A 75–110 GHz Automated Tuner with Exceptional Range and Repeatability

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***Abstract*—A 75–110 GHz automated programmable tuner has been constructed displaying maximum reflection coefficients in excess of 0.9 (VSWR $\geq$ 19) over the majority of the band and typical repeatability of −45 dB. This tuner has been developed for on-wafer noise measurement applications at W-band.**

I. Introduction

The measurement of the noise parameters of devices in recent years has changed from the "hands-on" approach where device-under-test (DUT) noise figures were experimentally obtained employing a manual tuner to one where automated tuners and numerical extraction techniques are used [1]. Automation places greater demands upon the tuner design, which must now have good repeatability since the load that produces the minimum noise figure is not directly measured. Working at high frequencies, above 75 GHz, currently precludes the use of solid-state tuners and therefore requires high-precision mechanical tuners.

A tuner has been developed that displays both excellent range and repeatability based upon the conventional slide-screw technique [2], but fabricated with the on-wafer application in mind. The tuner was constructed around existing wafer probe mounting structures and has resulted in the novel arrangement, illustrated in Fig. 1, where the probe carriage is supported on guide rails offset from the waveguide axis. This design enables the tuner to be connected directly to the probe and hence minimizes interconnection losses. The figure also shows the tuner connected to a waveguide switch used to select either a fixed load (for the tuner operation) or a "through" connection. The latter is used to attach the probes to an S-parameter test set module and enables the tuner to be part of a combined on-wafer dc, noise, and S-parameter characterization system.

II. Tuner Design

The principle design requirements for the tuner were to achieve a useful range of reflection coefficients, Γ, and good repeatability since it would be required to reproduce a wide range of loads with no immediate verification. This has the benefit that once achieved, it permits a highly accurate experimental characterization of the tuner without the necessity of a good tuner model. The tuner is moved through a predetermined set of positions and each load is measured directly and tabulated as part of the system calibration rather than relying upon a model to calculate the load values. A typical load constellation, illustrated in Fig. 2, contains 72 points, although the number of data points is limited only by the available measurement time.

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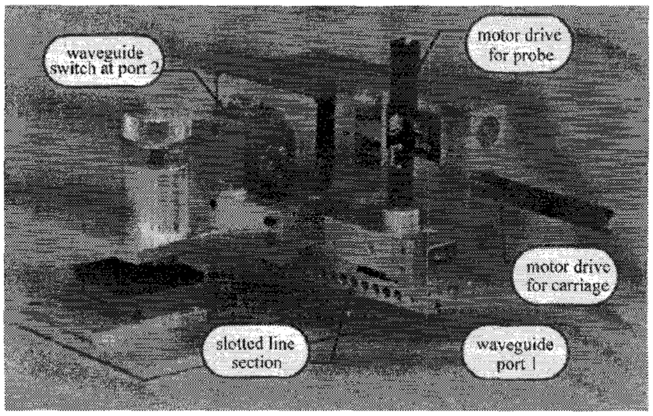

Fig. 1. Photograph of the W-band slide-screw tuner connected to a waveguide switch as part of a combined on-wafer noise and s-parameter measurement system.

The slide-screw tuner consists of a needle probe that is inserted at variable depth into the waveguide cavity through a slot in the centre of the broad wall, thus varying the reflection coefficient. The probe is mounted on a carriage that is moved along the waveguide, thus changing the phase of the reflections from the probe. Since the accuracy of the carriage motion is critical, it is engineered to move with low friction and without play. Both the probe and carriage are driven by encoded linear actuators in conjunction with an antibacklash system. The linear motors have a nominal positional accuracy of 0.1 μm, corresponding to 20 and 40 seconds of arc at 75 and 110 GHz, respectively. The encoder module has a resolution of better than 0.05 μm, however, and hence improved accuracy has been consistently obtained by driving the motors beyond the desired position and then backtracking in the direction of the antibacklash system. The encoded linear actuators are connected to an IBM-compatible PC and controlled by software developed at The University of Leeds. This continuously stores the motor positions and hence does not require the tuner to be reset or recalibrated if disconnected.

The tuner waveguide cavity was constructed from two aluminum split wall sections aligned with precision dowels.

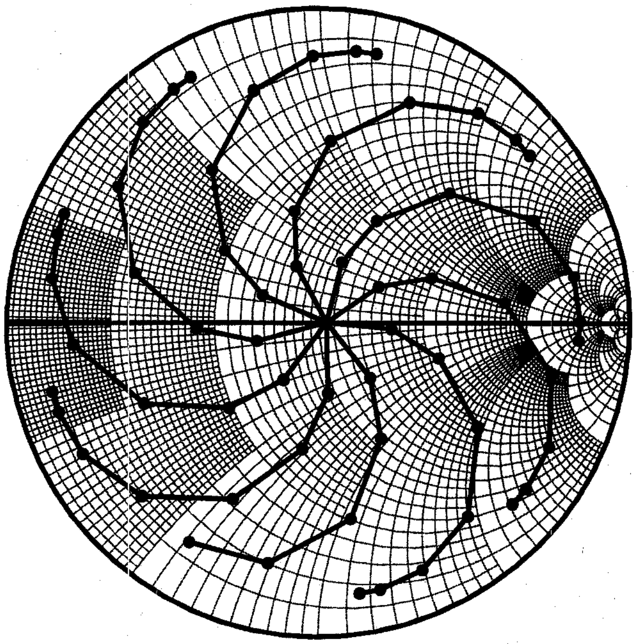

Fig. 2. Typical load constellation measured at 100 GHz. The pattern was generated from eight different needle positions and nine different carriage positions.

The slot detail was machined prior to finishing the waveguide walls to prevent burr formation, and a high-quality waveguide finish was produced by using an exact size milling tool for the final cut. The whole waveguide structure is then located below the carriage, again accurately located on dowels. The probe guide is machined with eccentric walls that when rotated allow the probe to be precisely positioned in the center of the waveguide cavity. A 250-μm-diameter probe is aligned centrally in a 300-μm slot, leaving only 25-μm gap on either side. The small slot width helps reduce the transmission losses within the tuner and hence contributes to the high reflection coefficients obtained. No choke elements (as described in [2]) were included in the design due to the small size of the wavelength above 75 GHz and the complexity associated in machining these features. The tuner does not appear to be adversely affected by the omission of these features since it still produces high maximum VSWR across the whole of the band.

III. Range and Repeatability

The typical load constellation illustrated in Fig. 2 was obtained from the tuner at 100 GHz and is generated from eight and nine different load and carriage positions, respectively. From 75 to 100 GHz the maximum attainable reflection coefficients have a magnitude greater than 0.9, corresponding to a VSWR greater than 19, with a peak value of 0.93 (VSWR = 28) at 91 GHz. Above 100 GHz the maximum attainable VSWR falls away somewhat, dropping from 15 at 100 GHz to 5 at 110 GHz.

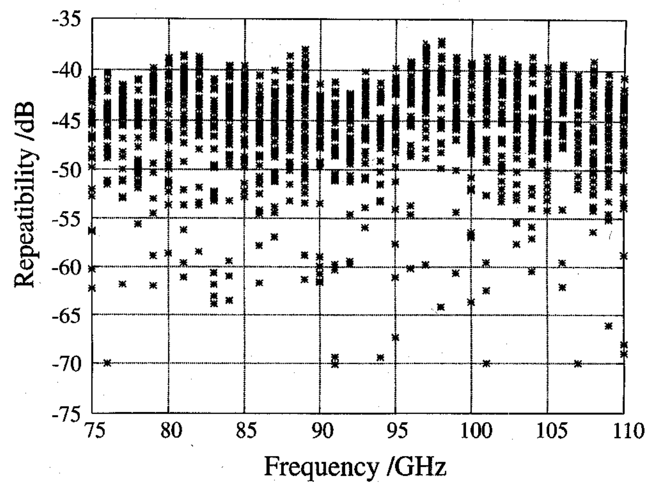

Fig. 3. Tuner repeatability observed for 50 consecutive load measurements.

The tuner exhibits excellent repeatability, essentially consistent across the whole band. Typically, the repeatability observed between consecutive load measurements is around −45 dB, where repeatability (dB) $= 10\log_{10}(\Gamma_i - \Gamma_{i-1})$. Fig. 3 illustrates the repeatability observed between 50 consecutive load measurements, displaying a worst case repeatability better than −35 dB and average repeatability of −45 dB.

IV. Conclusion

The conventional slide-screw tuner has been extended to W-band where the accuracy critical to reliable measurements is maintained by means of the use of high-quality machined components and precision encoded linear drives. The tuners exhibit both excellent range and repeatability, making them ideal for the on-wafer noise measurement application for which they were designed.

Acknowledgment

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