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# CALIBRATED TUNER FOR CHIP CHARACTERIZATION ABOVE 18 GHz

SANDER WEINREB, BEVAN BATES*, AND RONALD HARRIS

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# CALIBRATED TUNER FOR CHIP CHARACTERIZATION ABOVE 18 GHZ

Sander Weinreb, Bevan Bates and Ronald Harris

## ABSTRACT

A device which produces a known, mechanically-variable impedance and is useful for noise parameter or power load-pull measurements is described. The device integrates a three-stub waveguide tuner, a waveguide-to-microstrip adapter, a DC bias tee, and a removable chip-carrier into one compact unit. The design features a high degree of tuner repeatability, electrical readout of stub length, ease of calibration due to an accurately analyzable tuner structure, and operation at cryogenic temperatures if desired. The calibration procedure and a prototype unit operating in the 18-26.5 GHz band are described along with sample transistor noise parameter measurements.

## INTRODUCTION

Networks which can present a known, variable impedance at one port are desired for noise parameter and power load-pull measurements of semiconductor devices. At frequencies below 18 GHz, computer-controlled coaxial tuners and chip test fixtures are available. In this paper we will describe a waveguide and microstrip variable network which should be applicable in the 18-110 GHz frequency range.

## DESCRIPTION

A photograph of the assembled tuner, a view of the interior, and an equivalent circuit are shown in Figures 1, 2, and 3, respectively. A milled, split-block construction in gold-plated brass with the split occurring in the center of the broad wall (at a point of zero current flow) is utilized. The basic element of the tuner is a waveguide E-plane T-junction with a non-contacting short in one arm. This was chosen because the T-junction model is accurate [1,2], and the non-contacting waveguide shorts are highly repeatable and have very little loss. The T's are then arranged to keep the unit compact but yet allow space for mechanical drives and readouts. Compactness is desirable to reduce losses, decrease frequency sensitivity, and to allow insertion of an amplifier comprised of two tuners and a chip carrier in a cryogenic refrigerator for measurements of noise parameters vs. temperature.

The spacing between shorts, location of coupling probe, and length of microstrip to the chip under test have been chosen to maximize the range of the reflection coefficient plane which can be presented to the chip by movement of the front and mid shorts as defined in Figure 3; the loci of reflection coefficient as a function of position of these short positions

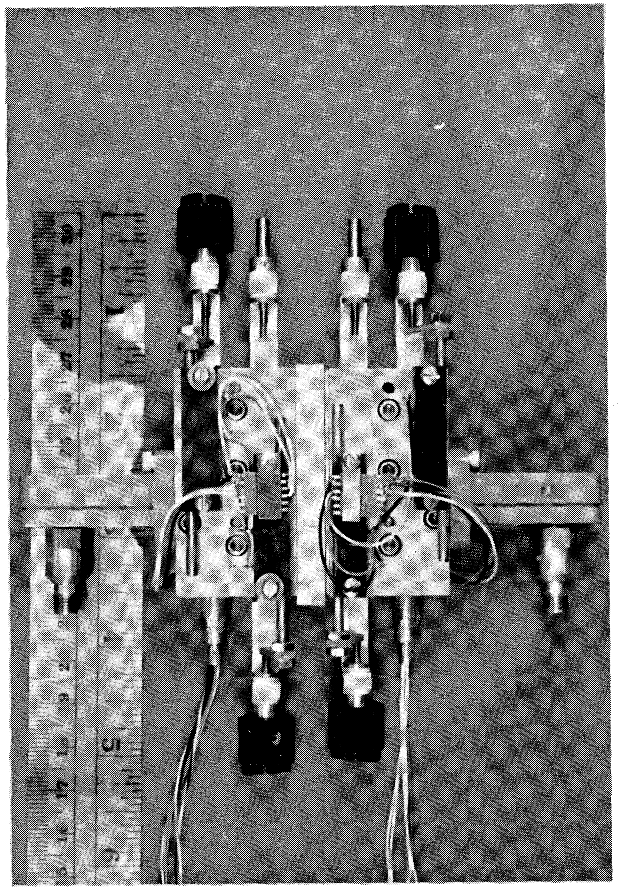

Fig. 1. Two 18-26.5 GHz tuners with waveguide-to-coax adapters and a chip carrier. Each tuner contains three non-contacting, movable shorts with electrical readouts of the positions of two of the shorts.

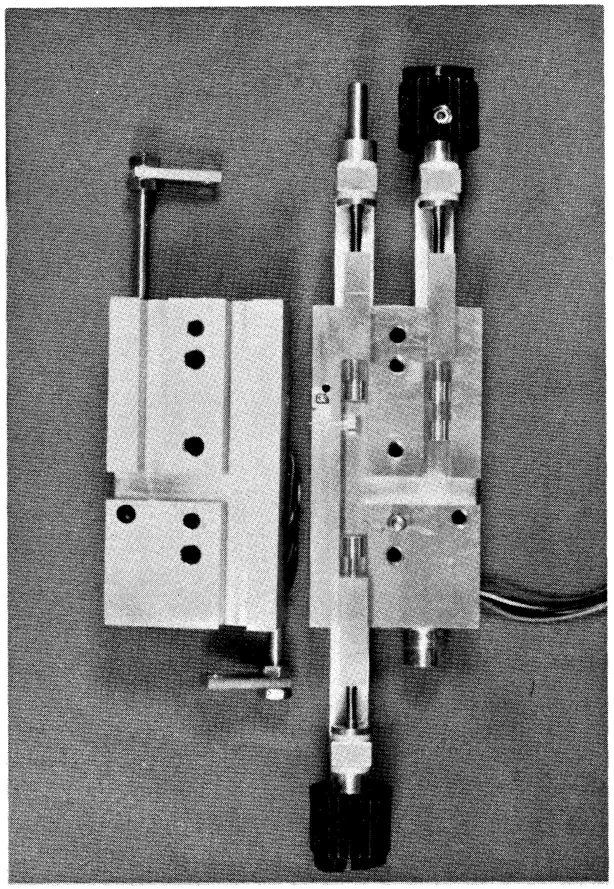

Fig. 2. Interior view of split-block tuner. The chip carrier contact is at the left of the right-hand block, and the waveguide input is at right. An expanded drawing of the chip carrier contact region is shown in Figure 5.

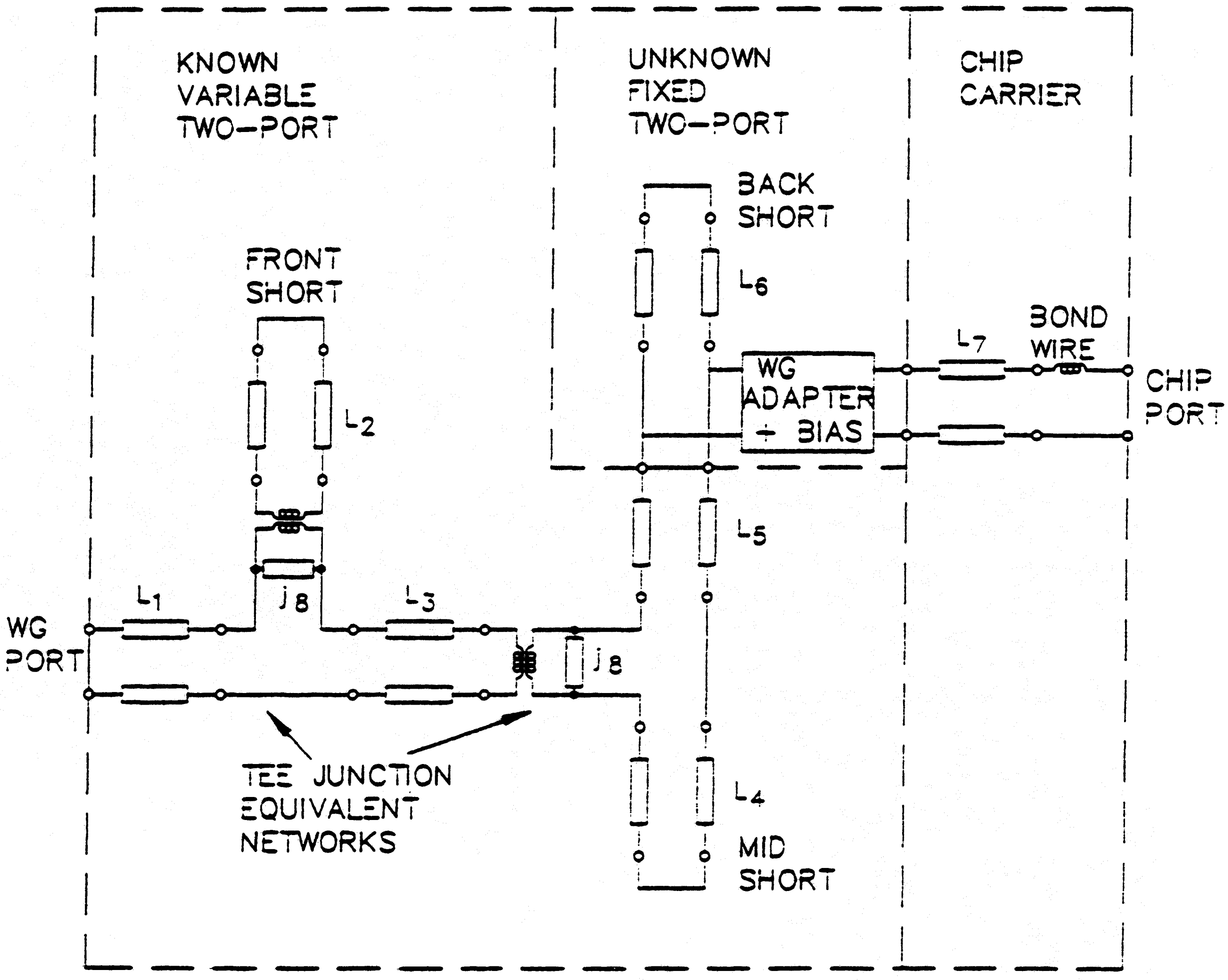

Fig. 3. Equivalent circuit of tuner. $L_1$ to $L_6$ are lengths of waveguide; $L_7$ is a length of microstrip.

is shown in Figure 4. These two shorts have miniature linear position readout pots [3] to give electrical readout of position. The third short is fixed in a position to present a match on the coupling probe output when the other two shorts are adjusted for minimum reflection through the T associated with each short.

A .25 mm thick alumina microstrip is epoxied on a small recess at the edge of the waveguide as shown in Figure 5. Initially a .25 mm diameter gold-plated steel pin was soldered to the 50 ohm line across the microstrip to support a 1.25 mm diameter coupling post in the waveguide at one end and to form a contact to a microstrip chip carrier at the other end. This solder joint had insufficient strength and was broken several times while contacting to the pin. The pin contact to the microstrip was then replaced by a beryllium-copper ribbon spring contact; at present, there is insufficient data to assess the reliability and repeatability of this contact.

## CALIBRATION

The unknown network can be considered to be a cascade of a known variable network containing the movable shorts and an unknown fixed network which contains the coupling probe, microstrip bias circuit, and chip carrier. The variable network is known in the sense that its performance can be calculated from physical dimensions [2], or can be measured by replacing the back short by a termination and removing the coupling probe. The agreement between theory and measurement is good as is shown in Figure 6.

The fixed network was determined by terminating the bond wire with a short, open, and delayed open at arbitrary positions of the tuner and performing measurements at the waveguide input port. The resulting S-parameters at 23 GHz were $S_{11} = 0.256 \angle 52.6°$, $S_{21} = S_{12} = 0.916 \angle 94.4°$, and $S_{22} = 0.293 \angle -47.6°$ indicating that the coupling network and bias tee are not highly mismatched or lossy.

## RESULTS

Two tuners have been constructed for 18-26.5 GHz waveguide and a GE HEMT transistor was inserted between the tuners for measurement of noise parameters. The noise vs. frequency was measured for several positions of the input tuner with the output tuner adjusted for maximum gain at 23 GHz in each case; sample curves are shown in Figure 7. The noise temperature at 23 GHz was then corrected by the known available gain of the tuner. Four values of noise temperature along with the known generator impedance presented by the tuner were then used to solve for the device noise parameters of $T_{min} = 190$ K, $R_{opt} = 13.4\ \Omega$, $X_{opt} = 14.4\ \Omega$, $g_n = .0385$, and $N = 0.516$.

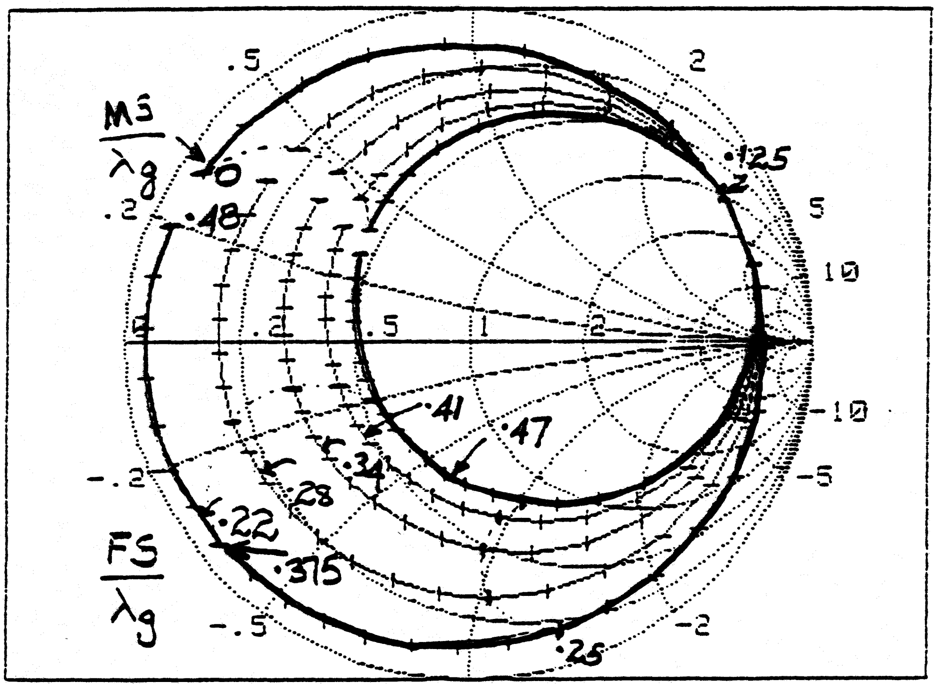

Fig. 4. Loci of impedance seen by the device as a function of waveguide short positions. Each circle is the locus obtained for a particular position of the front short as the mid short is varied.

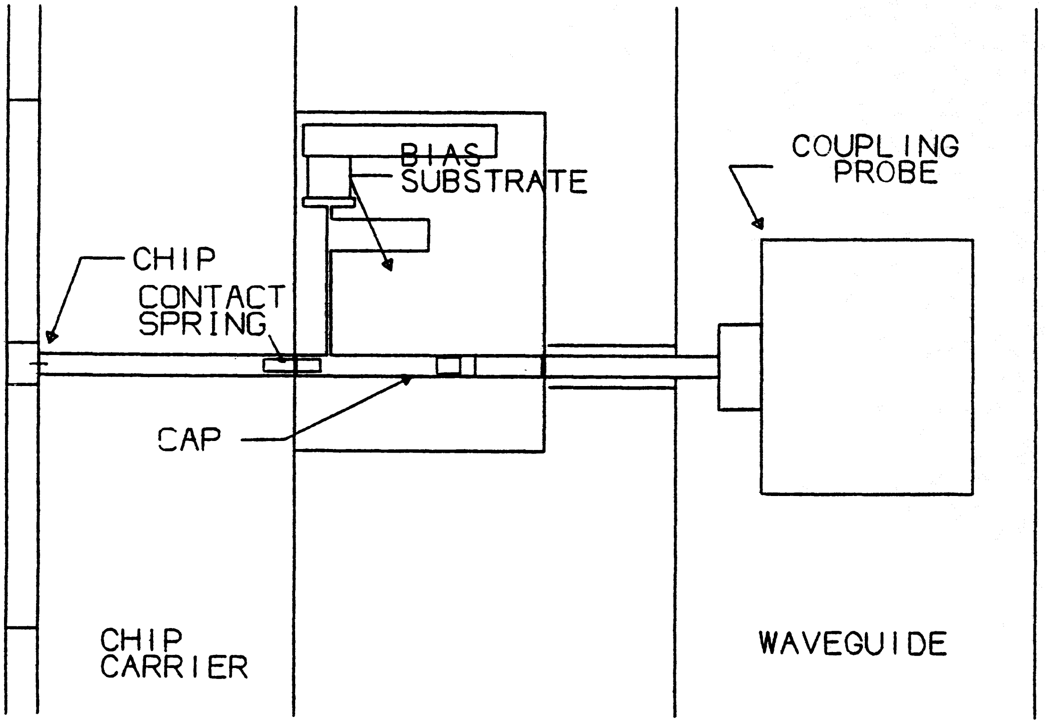

Fig. 5. View of waveguide (narrow wall), 3.05 mm diameter coupling probe, alumina bias substrate, and chip carrier.

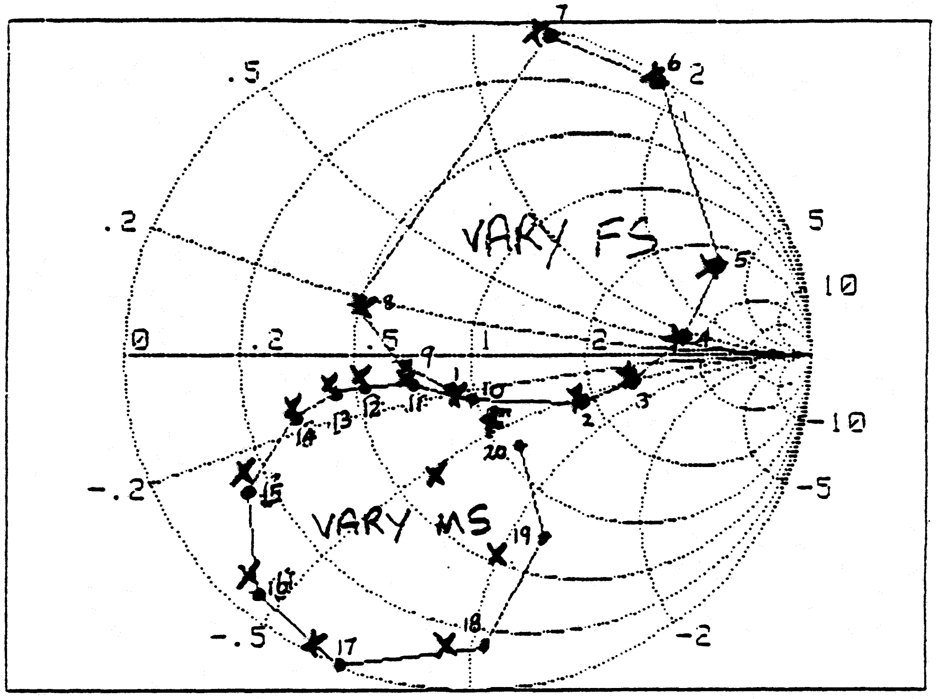

Fig. 6. Comparison of theoretical model (•) and measured data (x) for the known variable network consisting of two cascaded waveguide T junctions. The plots are for reflection coefficient at the input waveguide port as a function of positions of the mid-short (MS) and front-short (FS) with a termination replacing the back short and the microstrip coupling probe removed.

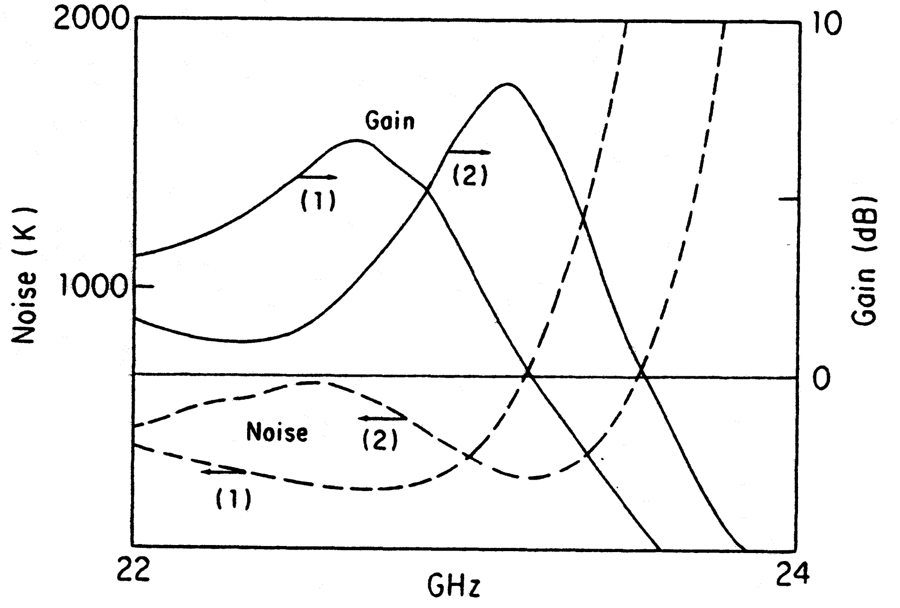

Fig. 7. Gain (solid line) and noise temperature (dashed line) for two positions of the input tuner connected to a GE HEMT transistor.

The results did not differ by large amounts if a different set of tuner positions were used; however, the results are preliminary and further tests are needed to test the accuracy. One useful test which has not yet been performed is to measure the noise parameters over a range of frequencies and look for a smooth frequency variation.

## PROBLEMS

The first and most troublesome problem is the already-mentioned difficulty of making a reliable and repeatable contact to both the 0.25 mm wide microstrip line and the ground plane under the line. Some possible remedies are:

1) Spring contacts for both the line and ground plane
2) Mechanical designs to prevent over-stress of the contact such as stops or spring-loading
3) Replaceable leaf contacts on polystyrene push rods
4) Welded connection with easy replacement of mating surfaces
5) Integrate waveguide probes with each chip carrier - probes would remove with chip carrier

A second problem was transistor oscillation at ~ 6 GHz. The bias substrates have 50 ohm tantalum-nitride resistors to terminate the transistor gate and drain at low frequencies. However, the waveguide probe and connecting transmission line were presenting a short circuit in shunt with the 50 ohm resistor and thus reactive terminations were presented to the transistor at low frequencies where it is conditionally unstable. This situation was alleviated by adding a small coupling capacitor in the tranmission line to the coupling probe. A more complex stabilization network may be required to prevent oscillation in all cases.

The third problem was radiation from the edge of the bias substrate near the chip carrier. This radiation causes a power loss which is dependent on the exact location and shape of the chip carrier; it is detrimental to calibration and repeatability. A temporary solution was to coat this edge with conductive epoxy. In the future, wrap-around metallization may be applied to the edge or the tuner block may be milled to provide an enclosure around the bias substrate except in the immediate area of the chip-carrier contact.

## REFERENCES

[1] N. Marcuvitz, Waveguide Handbook, M.I.T. Radiation Lab Series, vol. 10, Boston Technical Publishers, pp. 337-350, 1950.

[2] E. D. Sharp, "An Exact Calculation for a T-Junction of Rectangular Waveguides Having Arbitrary Cross Sections," IEEE Trans. Microwave Theory Tech., vol. MTT-15, pp. 109-116, Feb. 1967.

[3] Model 116-1-103, Subminiature Instruments Company, Riverside, CA 92507 or Model LCP8-10-10K, ETI Systems, Oceanside, CA 92054.