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A 20–50 GHz RF MEMS Single-Stub Impedance Tuner

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***Abstract*—A novel radio-frequency (RF) microelectromechanical system (MEMS) single-stub impedance tuner has been developed. The design is based on combining the loaded line technique with the single-stub topology to obtain wide impedance coverage with high $|\Gamma_{MAX}|$. The tuner consist of ten switched MEMS capacitors producing 1024 (2^{10}) different impedances. The design has been optimized for noise parameter and load-pull measurements of active devices and shows excellent measured impedance coverage over the 20–50 GHz frequency range.**

***Index Terms*—Impedance tuner, load-pull, matching network, multiband, noise parameters, radio-frequency (RF) microelectromechanical system (MEMS).**

I. INTRODUCTION

IMPEDANCE tuners are needed in noise parameter (NP) and load-pull measurements of active devices and are currently built using coaxial or waveguide structures [1]. However, integrated tuners can be assembled inside an radio-frequency (RF) probe minimizing the loss between the tuner and a device under test. Integrated tuners are based on the double-stub [2] or triple-stub topologies [3], and can be made using GaAs or RF microelectromechanical system (MEMS) devices. A problem related to GaAs tuners is limited impedance coverage because of the resistance of active devices. In [4], we presented a distributed-type 20–50 GHz matching network which was optimized for power (PA) amplifier applications. In this case, the loss is minimized and the impedance coverage is designed to address the low impedance of PAs. In contrast, tuners in NP measurements must have wide impedance coverage with high reflection coefficients, and the loss of a tuner is not critical. This letter presents a tuner optimized for NP measurement purposes. The tuner is built using a combination of loaded-line techniques and a single-stub providing high reflection coefficients, and results in a wide impedance coverage area from 20 to 50 GHz.

II. DESIGN OF THE SINGLE-STUB IMPEDANCE TUNER

Standard single-stub tuners result in a limited impedance coverage area and are not useful, but on the other hand, the stub-topology is beneficial since it can provide high reflection coefficients. The design presented here is based on variable loaded-lines which are added before and after the single stub (Fig. 1). The impedance and electrical length of the loaded lines and of the single stub are controlled at discrete positions by digital-type RF MEMS capacitors.

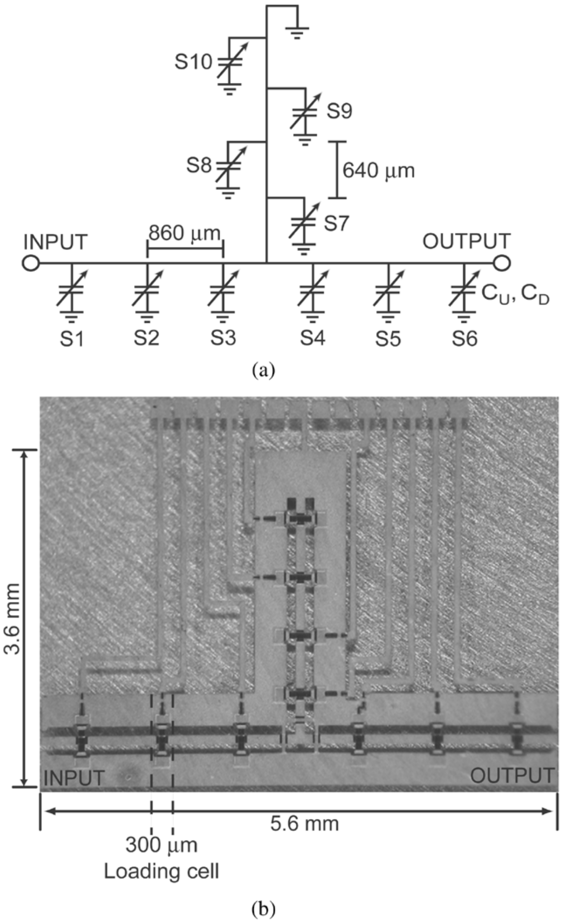

Fig. 1. (a) Circuit diagram and (b) photograph of the fabricated 20–50 GHz single-stub impedance tuner based on ten switched capacitors.

The single-stub tuner can be designed by optimizing several key parameters. The number of the switched capacitors (N) and their capacitance values (C_U, C_D) have the most important effect on the tuning range and bandwidth. In general, a larger N yields more wide-band operation and better impedance coverage but results in an increased component size and loss. Other parameters that need to be optimized are the spacing of the switched capacitors (s) and the length of the stub. There are many variables and different acceptable solutions, and Agilent ADS[1] is used to for the optimization procedure.

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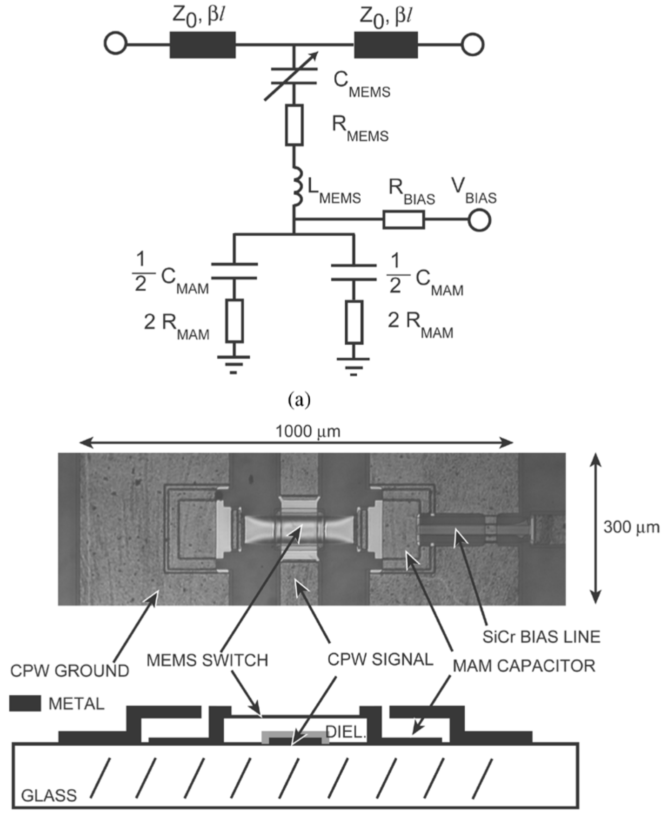
[1] Advanced Design System 2002, Agilent Technologies, Santa Clara, CA, 2002.



(a)

(b)

Fig. 2. (a) Equivalent circuit and (b) picture with cross-sectional view of a switched MEMS capacitor (unit cell in tuner design).

In general, it is found that for a glass substrate (ε_r =4.6, $\varepsilon_{\mathrm{reff}} = (1+\varepsilon_r)/2$ =2.8) with $Z_0 = 87\ \Omega$ (100/100/100 CPW line), a capacitance ratio around 2.5 is best for wide impedance coverage ($C_U = 52$ fF, Xu $= -j100\ \Omega$, and $C_D = 138$ fF, $X = -j38\ \Omega$, at 30 GHz). The loading cell dimension (lc) is around 300 μm, and the localized impedance and effective dielectric constant of each cell are $Z_U = 45\ \Omega$, $\varepsilon_{\mathrm{reffU}}$ =10.1, and $Z_D = 30\ \Omega$, $\varepsilon_{\mathrm{reffD}}$ =22.3 [5] in the up- and down-state positions of the capacitors. The loading cells are placed $s_1 =$ 860 μm and $s_2 = 640\ \mu$m apart in the t-line and stub, respectively. It is important to note that there are many different values of C_U, C_D, lc, s_1, and s_2, which yield excellent impedance coverage due to flexible nature of this design. The values chosen above are a compromise between 20 GHz (high capacitance values, large s), and 50 GHz (low capacitance values, small s). The quality factor of the switched MEMS capacitor is calculated with $Q = (2\pi f C(R_{\mathrm{MEMS}} + R_{\mathrm{MAM}}))^{-1}$ resulting $Q_U =$ 146 and $Q_D = 55$ at 30 GHz in up and down states. This means that the switched capacitors do not contribute a lot of loss to the tuner circuit.

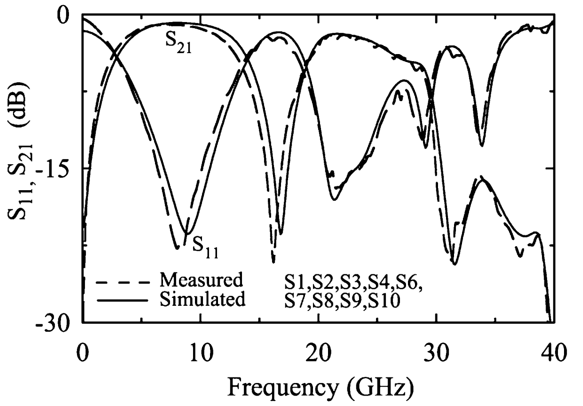


Fig. 3. Measured and simulated S-parameters for the reconfigurable single-stub impedance tuner when switches S1, S2, S3, S9, and S10 are in the down-state position.

TABLE I
MEASURED T-LINE PROPERTIES FROM THE TRL CALIBRATION AND FITTED VALUES FOR THE SWITCHED MEMS CAPACITOR

Z_0 (Ω),	87
$\varepsilon_{\mathrm{reff}}$	2.72
α (dB/cm), 20/30/40 GHz	0.52/0.78/1.1
C_{MEMS} Up State (fF)	74
C_{MEMS} Down State (fF)	683
C_{MAM} (fF)	173
R_{BIAS} (kΩ)	> 3
L_{MEMS} (pH)	13.5
R_{MEMS}+ R_{MAM} (Ω)	0.7

III. FABRICATION AND MEASUREMENT

The switched capacitor (C_U, C_D) is a combination of a capacitive MEMS switch (C_{MEMS}) attached to fixed metal–air–metal (MAM) capacitors (C_{MAM}) (Fig. 2) and the fabrication process is well described in [5]. Note that in this design, the dielectric thickness is 3000 Å, and the capacitance ratio of the MEMS switch is only 9.3. This is acceptable since the final capacitance ratio is 2.5.

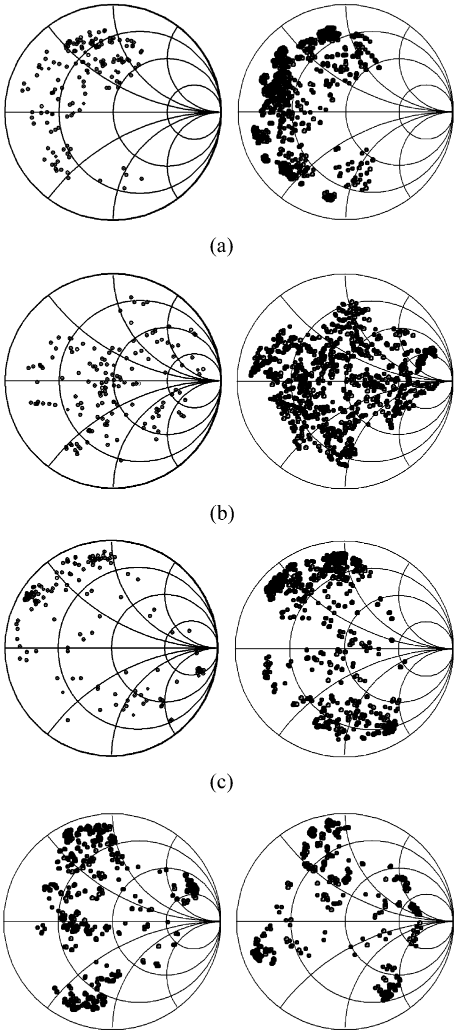
The measured and simulated (with Agilent ADS) S-parameters with half of the switches in the down-state and half in the up-state are shown in Fig. 3 (see also Table I). This shows that the t-line model predicts very accurately the behavior of the circuit over a wide frequency range.

IV. IMPEDANCE COVERAGE

The single-stub tuner has ten switched capacitors producing 1024 (2^{10}) different impedances. Measured (160 points) and simulated (1024 points) impedance coverage at different frequencies are shown in Fig. 4 with 50 Ω input and output terminations. There is a good one-to-one correspondence in the measured and simulated data, but this is not shown due to the number of points on the Smith chart. From the 160 measured points, the measured $|\Gamma_{\mathrm{MAX}}|$ is 0.86, 0.88, 0.94 at 20, 30, and 40 GHz.

The single-stub tuner can be used as a reflection type tuner with an open or short-circuited output port. The simulated impedance coverage of the tuner with open circuit termination at the output port is shown in Fig. 5. Notice the near circular and complete coverage of the Smith chart from 15 to 45 GHz. This is excellent for transistor and low noise amplifier characterization.

The single-stub impedance tuner can also be used as a matching network. However, for this application, the authors recommend the distributed-type matching networks due to their smaller size and lower loss [4], [5].



(a)

(b)

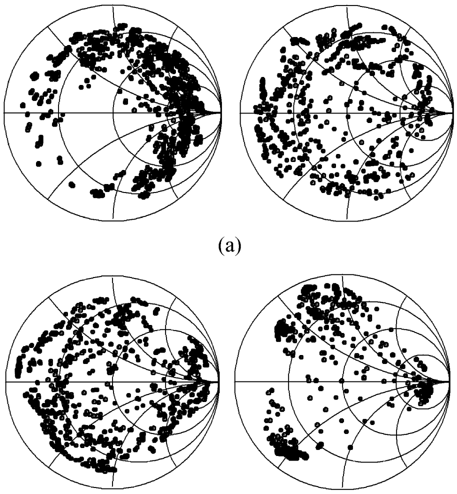
(c)

(d)

Fig. 4. Measured (160 points) and simulated (1024 points) impedance coverage of the single-stub impedance tuner. (a) Measured 20 GHz, simulated 20 GHz. (b) Measured 30 GHz, simulated 30 GHz. (c) Measured 40 GHz, simulated 40 GHz. (d) Measured 44 GHz, simulated 48 GHz.

V. CONCLUSION

This letter presented a novel impedance tuner for 20–50 GHz noise parameter and load pull measurements of active devices. The tuner is based on a single stub and two loaded-lines. The tuner has better impedance coverage than any previously published integrated impedance tuner at this frequency range. The results indicated that this design is quite competitive with coaxial and waveguide based tuners and can be integrated inside an RF probe.



(a)

(b)

Fig. 5. Simulated (1024 points) impedance coverage of the tuner when the output is terminated with an open circuit. (a) Simulated 15 GHz, simulated 25 GHz. (b) Simulated 35 GHz, simulated 45 GHz.

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