Memorandum

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cc: J. Webber

From: J. Effland, G. A. Ediss, R. Groves

Date: 28 November 2001

Subject: Measurement of WR-10 Waveguide Windows Using Power Meter and Network Analyzer

1. Summary

Quartz windows have been fabricated in WR-10 waveguide by Dan Koller for use in the LO path of the JT-1 Dewar. A Gunn source, tripler, and power meter were initially used to measure their insertion loss[1]. Those results have been refined by Geoff Ediss who measured the windows using UVA's HP 8510 vector network analyzer with 220-325 GHz frequency extenders from Oleson Microwave Labs . This memo describes the equipment setups and presents insertion loss measurements between 200 and 300 GHz for these windows, which will operate in overmoded waveguide.

Frequency resolution using the power meter was poor, but was sufficient to suggest an insertion loss spike in Window 1 near 225 GHz, and this was confirmed by the network analyzer, which measured a maximum insertion loss of 5.5 dB. In addition, the network analyzer shows that same window exhibits a number of insertion loss spikes across the frequency band. Two windows are required for the JT-1 Dewar, so Window 2 will initially be used there but at least one more window will need to be made.

2. Test Setups

2.1 Power Meter Measurements

Figure 1 shows the equipment setup using the Gunn source, tripler, and power meter. To minimize insertion loss, the windows are designed for the same overmoded waveguide size (WR-10) as the Dewar's LO waveguide. The measurement setup used single-mode WR-4 couplers to provide good fundamental-mode matching to the LO tripler, the spectrum analyzer mixer, and the window. The latter was sandwiched between a cascade of WR-4 to WR-10 tapers that were included when reference power was measured without the windows.

Power level differences were measured with the spectrum analyzer operating as a narrow band receiver because it offers acceptable measurement accuracy when measuring the relatively small insertion losses of the waveguide

[1] "Measurement of WR-10 Waveguide Windows," NRAO CDL Internal Memo, J. Effland and R. Groves, 21 June 2001.

windows. Although power meters provide lower measurement uncertainty, their wide-band power heads can cause significant measurement errors originating from tripler harmonics, so they were not used for the loss measurement.

Three power measurements from the spectrum analyzer were recorded directly into a spreadsheet: The power received without the window but including the WR-4 to WR-10 tapers, with the window, and then repeated again without the window. The insertion loss was calculated as the average of the first and last power readings minus the reading with the waveguide window.

2.2 Network Analyzer Measurements

The University of Virginia's Electrical Engineering Department recently purchased an HP 8510 with Oleson frequency extenders that operate up the 325 GHz. Two one inch (2.54 cm) tapers were fabricated to transition from the WR-3 waveguide on the extender to WR-10 at the window. No normalization or time gating was used for the network analyzer data because the University has ordered but not yet received the required calibration kit. Instead, raw transmission S-parameter data were written in complex format into text files stored on a floppy disk. The data were subsequently normalized using a spreadsheet program.

3. Results

3.1 Power Meter Measurements

The insertion loss measured with the setup diagrammed in Figure 1 for the two fabricated windows is shown in Figure 2. The WR-4 coupler-based waveguide setup was validated by measuring 7.62 cm (3") and 15.24 cm (6") sections of straight WR-10 waveguide that were inserted as the device under test, then repeated with both sections in cascade. The results, shown in Figure 3, include a line showing the algebraic sum of the individual 7.62-cm and 15.24-cm insertion loss measurements. If the measurement was perfect, that line should match the measured 22.86-cm (9") cascade data, but it is apparent that significant measurement errors are present at certain frequencies.

Another check of the setup using the WR-4 tapers consisted of measuring the insertion loss with and without a 7.62-cm waveguide section in cascade with the waveguide window. This approach changes the resonant frequency of trapped modes, because the waveguide cavity length increases by 7.62 cm. The frequency range of interest is the high insertion loss region between 220 GHz and 230 GHz. As shown in Figure 4, there is no significant difference in the data measured with and without the 7.62-cm waveguide section.

Concerns about contamination of the window by slivers of gold from plating that may have flaked off while inserting the window into the test fixture were unfounded. Window #1 was carefully cleaned and its insertion loss measured again between 228 GHz and 230 GHz was the same as that prior to cleaning.

Two other waveguide configurations were used initially to measure the insertion loss. First, the windows were sandwiched between waveguide tapers with no couplers after the tripler. That is, following the tripler were several tapers to reach the WR-10 waveguide size of the window and another set of tapers reduced the waveguide size to WR-5 for the spectrum analyzer mixer. That configuration generally produces a poor impedance match at the tripler output that can degrade tripler performance resulting in large amplitude variations with frequency and spurious signals output from the tripler.

Attempts to validate the simple taper-based waveguide setup provided surprisingly consistent results. The insertion loss of a 7.62-cm section of WR-10 waveguide was measured in place of the window. This was repeated for a 15.24-cm section and then for both the 7.62 cm and 15.24 cm sections in cascade. Table 1 gives the results, which show that the cascade was equal to the sum of the individual measurements.

Table 1 : Setup (Waveguide Tapers Only) Validation using Straight W/G Sections		
Waveguide Length	**Measured Insertion Loss**	
	227 GHz	**245 GHz**
7.62 cm (3")	1.0 dB	1.0 dB
15.24 cm (6")	3.0 dB	2.5 dB
7.62 cm cascaded with 15.24 cm	4.0 dB	3.5 dB

The second preliminary setup consisted of essentially the same configuration as shown in Figure 1, but WR-10 couplers were used and the waveguide tapers were located between the tripler and coupler and a second set before the spectrum analyzer mixer. With this configuration the couplers operate in overmoded waveguide which causes wide variations in coupling value and also has the same potential problems with poor tripler match as the initial taper-only configuration. Indeed, rapid signal level variations were observed across the 200 to 260 GHz band using this configuration. In some cases, high insertion loss spikes caused the signal level to be too low to measure with the spectrum analyzer.

Despite the shortcomings of the initial setups, it is useful to compare results from all three measurement configurations, as shown in Figure 5. All three measurement approaches suggest that window suffers from large insertion losses near 225 GHz, but its loss at other frequencies is generally too small to measure with the setups described in this memo.

3.2 Network Analyzer Measurements

The stability and repeatability of the network analyzer data were determined by normalizing two subsequent sweeps obtained with the WR-3 to WR-10 tapers connected directly together. The results are shown in Figure 6 where a best-fit line to the data shows little average insertion loss change with frequency.

Figure 7 shows the measured insertion loss for both windows. Each sweep was normalized to a reference sweep obtained by connecting the tapers together without the window. The best-fit line for Window 2 suggests about a 0.5 dB increase in insertion loss across the band, but the absolute value of the insertion loss is too small to measure with the uncalibrated data. A number of significant insertion loss spikes are also evident in Window 1.

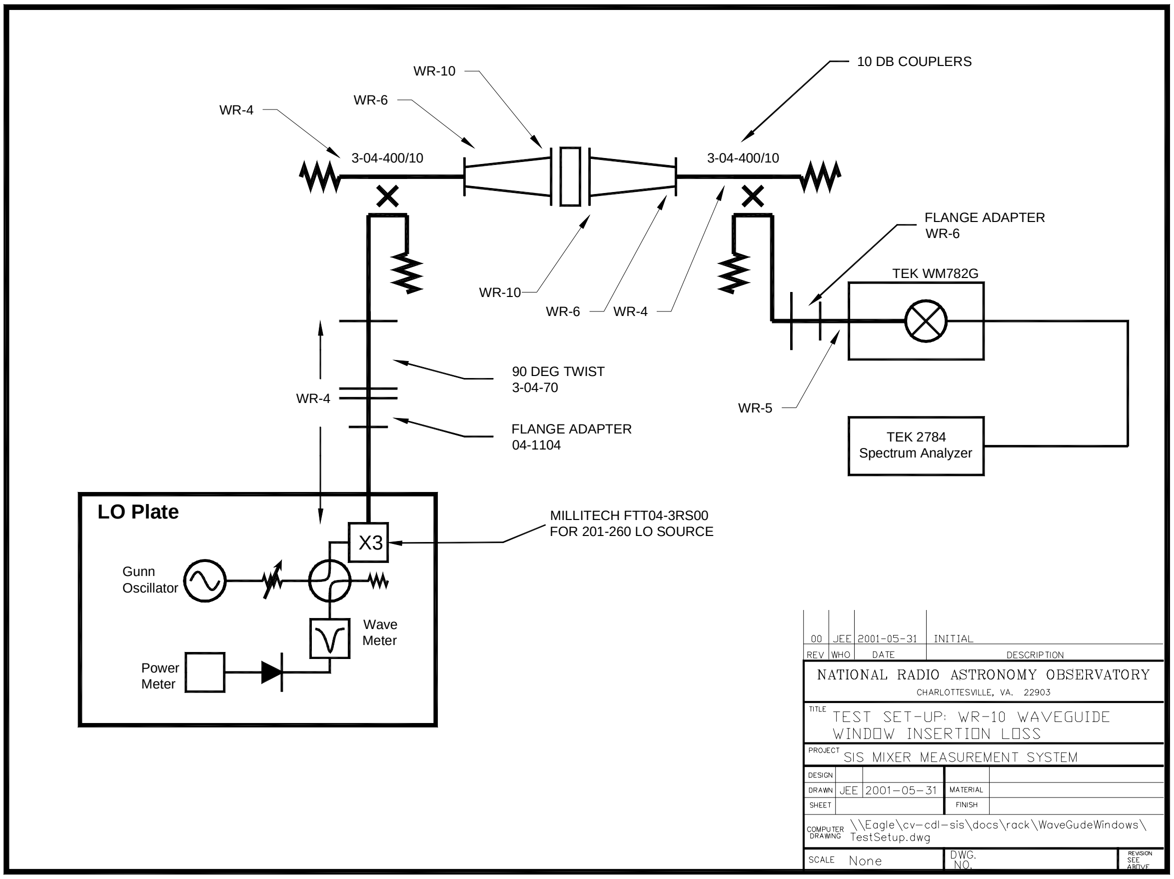

Figure 1: Test Set-Up

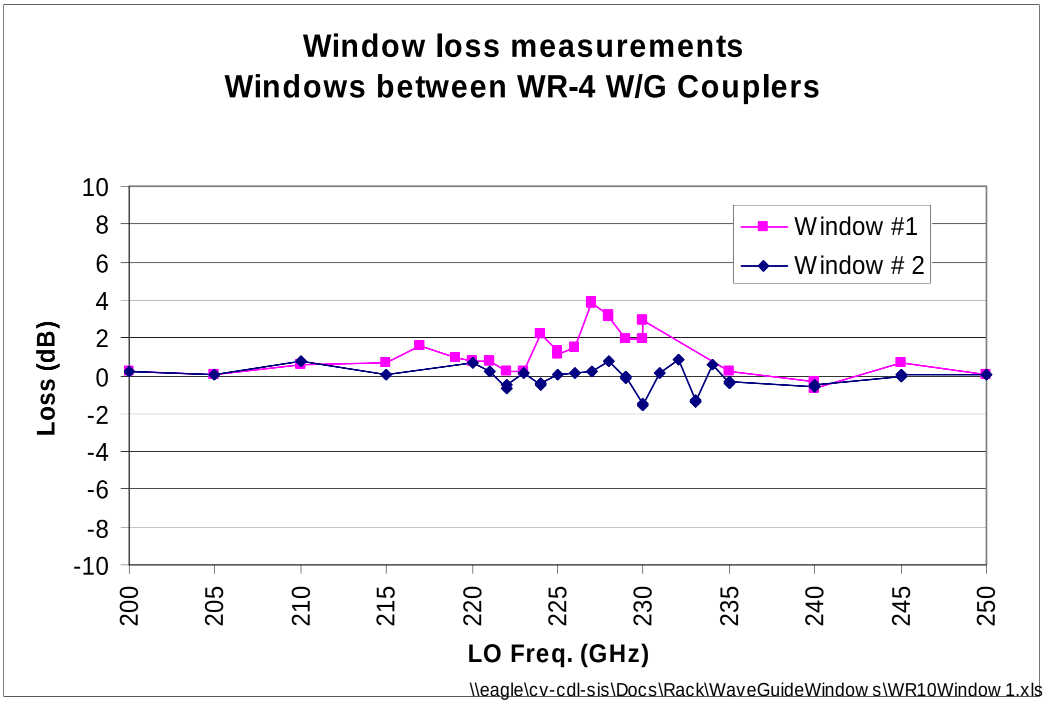

Figure 2: Measured Results

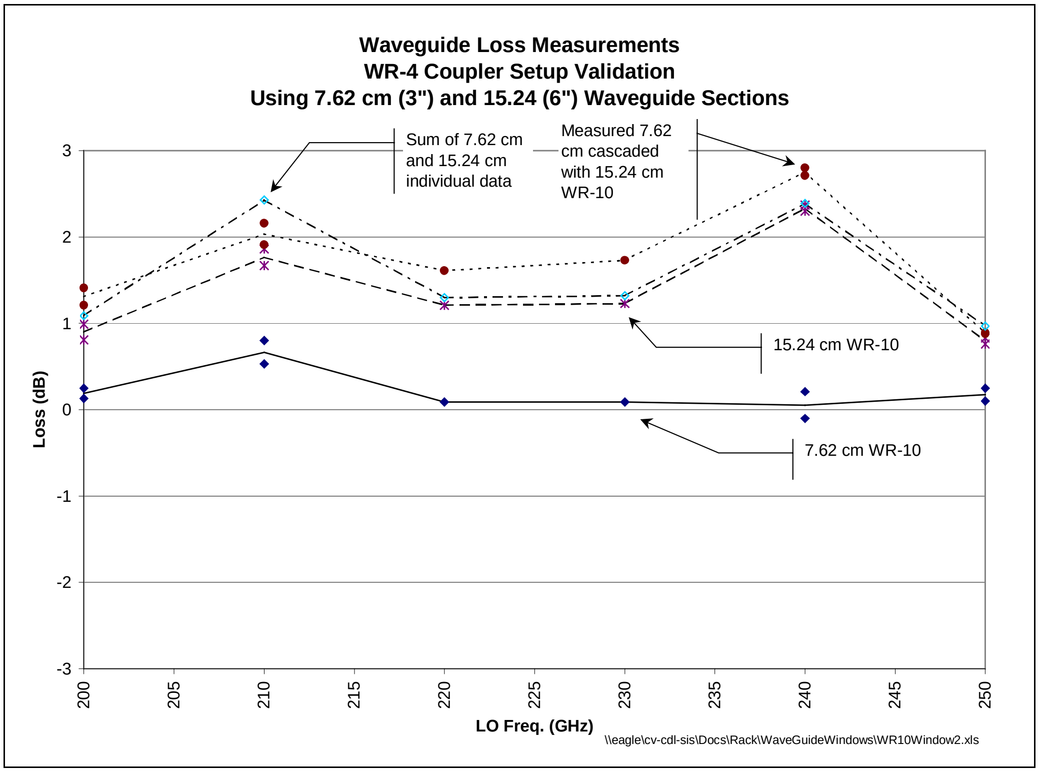

Figure 3: Validation of Setup with WR-4 Couplers

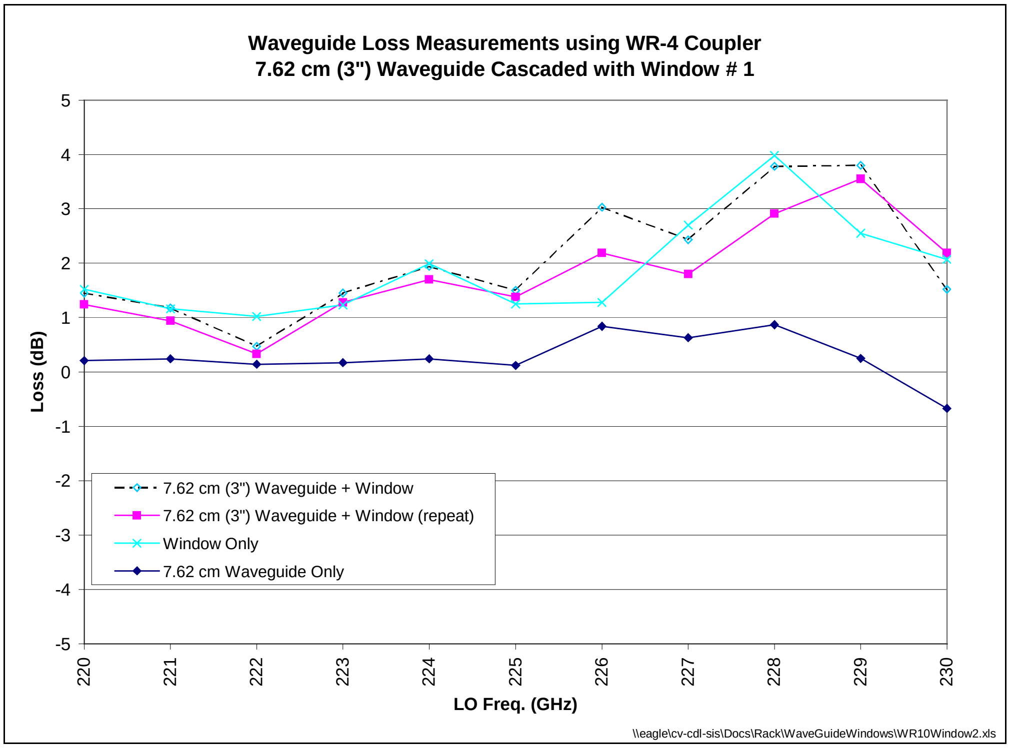

Figure 4: Window Cascaded with 7.62 cm Waveguide

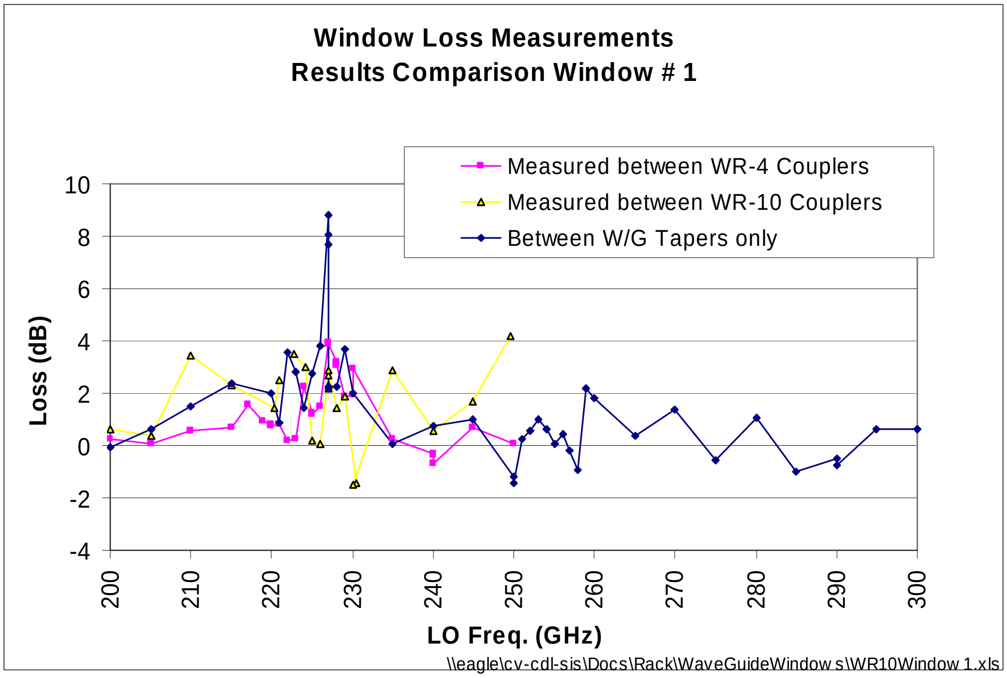

Figure 5: Comparison of Results for Different Setups

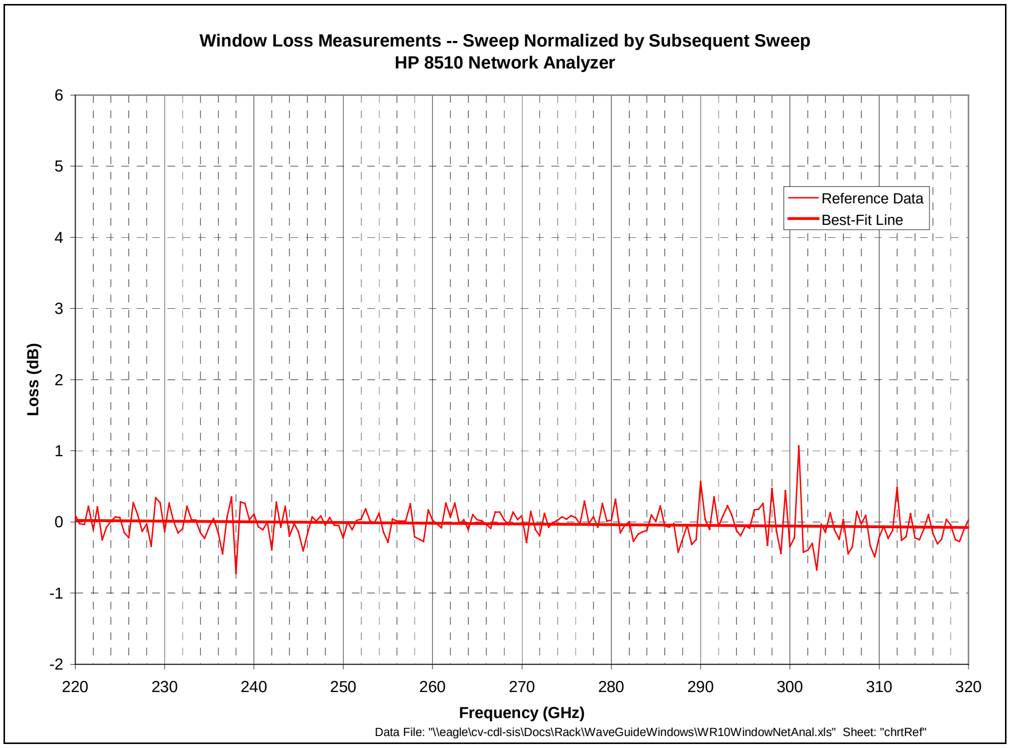

Figure 6: Network analyzer data: Normalization of the first sweep by a subsequent sweep demonstrates the stability and repeatability of the network analyzer measurement system.

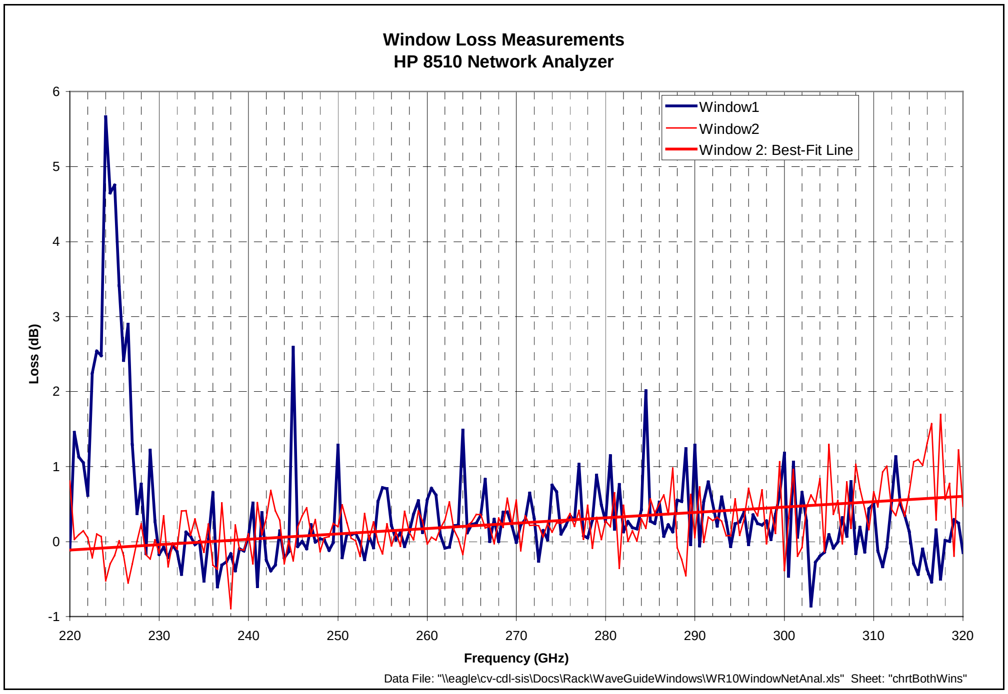

Figure 7: Network analyzer data: Insertion loss measurements of both windows