# ACTIVE PROBES FOR 2-PORT NETWORK ANALYSIS WITHIN 70-230 GHZ

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*Abstract*—**Active probes for 2-port on-wafer network analysis within 70-230 GHz are presented. The probe contains an integrated circuit, based on nonlinear transmission lines (NLTL), which has all elements of an S-parameter test set. 2-port measurements with these active probes were carried out. Compared to earlier active probe systems [1], measurement accuracy is greatly improved.**

## I. INTRODUCTION

Recent advances in III-V technology, especially with InP based HEMTs [2] and HBTs [3], demand characterization over an extended bandwidth. Commercial broadband on-wafer S-parameter measurement set-ups are presently limited to 120 GHz bandwidth. We have fabricated active probes for a measurement set-up for 70-230 GHz network analysis.

## II. SYSTEM

Fig. 1 shows a conventional S-parameter measurement system, containing a multiplier to generate the RF signal, directional couplers to separate the incident and reflected waves and samplers or harmonic mixers to convert the signals down to a lower IF. The objective was to integrate all high frequency components on one chip. Therefore no cables, wave guides and connections between them are necessary. Only the connection to the device under test (DUT) is necessary, which can be very short by packaging the chips into active probes [1]. For the frequency multiplier a NLTL is used, because it can generate high frequency signals in a very wide bandwidth. For separating the incident and reflected waves, coplanar directional couplers are integrated. To convert the signals down to a lower IF, two high speed sampling circuits are used, which are driven by a second NLTL [4].

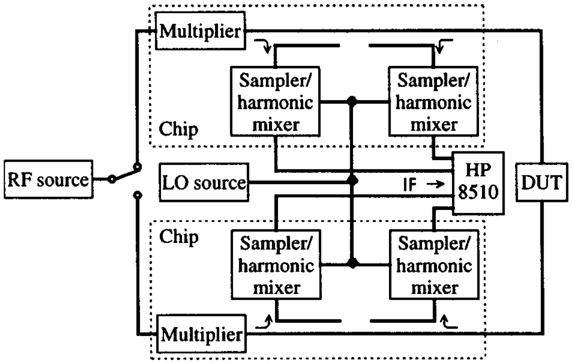

**Figure 1:** S-parameter measurement system.

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**Figure 2:** The active probes mounted on a wafer probe station.

These chips are packaged into active probes, which replace a conventional S-parameter test set.

## III. THE ACTIVE PROBE

Fig. 2 shows the active probe mounted on a wafer probe station in comparison to a commercial probe. Fig. 3 shows the bottom view of the active probe. The chip is mounted next to the probe tip. The connection to the DUT is provided by a flexible micro-coax cable. These coaxial probe tips were obtained from commercial (GGB industries) microwave wafer probes.

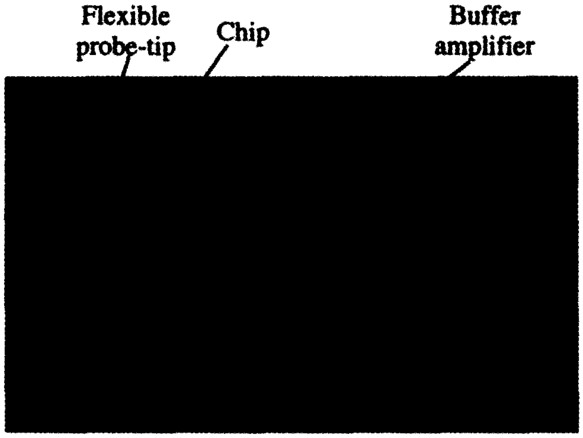

**Figure 3:** Bottom view of the active probe

The high speed samplers have a very high output resistance, so the capacitance of the IF cables would limit the IF bandwidth, if they were directly connected to the sampler. To increase the IF to 20 MHz, buffer amplifiers for the IF signals are incorporated into the active probe. This has the advantage, that the probes can be connected directly to the HP8510. Further the high 20 MHz IF greatly reduces the effect of LO synthesizer close-in phase noise, which was the dominant error contribution in earlier active probe based systems, where a 10 kHz IF was used [1].

## IV. MEASUREMENTS

To describe the performance of the system the raw directivity was measured, where the reflection of a short is compared to the reflection of a load. The result is shown in fig. 4. The raw directivity is better than 5 dB except at few isolated frequencies. The directivity decreases as frequency is increased.

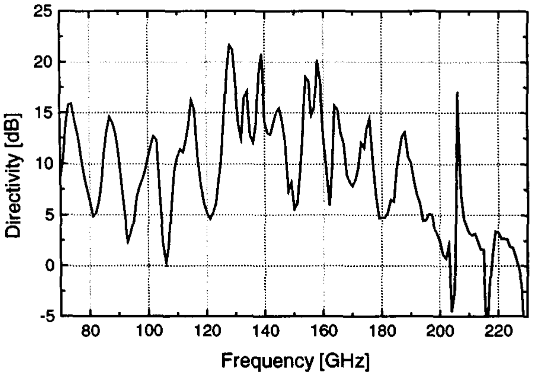

**Figure 4:** Measured raw directivity of the active probe.

Fig. 5 shows the measured maximum power at the IF ports. The noise level is -135 dBm/Hz. The dynamic range is more than 100 dB between 105 and 200 GHz, decreasing to 85 dB at 230 GHz.

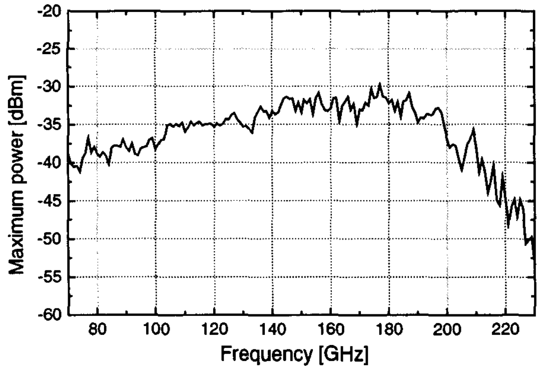

**Figure 5:** Measured maximum power at the IF-ports.

The system was calibrated with the TRL (thru reflect line) method, where the thru standard was a 1 ps thru-line (200 μm), the reflect standard a short and the line standard a 450 μm long line. For calibration the 10 term error model was used. Fig. 6 and 7 show the measurements of a 900 μm long line. As the reference planes after TRL calibration are in the middle of the thru standard, the measured line length is reduced by 100 μm at both ports. Due to the reduced directivity, the measurement accuracy degrades at the upper end of the bandwidth. With improved packaging, especially improving of the connection between the chip and the micro-coax probe tip, we should be able to increase the directivity and improve the accuracy.

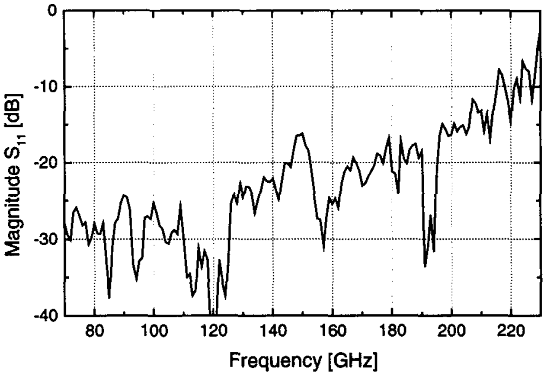

**Figure 6:** Measurement of $S_{11}$ of a 900 μm long line.

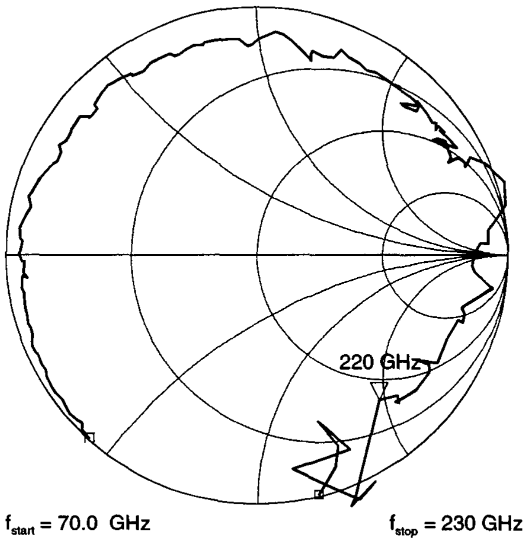

**Figure 7:** Measurement of $S_{21}$ of a 900 μm long line.

Fig. 8 shows the measured S-parameters of an integrated coplanar 10 dB directional coupler, designed for 90 GHz center frequency and fig. 9 the S-parameters of a 10 dB coupler, designed for 180 GHz center frequency. The latter is used in the integrated network analyzer circuit. The couplers were characterized with the active probes (full two port) and with a broadband commercial S-parameter set-up (HP8510XF). In the overlapping region from 70-120 GHz the measurements are in good agreement.

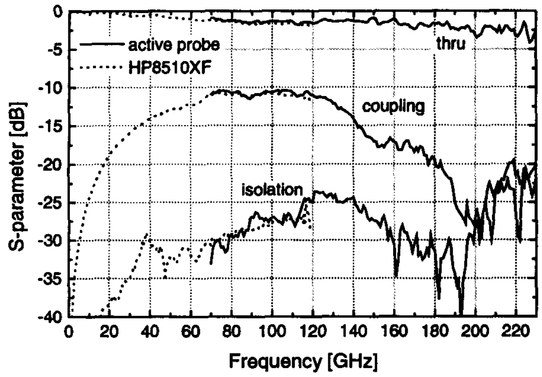

**Figure 8:** S-parameter measurements of a coplanar directional 10 dB coupler, designed for 90 GHz center frequency.

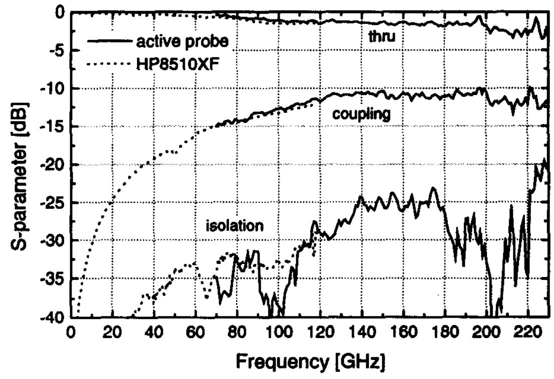

**Figure 9:** S-parameter measurements of a coplanar directional 10 dB coupler, designed for 180 GHz center frequency.

## V. CONCLUSION

We have presented the first active probes, which can be used as a S-parameter test set for the HP8510. Several measurements have shown the performance of these probes for high accuracy network analysis within 70-230 GHz.

## VI. ACKNOWLEDGMENT

We gratefully acknowledge the support of H. Walcher and J. Windscheif for packaging the chips.

## VII. REFERENCES

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