A V-BAND NETWORK ANALYZER/REFLECTION TEST UNIT

L. T. Yuan, G. M. Yamaguchi and J. E. Raue
TRW Systems Group
Redondo Beach, California 90278

Abstract

This paper describes the design, fabrication and performance of a novel V-band network analyzer/reflection test unit which is capable of operation over a wide frequency range in the 50 to 75 GHz band. The broadband performance of the reflection test unit design results in a continuous measurement over a 10 GHz band with a single sweep. The reflection test unit, utilizing a matched pair of wideband crossbar mixers, features high tracking ability, low source reflection coefficient (i.e., <0.08) and high system directivity (i.e., >31 dB).

Introduction

In recent years network analyzer/reflection test units have been used extensively for circuit and device characterization. They are powerful tools for optimizing circuit or device performance, particularly for broadband applications where circuit or device parameters have to be known over a wide range of frequencies. However, the commercial network analyzer/reflection test units currently available can only be operated up to Ka-band frequencies (26.5 to 40 GHz). For frequencies higher than Ka-band, circuit and device characterization generally relies on the slotted line techniques by performing fixed frequency point-by-point measurements; these are tedious, time-consuming and quite often fail to identify resonances between measurement points.

Increasing interest in communications systems operating at V-band frequencies (50 to 75 GHz) has created the need for the evaluation of circuits and devices at V-band frequencies. It is this demand that has prompted the development of a V-band network analyzer/reflection test unit. This unit is capable of operation over a frequency range from 55 to 65 GHz. The broadband performance of the present design results in a continuous measurement over a 10 GHz band with a single sweep. This substantially simplifies measurement procedures since only a single reference short calibration is required and measurements can be performed over the entire 10 GHz range without interruption.

System Description

The mechanical configuration of the V-band network analyzer/reflection test unit is shown in Figure 1a. It consists of a reflection test setup, a network analyzer (HP8410A), a harmonic converter (HP8411), a 55 to 65 GHz sweep oscillator (Hitachi MS371/MM435), a high-Q avalanche diode oscillator, and a matched pair of broadband mixers. The reflection test setup is a symmetrical co-planar design. Figure 1b shows the schematic diagram of the setup which includes:

- o Two power splitters
- o Six waveguide bends
- o Five straight waveguide sections
- o Four directional couplers
- o Four broadband isolators
- o Two matched broadband mixers

It is noted that in each channel, two isolators are provided in the LO path to prevent crosstalk from occurring between the test and reference channels. The mixers downconvert the entire swept frequency range to an IF of 2 to 12 GHz, which is coupled to the test and reference ports of the harmonic converter.

Broadband Mixer Design

The heart of the reflection test unit is a matched pair of broadband mixers. These mixers, employing a crossbar configuration [1,2], feature low conversion loss and broadband performance. The V-band mixer consists of a crossbar wafer mount, two Schottky barrier diodes and a back-short housing as shown in Figure 2a. The back-short housing also serves as a mounting block for the wafer mount. The crossbar diode wafer was fabricated with two back-to-back Schottky barrier diodes connected in series across the broad walls of the waveguide as shown schematically in Figure 2b. The RF signal and LO power are fed to the waveguide port via a directional coupler. The IF output signal is taken out from the center crossbar via an OSM coaxial connector. Electrically, the two mixer diodes are connected in series with respect to the RF signal and in parallel with the IF output, thus yielding a higher RF and a lower IF impedance than that of a single diode mixer. This provides an improved impedance match condition at both the RF and IF ports, resulting in the broadband performance of the mixer design. An outstanding feature of the mixer design is that the IF output is taken out from the side wall of the waveguide where the RF fields are at a minimum, thereby virtually eliminating RF signal and LO power leakage. This feature, together with the use of matched mixer diodes, eliminates RF choke at the IF output port. Thus, broadband performance of the mixer is further enchanced since the RF choke that imposes severe bandwidth-limiting performance at both the RF and the IF ports is eliminated.

Over the 10 GHz RF bandwidth (55 to 65 GHz), the VSWR of the mixers was less than 3.5:1. Exceptionally broad IF bandwidth was achieved which covered a multi-octave bandwidth from 2 to 12 GHz with VSWR less than 2:1. The extremely wide IF bandwidtn of the mixer design makes possible the use of only a single sweep to perform the entire 10 GHz RF measurements. This eliminates the repetitive calibration procedure over every 2 GHz of the RF bandwidth as required for the commercial network analyzer/reflection test units. The conversion loss of the mixers was 4 and 4.5 dB, respectively, measured at 59 GHz. The tracking ability of the two mixers over the entire 10 GHz operating range was excellent. The loss differential between the two mixers was approximately 0.5 dB, including the conversion, mismatch and parasitic losses of the mixers.

System Performance

The system performance of the V-band reflection test unit was evaluated by measuring the following parameters, namely:

1) the overall system tracking
2) the source reflection coefficients at both the test and the reference channels
3) the effective directivity of the system

The overall system tracking ability was determined by measuring the amplitude and phase deviations. Over the 55 to 65 GHz range with an IF window of 2 to 12 GHz, a maximum amplitude deviation of ± 1.5 dB and a phase deviation of less than ±12° were achieved. Figures 3a and 3b show the swept frequency response over the 55 to 65 GHz frequency range, when tested with the test port terminated by a fixed short circuit. For a narrower band operation, i.e., 56 to 64 GHz, the amplitude and phase deviations were ±1.1 dB and ±8°, respectively.

The source reflection coefficient at either the test or the reference channel, which is a measure of mismatches at the source, was measured by terminating the test port with an adjustable short circuit and the other by a fixed short circuit. By varying the position of the adjustable short circuit, the maximum deviation displayed on the HP8410A with an HP phase/gain plug-in (HP8413A) was recorded. The source reflection coefficient, Γ, is derived by

$$S = \log_{10}^{-1} \left(\frac{\text{maximum deviation in dB}}{20} \right) \qquad (1)$$

$$|\Gamma| = \frac{S - 1}{S + 1} \qquad (2)$$

where S = voltage standing wave ratio. The maximum deviation observed for both the test and the reference ports across the 55 to 65 GHz range was 1.4 dB. From equations (1) and (2), this corresponds to a VSWR of 1.17:1 or a source reflection coefficient of less than 0.08.

The effective directivity of the system was measured by the sliding load technique [3]. The measured directivity over the 55 to 65 GHz range was greater than 31 dB, corresponding to a residual VSWR of 1.06:1 at the test port.

Two types of devices have been characterized by using the V-band network analyzer/reflection test unit. One is a single-ended mixer designed for narrowband operations at V-band frequencies. The other is an avalanche diode amplifier designed to operate over a frequency range from 60.5 to 62 GHz. Figure 4 shows the RF impedance plot on the Smith Chart for the single-ended mixer measured over the frequency range from 55 to 65 GHz using the V-band reflection test unit. The continuous display of the RF impedance covering the entire RF range with a single sweep clearly indicates the advantage of the broadband characteristic of the design. In the RF impedance measurement for the single-ended mixer, no optimization of device performance or de-embedding of the device was performed. As for a comparison, the RF impedance of the mixer was also measured by using the slotted line techniques. The results, shown in Table 1, demonstrated the excellent correlation between the two techniques, certainly within the uncertainty limits of the system established by the effective directivity of 31 dB. Figure 5 shows an RF impedance plot on the Smith Chart of an avalanche diode amplifier operating between 60.5 and 62 GHz. A maximum gain of approximately 3.3 dB at 70 mA bias current was measured which is in good agreement with results obtained by direct power measurements.

Conclusion

Overall system performance of the V-band reflection test unit is encouraging, particularly the ultrabroad IF bandwidth which results in a continuous measurement covering a 10 GHz band with a single sweep. The key component responsible for the broadband performance of the present design is a matched pair of broadband mixers which were designed to perform over wide RF and IF bandwidths with overall mismatches less than 0.5 dB. The present design definitely is not limited to operate over the 55 to 65 GHz range. This range was selected primarily because it is the range covered by commercial sweepers presently available. Based on the same design concept, the operating frequency can be extended to other ranges by scaling.

Acknowledgements

The authors wish to thank A. I. Ohashi for his many helpful discussions and the critical reading of the manuscript. Thanks are especially due to A. L. Lance and W. D. Seal of the TRW Metrology Department for calibration of the system. Appreciation is also expressed to F. M. Garcia for carrying out the microwave measurements.

References

1. L. E. Dickens, et al, "A Mixer and Solid State LO for a 60 GHz Receiver," IEEE-GMTT International Microwave Symposium, May 19, 1971, pp. 188-190.

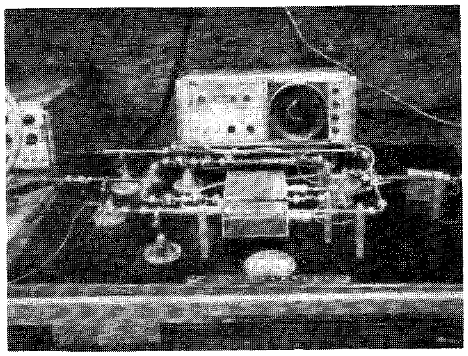
2. L. T. Yuan, "A Low Noise Broadband Ka-Band Waveguide Mixer," IEEE-GMTT International Microwave Symposium, May 12, 1975.

3. A. L. Lance, "Evaluate Couplers Fast and Accurately," Microwaves, Vol. 9, No. 11, pp. 34-36, Nov. 1970.

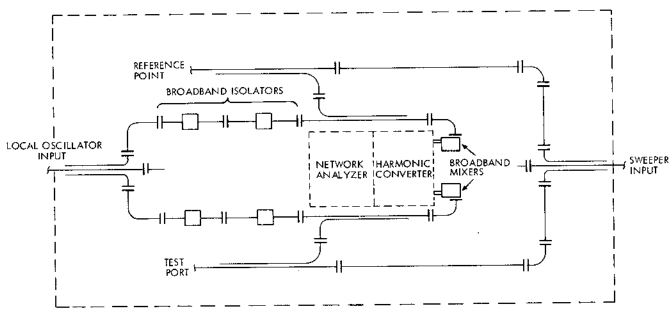
Table 1. Single-Ended Mixer VSWR Measurements

Frequency (GHz)	Bias Current (mA)	VSWR Measured by Slotted Line	VSWR Measured by the Present Unit	Range of VSWR* Measured Uncertainty
55	0.370	5.2	5.0	4.55 to 6.0
56	0.528	3.4	3.7	3.28 to 4.23
57	0.668	2.7	2.9	2.62 to 3.22
58	0.746	3.0	3.0	2.72 to 3.36
59	0.898	2.15	2.3	2.11 to 2.52
60	0.875	1.85	1.95	1.81 to 2.12
61	0.804	1.77	1.9	1.76 to 2.05
62	0.868	1.79	1.85	1.71 to 2.0
63	0.946	2.0	1.9	1.76 to 2.05
64	0.868	2.4	2.3	2.11 to 2.52
65	0.587	5.8	5.0	4.55 to 6.0

*based on an effective directivity of 31 dB

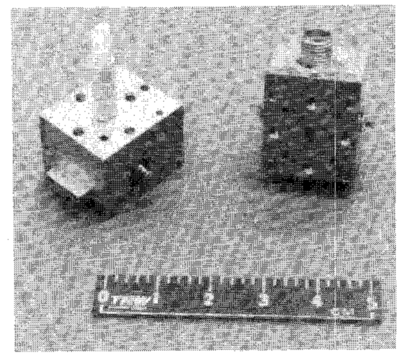


(a)

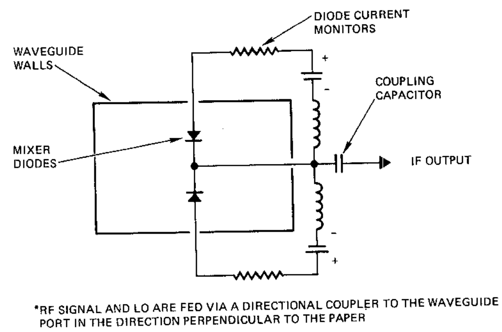


(b)

Figure 1. V-Band Network Analyzer/Reflection Test Unit; (a) Mechanical Configuration, (b) Schematic Diagram



(a)



(b)

Figure 2. V-Band Crossbar Mixer; (a) Mechanical Configuration, (b) Schematic Diagram

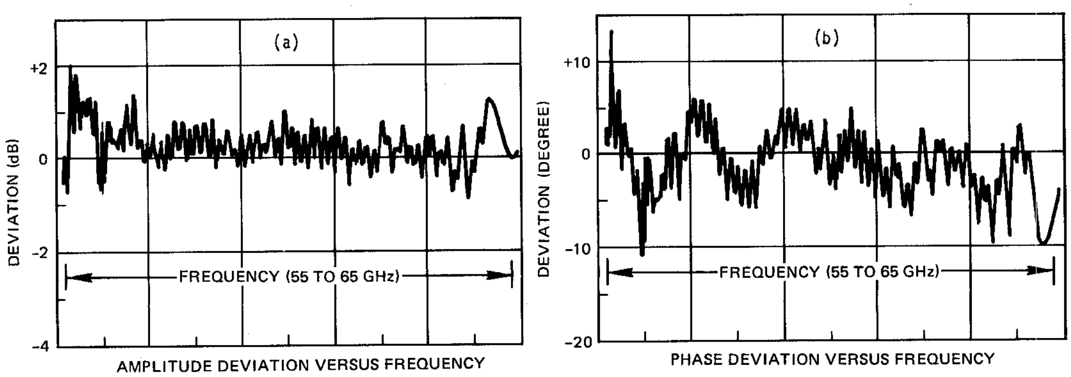


Figure 3. Amplitude and Phase Deviation vs Frequency

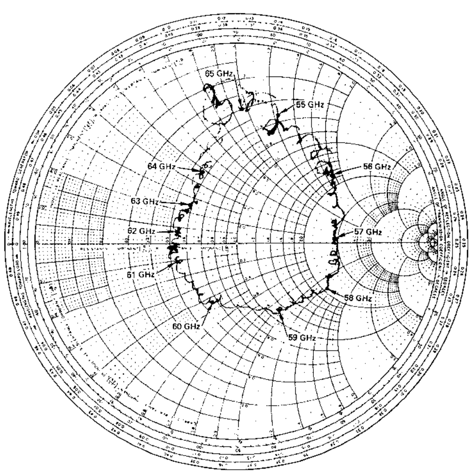


Figure 4. RF Impedance vs Frequency of a Single-Ended Mixer

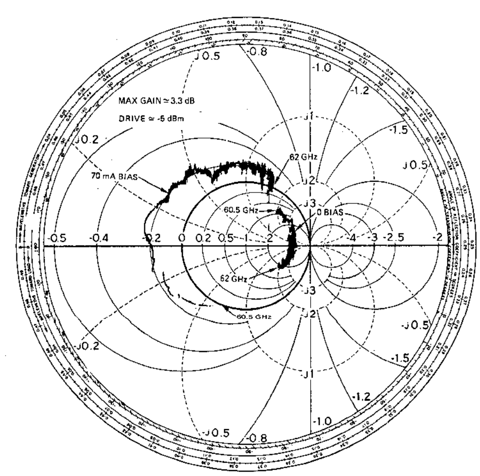


Figure 5. RF Impedance vs Frequency of an Avalanche Diode Amplifier