinct sets of values) or just general scatter. One of the difficulties with using this plotting package is making the scale of the axes appear the same during printing so that circles appear as circles and not ovals.

**Plot 7:** Scatter plots for the six measurements at selected frequencies.

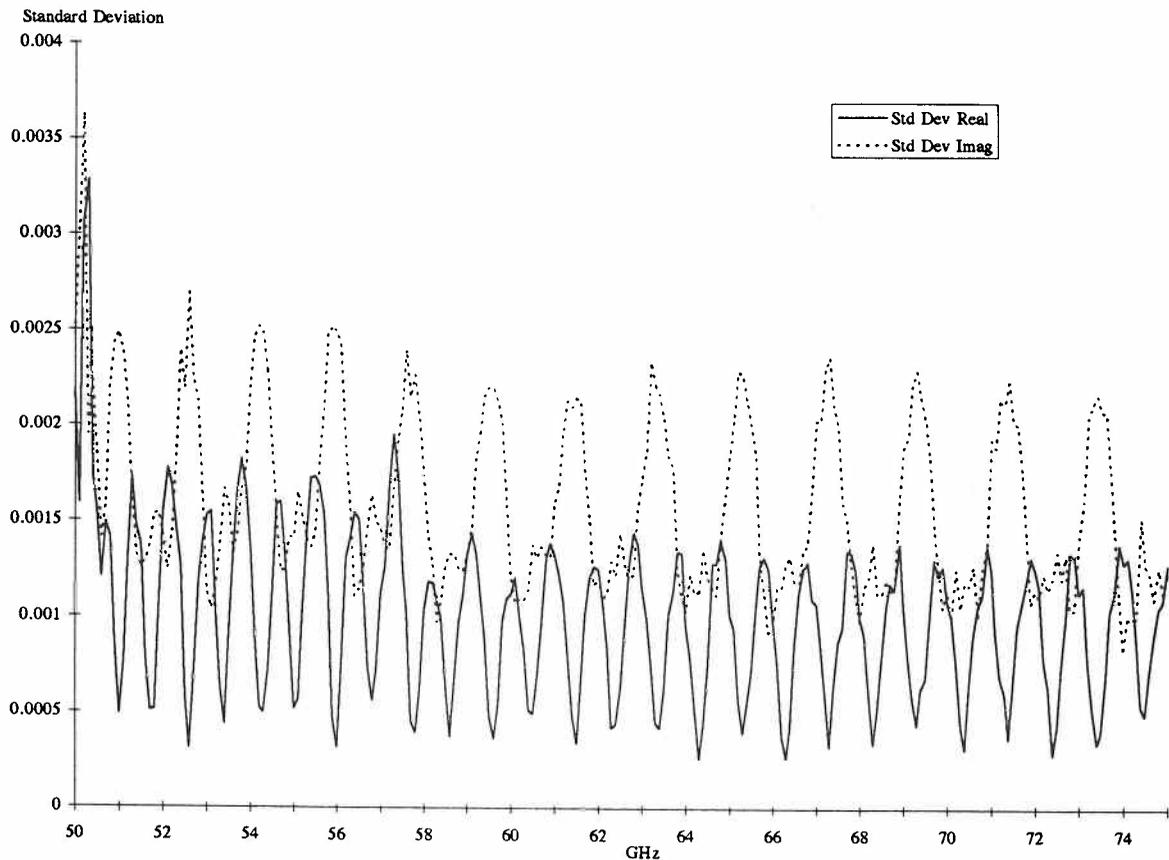


Even though I have not distinguished between the two measurements taken in the two orientations it is quite clear from examining the contents of the circles shown on the plot that there are not two camps at any of the frequencies shown. From this I conclude that the orientation is irrelevant and that the six measurements can be taken as coming from a single camp or population. This completes the first part of the investigation.

Having established that the measurements all come from the same population I can now start investigating the repeatability of the real and imaginary parts and any correlation between them.

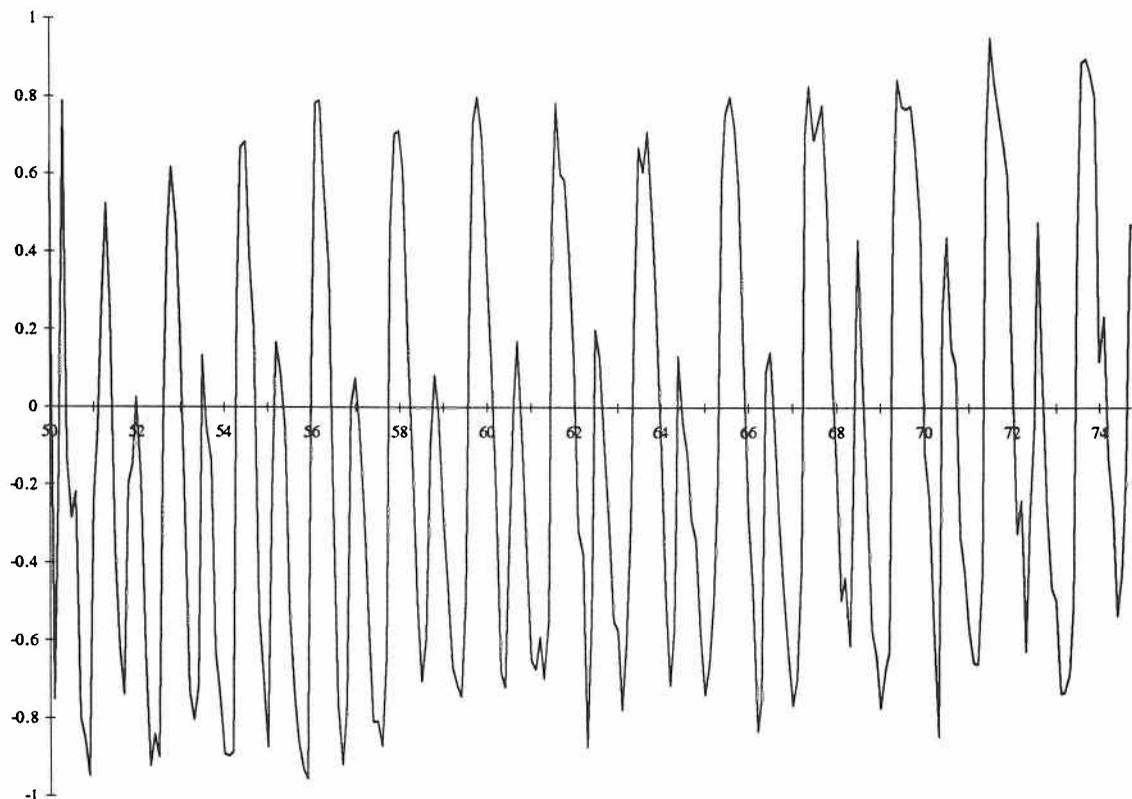
First I shall plot the standard deviation of the real component and the standard deviation of the real and imaginary component as functions of frequency to see if there are any relationships.

**Plot 8:** Repeatability, as standard deviations, of the real and imaginary parts of the VRC as a function of frequency



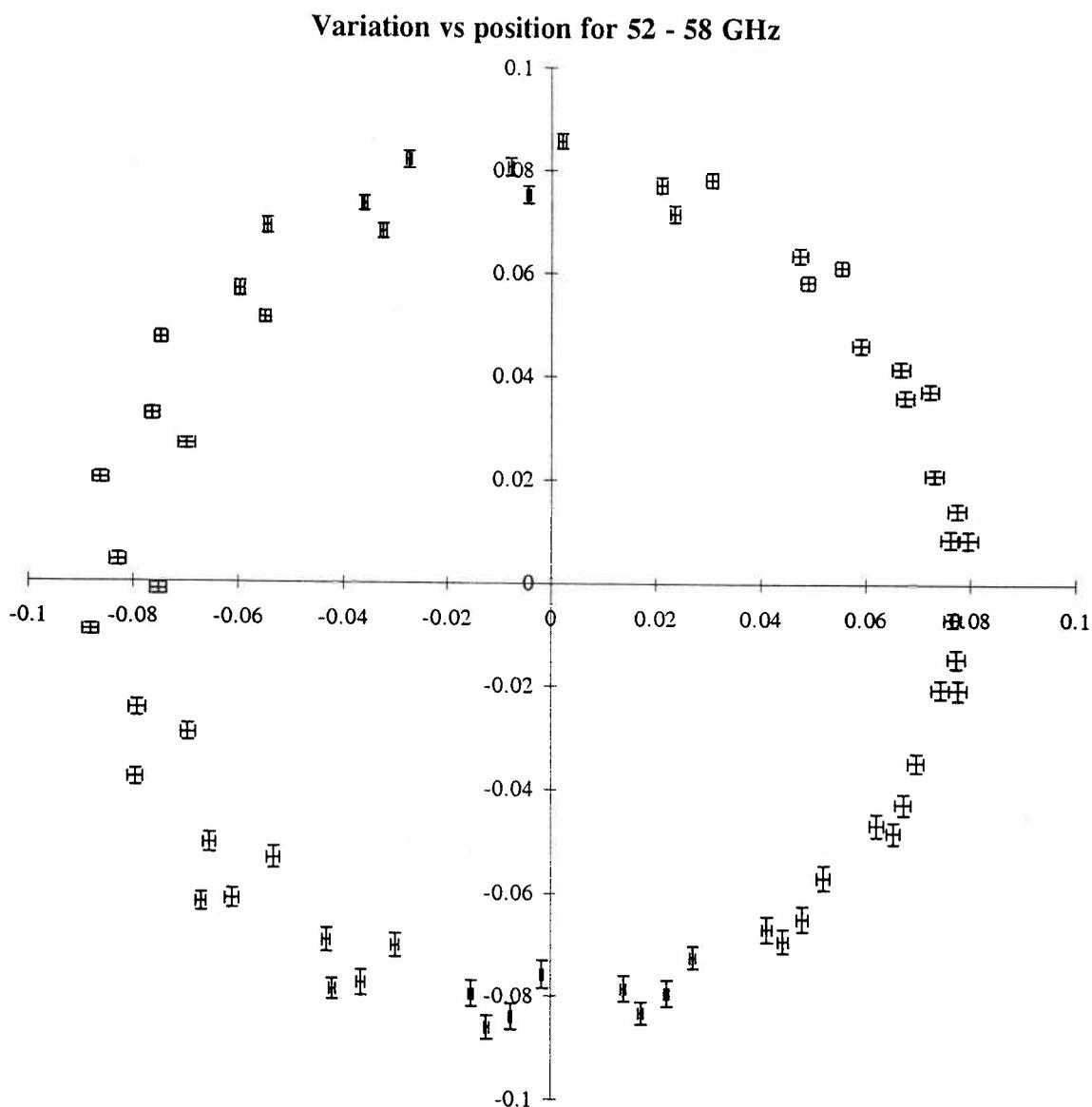
Some observations. The standard deviation in the imaginary part varies periodically with a period of about 2 GHz while the standard deviation in the real part has a period of 1 GHz. These cycles are in step. The average value (by eye) of the standard deviation in the imaginary part is either a) twice the size of the average value of the standard deviation in the real part or b) 0.001 greater than the average value of the standard deviation in the real part. From the data so far presented there is no way of predicting whether under different conditions the size of the standard deviation in the imaginary part will always be twice that of the real part or 0.001 greater than that of the real part. The standard deviations in the real and imaginary parts are obviously correlated to some degree and it seems like a good idea to plot their correlation as a function of frequency.

**Plot 9:** Correlation between the size of the variations in the real and imaginary components plotted against frequency



I think that this confirms my impressions from plot 8. The variations in the real and imaginary parts are strongly linked together but one appears to be changing at twice the rate of the other. I cannot think of any convincing explanation for this phenomenon. Although I know from a previous plot (see comments after plot 6) that it is not related to the absolute phase of the item because that changes too slowly, I think I will plot some points showing the variation in the real and imaginary parts against the position of the points in the complex plane to see if this gives any inspiration. The way to do this is to plot each point on a scatter graph so that its position on the complex plane is correct and then add error bars whose length reflect the variation in that coordinate. This means that points at which the variations in the real and imaginary plain are equal will have equal length error bars etc.

**Plot 10:** Plot of the size of the variations in the real and imaginary components for the points in the frequency range 52 - 58 GHz at the position of that point in the complex plane.



The plot above shows very clearly that repeatability in each of the Real and Imaginary components depends on its position in the complex plane which completely contradicts my earlier conclusions about the connection with phase. Under the circumstances I feel that I can only conclude positively that the repeatability of connection of a WG 25 item depends on the position of its voltage reflection coefficient in the complex plane. The relationship between the size of the standard deviations in the real and imaginary components is not simple but it is obvious that where the repeatability is the dominant uncertainty then the concept of circles of uncertainty does not apply to these, and possibly many other, reflection measurements.

I still have not identified the causes of the variation in the repeatability but it probably relates to the electric current flows. A short-circuit has low voltage and high current while an open-circuit has the opposite and it would seem reasonable that the variation would be less where the current is less. However, this does not explain many of the effects observed above.

I think that I have reached the end of this particular journey and so.... it's over to you!

