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Radar waveguide measurements using a network analyser's time domain option: some good practice tips

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1. INTRODUCTION

We have made radar waveguide measurements for many years. These measurements have two purposes. One is to find the location of a fault and repair it, while the other is to analyse the line, check that it is in specification and save the results for future use. Today these measurements are made using an HP8720C vector network analyser (VNA) and its time-domain option.

These measurements are made for mobile radars, navy radars and radar ground stations. The main measurements include frequency-domain, insertion loss and time-domain measurements.

The key point is that every measurement document includes all the necessary information: how the measurements were made; what was the frequency band; number of points; calibration method; calibration kit; windowing function and gate shape. This enables us to reproduce the measurement set-up at a later date, if required.

ANAMET Report 027 [1] includes more information for the windowing function, gate shape, etc, which affect measurements made using the VNA's time-domain option.

2. MEASUREMENT EXAMPLE

This section describes one typical measurement, step by step, because it includes many practical tips for the waveguide measurements.

2.1 BASIC SET UP

Check what is the waveguide band (i.e. frequency range) to be used (these are usually narrow band measurements), how long the line is, and what is the minimum resolution (meters/ns) that is required.

For a given frequency range and line length, calculate the range in nanoseconds by using the formula:

$$Range(ns) = \frac{m}{c}$$

where c is the speed of electromagnetic radiation in vacuum.

Use the next formula to calculate approximately, how many measurement points you required:

$$N = \frac{Range(ns)}{\Delta f}$$

where N is the number of points, Δf is the frequency band (in GHz) and $Range(ns)$ is the measurement range (in ns).

If you want to know more accurately the maximum waveguide length (meters) of the line that you can measure, you can calculate it using the following formula:

$$Range(m) = ((\frac{\frac{N-1}{\Delta f}}{2}) \cdot c) \cdot 0.855$$

where c is the speed of electromagnetic radiation in vacuum and X (see Table 1, below) is the approximate coefficient of velocity factor of waveguide (based on practical experience).

Table 1 applies to measurements in waveguide R84 (WR112 , WG15), the bandwidth of which is 6,58 GHz - 10,0 GHz.

Frequency Band	Coefficient of velocity factor	
GHz	X	$X/2$
7 -8	0,7	0,35
8 -9	0,78	0,39
9 - 10	0,83	0,415
6,6 - 10	0,78	0,39

Table 1

The coefficient of velocity factor in waveguide depends on the measurement frequency. This is because waveguide is a very dispersive medium.

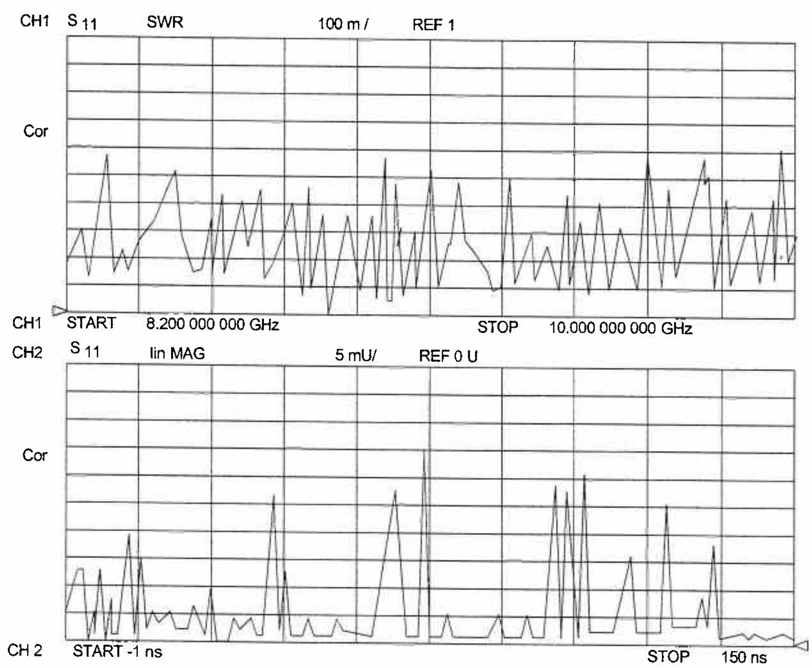
When preparing to make the measurements, add 5 - 10 meters to the line length in the calculation, because it is important to see a few meters forward from the antenna and see from the trace if there are reflections which could affect the results displayed (S11 in the frequency-domain).

2.2 VNA CALIBRATION AND DISPLAY SET UP

Calibrate the VNA using the appropriate waveguide calibration kit. Use either a one-port or TRL calibration. Be sure that the test port cables are long enough. Record all the calibration details.

After the calibration, set the VNA in dual channel display mode so that the frequency-domain display and the time-domain display can be seen simultaneously on the CRT.

As an example, we use the frequency-domain display format SWR, scale 100 mU/Div and time-domain display format Lin Mag, scale 10 or 5 mU/Div and stop time as the maximum measurement value (range). Picture 1, below, is a typical VNA display.



Picture 1

A velocity factor of *X* /2 can be used (based on practical knowledge, see Table 1), then the marker will show directly (in meters) where a discontinuity is located.

The reason for these settings is that its easy to see immediately if everything in the line is as expected.

2.3 CONNECTING TO THE WAVEGUIDE LINE

Connect the calibration kit adapter as close as possible to the transmitter.

CAUTION: Be sure that no other radar is operating nearby, as the output power may destroy your VNA through the waveguide test port!!

Put some reflecting material just in front of the feed horn, in order to learn the point where the waveguide line ends.

Use the VNA display mode DATA (&) MEMORY to check that the time-domain scale is of sufficient length. (reflect ON / OFF)

Remember that there should be a few meters free space in front of the feed horn/reflection. This is the only way to be sure that you are measuring in the waveguide line and not reflections in front of the antenna.

2.4 ANALYSING THE LINE

After the line length and external reflections have been checked, analyse all the peaks on the trace.

Peaks which are approximately 40 mU or larger, in Lin mag mode, should be checked. Remember that line insertion loss has an effect on peak magnitude.

If the observed peak has some logical explanation, then it is OK. However, if there is not a logical explanation, then the reason for reflection must be investigated further.

In addition, the GATE facility can be used. Make the time-domain channel active, position the gate flag (start and stop) around the peak. Put the GATE ON at the frequency domain channel and check the frequency response for the peak contained within the gate. Now all the peaks can be checked one at a time, including their frequency responses.

Another way to use GATE facility is to position the start gate flag at 0 ns (the calibration point) and the stop gate flag at the end of the line (antenna feed horn) then slowly move the stop gate flag close to the start point and notice the changes in the frequency response in the DATA (&) MEMORY display. You can then see which of the reflection peaks produce summary reflections at the calibration point.

If there is a "good" explanation for a given peak, it can be checked by removing the faulty component and, if necessary, replacing it. (Often the reason may be a broken flexible/twistable waveguide section.)

From experience, typical radar waveguide SWRs are as follows:

- < 1,2 for a radar station with only a few components;
- < 1,5 for a navy ship/mobile radar with only a few components;
- < 1,9 for a navy ship/mobile radar with more components.

2.5 ANALYSING OTHER COMPONENTS

You can also check rotary joints, polarisation, waveguide band switches (low band, high band etc.) and, if needed, other components. Before these are checked, however, you need to know their exact position in the line.

If you want to know the actual position of the reflection (in meters), use the VNA electrical delay mode and the appropriate waveguide delay.

Set the waveguide cut-off frequency and move the reflection 0 ns reference by increasing the delay. After that, you can read the distance on the display. Divide the result by two, remembering that the displayed value is the distance to, and from, the reflection.

Return to the basic set up and save the data in the memory and check it using DATA (&) MEMORY.

Switch, turn or move the component (limit to limit) and check for any changes. Use a more sensitive scale (for increased resolution) on the display, in the DATA(-)MEMORY mode.

If there is considerable difference in the error trace, usually this indicates that something has become damaged. It is also easy to check for changes in insertion loss by using the same method (see the next section).

2.6 INSERTION LOSS MEASUREMENT

Disconnect the line as close as possible to the end and terminate it using a short-circuit.

Change the frequency response format to Log mag mode and use the scale 1-2 dB / Div.

Check that there are no large 'dips' in the insertion loss response. If you do not have a good quality short-circuit, it is still possible to see dips in the response even using a poor quality shortcircuit.

CAUTION: In some cases it may not be possible to disconnect the line. In which case you have to try to cover the feed horn, for example using tin tape. In these situations you can use the smoothing aperture, but you need to be very careful and be sure that there are no faults which become obscured by using the smoothing aperture.

If you measure through the polarisation, remember that the polarisation position has a large effect on the insertion loss. Divide the loss result by two, because, as before, the displayed value is loss to, and from, the short-circuit.

Table 2, below, gives some maximum waveguide insertion loss values, obtained from a range of manufacturer's specifications.

Waveguide designation			Attenuation in dB/m				
IEC R	EIA WR	British WG	Rectangular	Flexible / Twist able	Elliptic		freg.
32	284	10	0.024	0.12	0.018-0.014	2.5-3.1	GHz
					0.029-0.021	3.1-4.2	GHz
48	187	12	0.046	0.16	0.037-0.035	4.4-5.0	GHz
					0.053-0.042	5.0-6.0	GHz
70	137	14	0.075	0.28	0.049-0.043	5.9-7.1	GHz
84	112	15	0.103	0.30	0.062-0.056	7.1-8.5	GHz
100	90	16	0.143	0.40	0.104-0.084	8.5-10.0	GHz
					0.092-0.089	10.7-11.7	GHz
					0.122-0.112	10.96-13.25	GHz
140	62	18	0.221	0.80	0.144-0.137	14.0-15.35	GHz
					0.203-0.189	17.3-19.7	GHz
					0.288-0.281	21.2-23.6	GHz

Table 2

3. CONCLUSIONS

Nowadays we measure almost every new radar waveguide line and save the measurement results for future use.

Occasionally we find reflections which should not be exceeded, and this can save both time and money through successful identification.

When doing frequency domain measurements, we can estimate the uncertainties, but time-domain measurements can be more useful for diagnosing problems, despite being only 'relative' measurements.

4. references

[1] N M Ridler (Ed), "Time domain analysis using network analysers: some good practice tips", ANAMET Report 027, September 1999.