A NOVEL MMIC SOURCE IMPEDANCE TUNER FOR ON-WAFER MICROWAVE NOISE PARAMETER MEASUREMENTS

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ABSTRACT

A novel MMIC source impedance tuner is reported which can be incorporated into a wafer probe tip. This eliminates the effect of cable and probe losses on reflection coefficient, which enables higher magnitudes to be synthesized at the test device input than for conventional tuners, potentially increasing noise parameter measurement accuracy.

INTRODUCTION

The design and characterisation of a novel GaAs MMIC source impedance tuner for use in on-wafer microwave noise parameter measurements is reported. This tuner can be incorporated directly into a probe tip, eliminating any loss between tuner and test device, and facilitating improved accuracy on-wafer noise parameter measurements. The noise parameters of a linear two-port are normally determined from a set of noise figure measurements for different source impedances using a least-squares data fitting technique [1]. This requires the use of a tuner to vary the impedance and hence the reflection coefficient at the input of the test device. Ideally, the tuner should be capable of synthesizing any impedance within the unit circle on the Smith Chart to enable a well spread out constellation of source impedances to be used [2]. Maximum reflection coefficient magnitudes of 0.9 can be achieved using passive mechanical tuners [3]. However, in on-wafer measurement systems, a conventional source impedance tuner is separated from the test device by a lossy probe and length of cable, so reducing the maximum achievable reflection coefficient at the test device input. This effect is significant with a 3 dB cable and probe loss resulting in a maximum reflection coefficient of 0.9 being reduced to only 0.45. Tuneable wafer probes have been previously described to overcome this effect [4], but these had limited Smith Chart coverage area and bandwidth. The use of an MMIC tuner, which could be incorporated directly into a probe head, has also been suggested [5], but the results reported show only a limited number of possible impedance points. The novel MMIC tuner described here offers complete phase coverage of the Smith Chart, synthesizing 50 discrete impedance points, and could be incorporated into a wafer probe head to minimise losses and potentially increase noise parameter measurement accuracy.

MMIC TUNER DESIGN

A simplified schematic diagram of the design is shown in Figure 1. The tuner designed here achieves phase coverage of the Smith Chart by starting at the open and short circuit points and adding a variable offset to transform the impedance seen at Port 1 around the chart. This is accomplished using HEMT switches to add various lengths of microstrip transmission line. The switch is designed with a large (400μm) gate width to minimise the “on” state impedance with a corresponding cost in “off” state isolation. A spiral inductor is connected in parallel with each HEMT to resonate its “off” state capacitance and improve the isolation [6]. A low pass filter consisting of a single spiral inductor and MIM capacitor was connected at the gate of each HEMT to allow DC control voltages to be applied whilst acting as an RF open circuit. Eight switches are used to enable each of four lengths of line to be independently switched, either to ground to form a short circuit, or to become an open stub. Amplitude coverage of the Smith Chart is achieved by altering the gate bias on each switch so that it acts as a variable attenuator. Switches 1 to 4 are biased “on” and switches 5 to 8 “off” by default creating a through path between the two ports. A photograph of the chip layout, which measures 2400 µm × 800 µm, is shown in Figure 2.

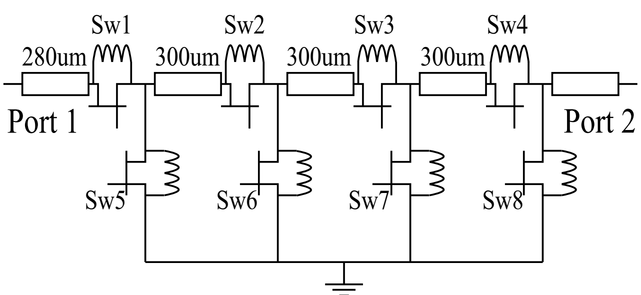


Figure 1. Simplified Schematic Diagram of Tuner.

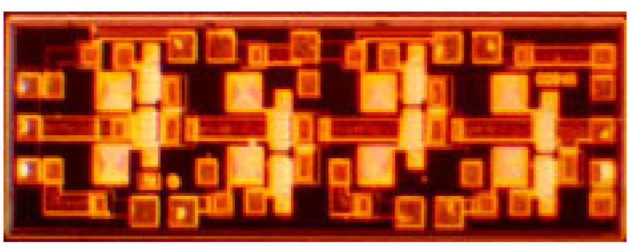
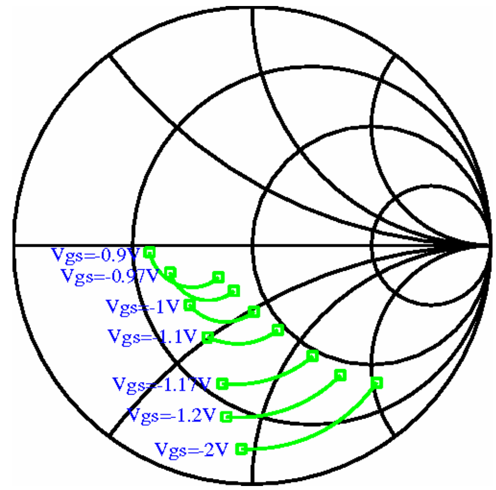


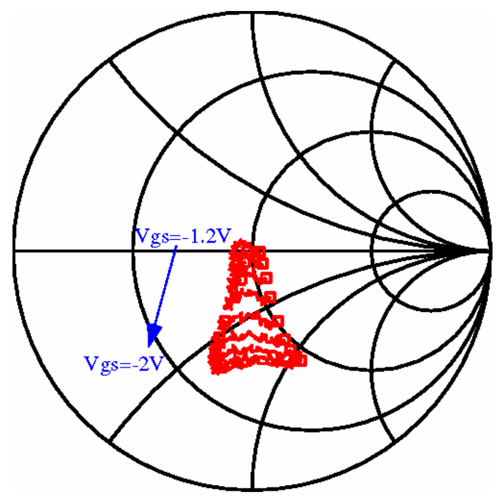
Figure 2. Photograph of MMIC Tuner.

SIMULATED AND MEASURED RESULTS

Circuit simulations were performed using the HP Microwave Design System, and a vector network analyser was used in conjunction with a probe station and wafer probes to measure the S-parameters of the MMIC tuner circuit on-wafer. Figure 3 shows the simulated and measured impedances achieved for the tuner for various values of gate bias on switch 1 which creates an open circuit stub. All other switches were in their default states. For clarity, only results obtained between 16 and 20 GHz



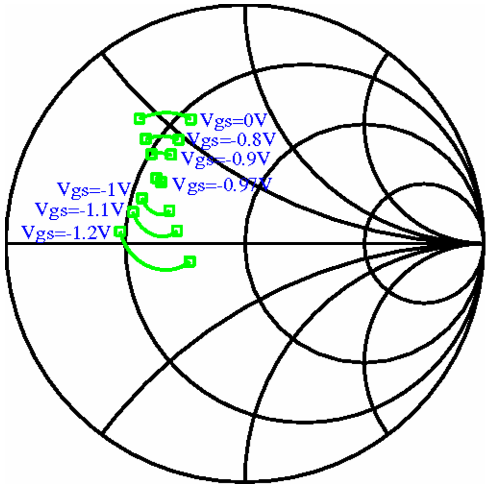
(a) Simulated



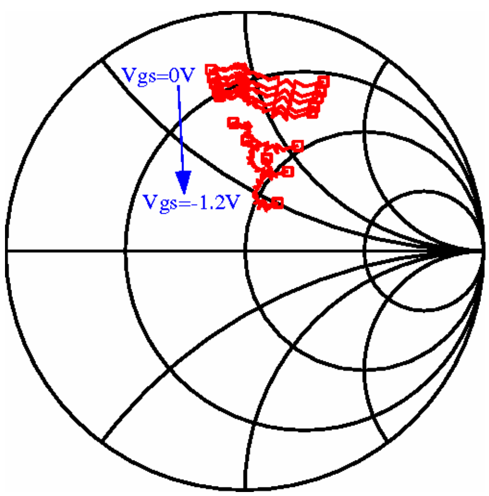
(b) Measured

Figure 3. Impedances Synthesized for Various Switch 1 Gate Bias Conditions Between 16 GHz and 20 GHz.

are shown, although the tuner is inherently broadband. The measured reflection coefficient magnitudes are lower than simulated due to poor switch “off” state isolation. Figures 4 and 5 show the impedances synthesized for various values of gate bias on switches 5 and 6, creating offset short circuit stubs. It can be seen how switching in the additional length of transmission line moves the phase of the reflection coefficient around the Smith Chart, and varying the gate bias alters the magni-



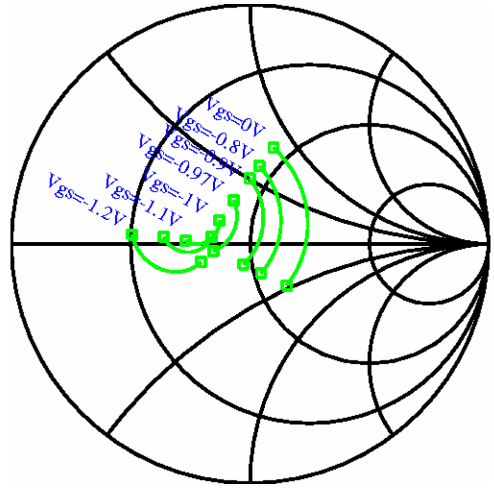
(a) Simulated



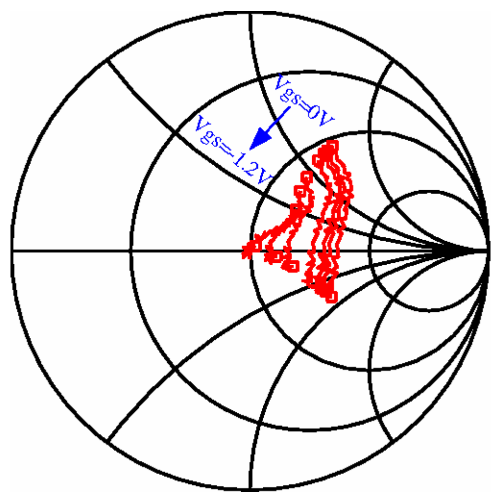
(b) Measured

Figure 4. Impedances Synthesized for Various Switch 5 Gate Bias Conditions Between 16 GHz and 20 GHz.

tude, as expected. More phase shift is exhibited in the measured data than in the simulations due to discrepancies between the equivalent circuit models used to simulate the designs and the components fabricated. The use of both offset short and open circuits enables high values of reflection coefficient to be synthesized in all quadrants of the Smith Chart. Complete phase coverage of the Smith Chart



(a) Simulated



(b) Measured

Figure 5. Impedances Synthesized for Various Switch 6 Gate Bias Conditions Between 16 GHz and 20 GHz.

is achieved, and Figure 6 shows the full measured constellation of impedances which can be achieved with the tuner. The coverage area is limited owing to much poorer "off" state isolation of the switches exhibited in practice than in the simulations. This could be greatly improved by using a HEMT with smaller gate width to increase switch "off" state isolation. Nevertheless, high values of reflection coefficient magnitude can be achieved, the maximum measured being 0.85. This value is as good as can be obtained at the output of passive mechanical tuners, and better than those achieved by many electronic tuners [7], neither of which can be positioned as electrically close to the test device as an MMIC.

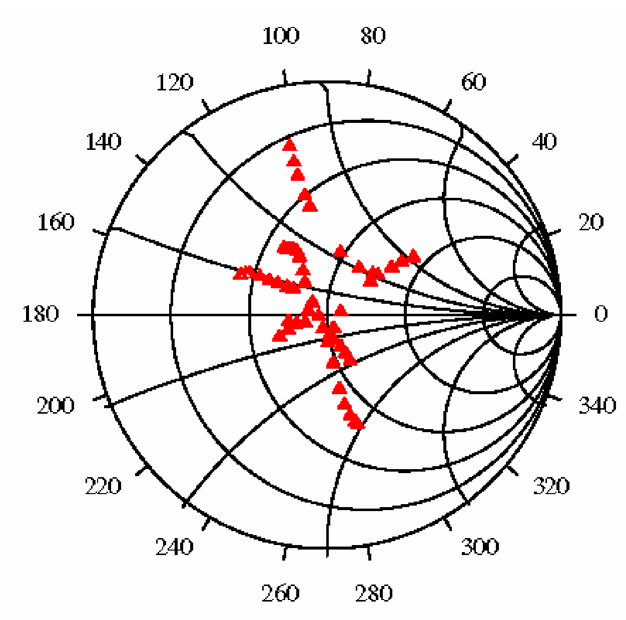


Figure 6. Measured Source Impedances Produced by MMIC Tuner at 18 GHz.

CONCLUSIONS

A novel MMIC tuner circuit has been reported which can achieve reflection coefficient magnitudes comparable to those produced at the output of passive mechanical tuners, and better than those produced by many electronic tuners. In addition, it can be connected directly to a test device on wafer, hence avoiding connector, cable, and probe losses. This proof-of-concept tuner can synthesize up to 50 different discrete impedance points, compared to the six demonstrated in a previous MMIC tuner design. The coverage area could be significantly improved with the use of a different size of HEMT switch. The tuner also has a larger useable bandwidth than previous attempts to fabricate tuneable wafer probes.

ACKNOWLEDGEMENTS

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REFERENCES

[1] R. Q. Lane, "The Determination of Device Noise Parameters," *Proc. IEEE*, vol. 57, no. 8, pp. 1461-1462, Aug. 1969.

[2] A. C. Davidson, B. W. Leake, and E. Strid, "Accuracy Improvements in Microwave Noise Parameter Measurements," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-37, no. 12, pp. 1973-1977, Dec. 1989.

[3] W. E. Pastori and G. R. Simpson, "ATS for Power and Noise Characterization Using PC-AT Based Software," *Microwave Journal*, pp. 82-92, Jan. 1993.

[4] G. Rabjohn and R. Surridge, "Tuneable Microwave Wafer Probes," in *Proc. of the 1988 GaAs IC Symp.*, pp. 213-216, Nashville, Tennessee, Nov. 1988.

[5] M. Dydyk, "MMIC Reflection Coefficient Synthesizer," in *39th ARFTG Conference Digest*, pp. 26-41, Albuquerque, NM, June 1992.

[6] V. E. Dunn, N. E. Hodges, O. A. Sy, W. Alyassini, M. Feng, and Y. C. Chang, "MMIC Phase Shifters and Amplifiers for Millimeter-Wavelength Active Arrays," in *1989 IEEE MTT-S Int. Microwave Symp. Dig.*, pp. 127-130, 1989.

[7] R. T. Webster, A. J. Slobodnik, Jr, and G. A. Roberts, " Determination of InP HEMT Noise Parameters and S-Parameters to 60 GHz," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-43, no. 6, pp. 1216-1225, June 1995.