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A V-Band Single-Stub RF MEMS Impedance Tuner

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***Abstract* — A V-Band reconfigurable single-stub impedance tuner has been developed which is suitable to be integrated inside an RF probe. The tuner has 10 RF MEMS switched capacitors producing 1024 (2^{10}) different impedances. The tuner is the first published integrated V-Band impedance tuner having good impedance coverage for the whole 50 to 75 GHz frequency range with a measured of $|\Gamma_{MAX}|$ = 0.90 at 60 GHz. Measurement results verifying the tuner performance are presented.**

I. INTRODUCTION

Impedance tuners are used in noise parameter and load-pull measurements of transistors and amplifiers. Tuners are typically waveguide components at V-Band (50-75 GHz) or W-Band (75-110 GHz) and they are tuned either with motorized [1] or manual [2] methods. Usually in on-wafer measurement, mechanical tuners have to be placed electrically far away from a device under test (DUT) in measurement set-ups because they are large in size. This limits the maximum achievable reflection coefficient and the accuracy of the measurements. In addition to measurement applications, impedance tuners can be used as reconfigurable matching networks for power amplifiers (PA) and antennas.

Both MMIC [3] and RF MEMS [4,5] based integrated matching networks and impedance tuners have been published previously for lower frequencies. We have presented a novel capacitive loading based tuning method for impedance tuners and applied it to X-Band triple-stub impedance tuners [5]. The electrical length of stubs and distance between them were tuned with switched RF MEMS capacitors. Using N (number of switched capacitors) switched capacitors it is possible to get 2^N different impedances. This method was applied for the designing of a reconfigurable V-Band single-stub tuner. In this work, we show that it is possible to achieve wideband good Smith chart coverage with the single-stub topology.

II. TUNER DESIGN AND FABRICATION

Impedance coverage and maximum achievable reflection coefficient are important design issues in impedance tuner design. A switched capacitor is used as a unit cell for the designing of the single-stub tuner. Several parameters affect to the design of impedance tuners. The number and capacitance values of the switched capacitors have the most important effect to the tuning range and bandwidth of the tuner. Other selectable parameters are the spacing of the switched capacitors (s), transmission line properties (Z_O, ε_{reff}), and the lengths of the stubs. The switched MEMS capacitor is a series combination of a capacitive RF MEMS switch and fixed MAM (metal-air-metal) capacitors. Fig. 1 shows a fabricated MEMS switched capacitor with cross-sectional view and the equivalent circuit. It is based on a coplanar waveguide (CPW) transmission line having dimensions of 60/60/60 µm on a glass substrate. The component values are presented in Table 1. The switched capacitors has up and down-state capacitances C_U = 31 fF and , C_D = 101 fF resulting X_U=-j86 Ω and X_D=-j26 Ω at 60 GHz. The quality factor of the switched MEMS capacitor is calculated with $Q = (2\pi f C(R_{MEMS}+ R_{MAM}))^{-1}$, and results in up and down states values of Q_U = 144 and Q_D = 44 at 60 GHz, respectively.

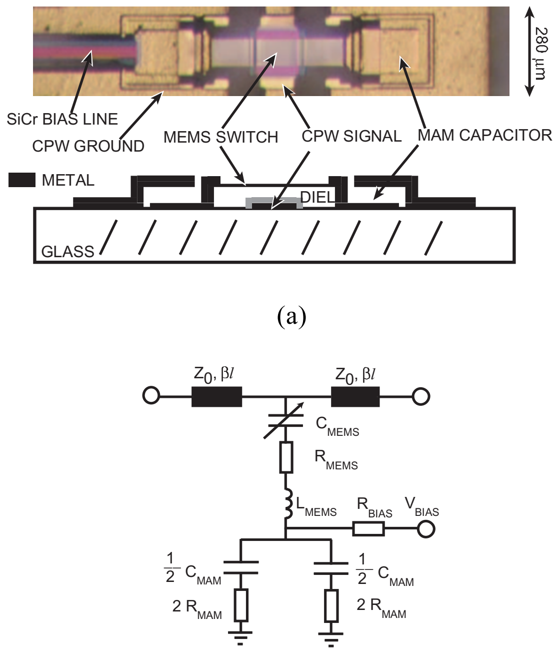


Fig. 1. a) A photograph and a cross-sectional view of the V-Band switched capacitor. b) Equivalent circuit of the switched capacitors.

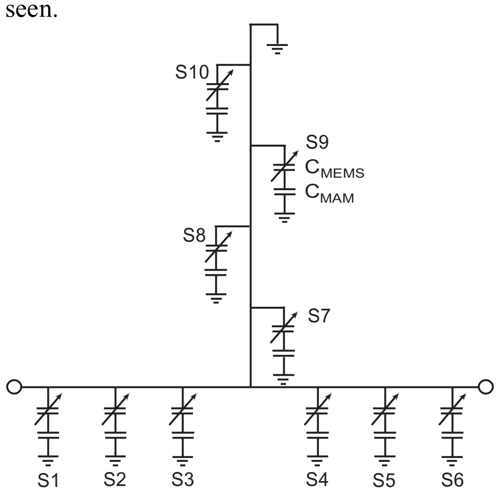
Dimensions of the titanium/gold/titanium (100Å/8000Å/300Å) MEMS switch are 250 µm x 60 µm x 0.84 µm, and it is suspended 1.3 µm above the transmission line. A 2000 Å silicon nitride layer was used as a dielectric interlayer. The fabrication process is based on standard techniques and is described in [4]. The circuit is electroplated to 3 µm thickness (except the MEMS bridges) to reduce the t-line and MAM capacitor loss.

SiCr bias lines with resistance of 700 Ω/square are used for actuating the MEMS switches. The measured pull-down voltage was 22 V, and a bipolar actuation voltage of +/−35 V was used for obtaining an excellent metal-to-dielectric contact in the down-state position, and to avoid charging of the dielectric layer.

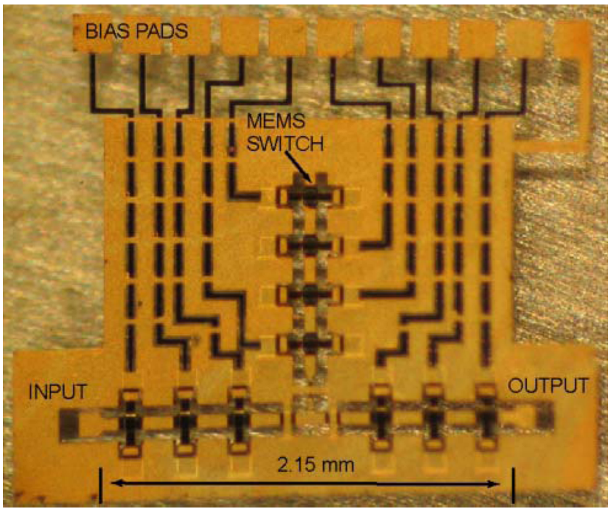
ε_r	4.6
Z_0 (Ω)	86
ε_{reff}	2.72
α (dB/cm) at 60 GHz	1.5
C_{MEMS} Up-State (fF)	42
C_{MEMS} Down-State (fF)	800
C_{MAM} (fF)	116
R_{BIAS} (kΩ)	> 3
L_{MEMS} (pH)	9.5
R_{MEMS}+ R_{MAM} (Ω)	0.6

TABLE I
FITTED VALUES FOR THE SWITCHED MEMS CAPACITOR

The T-junction in the tuner was simulated with Sonnet EM Suite [6]. Its S-parameters with the equivalent circuits of the switched capacitors were used in Agilent ADS [7] for simulating the S-parameters of the tuner. The single-stub design was optimised using Agilent ADS to get as large tuning range and bandwidth as possible with the minimum number of switched MEMS capacitors. Larger amount of switched capacitors yields better Smith chart coverage and more possible impedances since N switched capacitors produce 2^N different impedances. On the other hand, control system for the tuner comes more complicated and characterization of the tuner is more time consuming. The single-stub tuner was optimized to have 10 switched capacitors producing 1024 (2^{10}) different impedances. Spacing between the switched capacitors, *s*, is 280 µm in the sections before and after the stub (S1,S2,S3,S4,S5,S6) and 260 µm in the stub (S7,S8,S9,S10). The schematic and photograph of the fabricated tuner are shown in Fig. 2. Measured and simulated S-parameters of the tuner with two different switch setting are presented in Fig. 3. Good agreement can be seen.



(a)



(b)

Fig. 2. a) Schematics of the V-Band single-stub tuner. Switched capacitors S1-S10 are used for producing 1024 (2^{10}) different impedances. b) Photograph of the fabricated V-Band single-stub tuner.

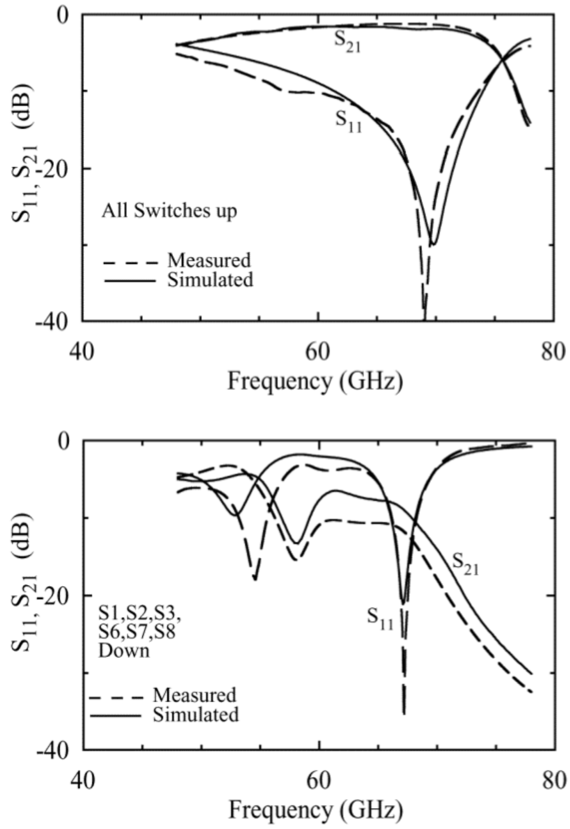


Fig. 3. Measured and simulated S-parameters of the single-stub tuner when all of the MEMS switches are in the up-state and when S1, S2, S3, S6, S7, and S8 are in the down-state.

III. IMPEDANCE COVERAGE

The measured (90) and simulated (1024) impedance points of the single-stub tuner are presented in Fig. 4 at V-Band. In this case, a 50 Ω load was placed at the output port, and the input reflection coefficient was measured with different switches actuated into the down-state position. The circuit model was used for simulating all possible switch combinations. The tuner can be used as a reflection type impedance tuner when the output is terminated with an open circuit, and simulated impedance coverage for the single-stub tuner is shown in Fig. 5. The tuner has good impedance coverage over the whole V-Band with 50 Ω terminations and can be used in noise parameter measurements at 40-80 GHz when the output is terminated with an open circuit.

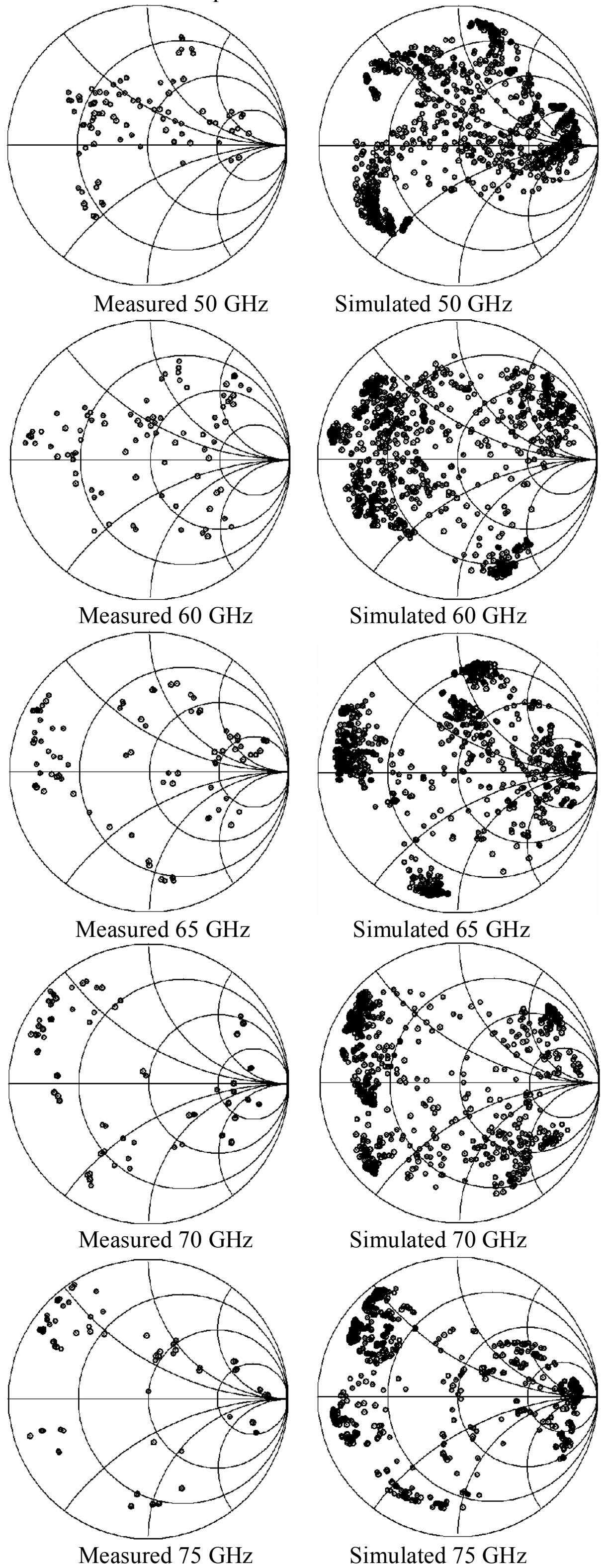


Fig. 4. Measured (90 points) and simulated (1024) impedance coverage of the V-Band single-stub impedance tuner.

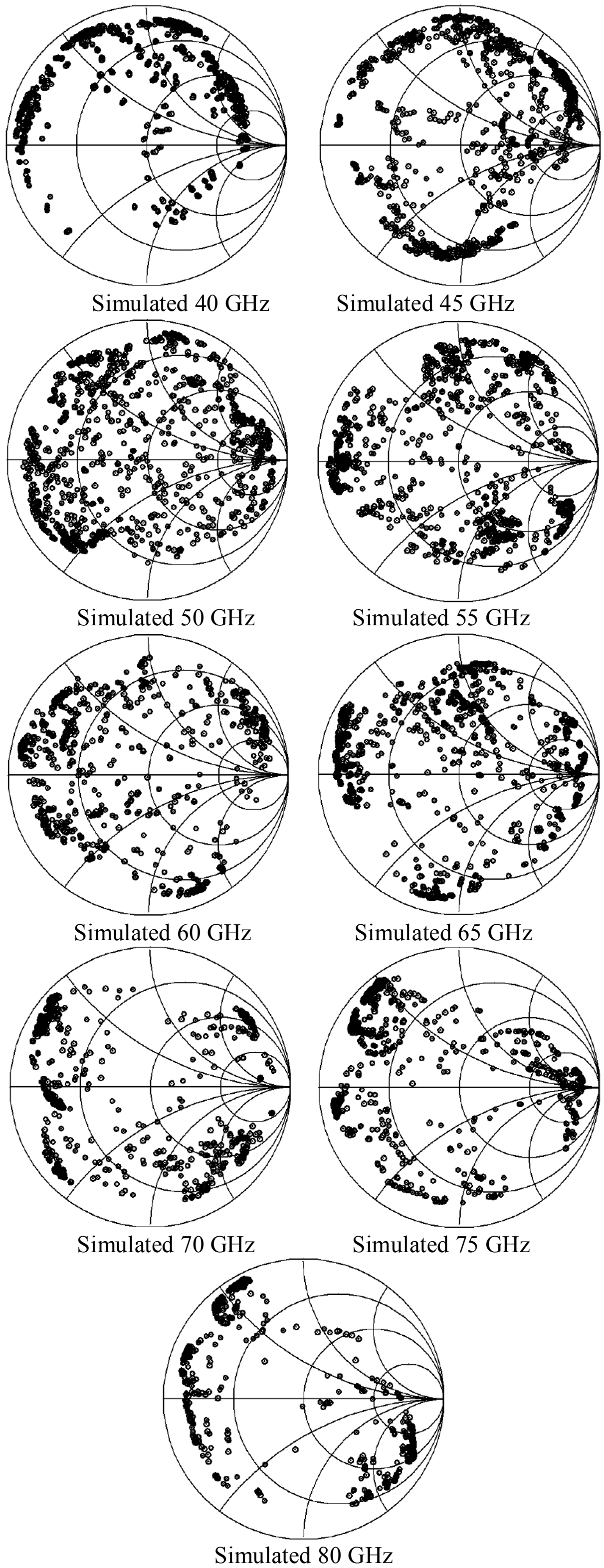


Fig. 5. Simulated (1024 points) impedance coverage of the V-Band single-stub impedance tuner when the output is terminated with an open circuit.

In addition to good impedance coverage, it is beneficial to have reflection coefficients with high amplitude. The highest measured reflection coefficients $|\Gamma_{MAX}|$ (from 90 measurements) at different frequencies are shown in Table 2. Measured $|\Gamma_{MAX}|$ was better than 0.9 at 60 GHz and above. It should be noted that less than 10 % of all impedances were measured, and it is expected to have higher reflection coefficients especially at the lower frequency part of the V-Band. Highest achievable reflection coefficient at the probe tip with mechanical waveguide based impedance tuner is about 0.8 at V-Band [1] and 0.7 at W-Band [2]. If the single-stub tuner is integrated inside an RF probe the loss between the tuner and probe tip can be minimized. Based on the measured $|\Gamma_{MAX}|$ values of the single-stub tuner, higher reflection coefficients are expected to get at the probe tip compared to the waveguide tuners.

f (GHz)	$\|\Gamma_{MAX}\|$
50	0.81
55	0.80
60	0.90
65	0.94
70	0.97
75	0.97
78	0.99

TABLE II

MEASURED (90 IMPEDANCES OUT OF TOTAL 1024 POSSIBLE) MAXIMUM REFLECTION COEFFICIENTS $|\Gamma_{MAX}|$ OF THE SINGLE-STUB IMPEDANCE TUNER.

VI. CONCLUSION

A novel impedance tuner for V-Band noise parameter and load-pull measurement applications was presented. The tuner is based on a single-stub topology and 10 switched RF MEMS capacitors producing 1024 (2^{10}) different impedances. The tuner is the first integrated V-Band impedance tuner. Measured and simulated performance over the 50 to 75 GHz range were presented showing excellent impedance coverage over the whole band and $|\Gamma_{MAX}|$ better than 0.90 at 60 GHz and above.

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