W-Band RF MEMS Double and Triple-Stub Impedance Tuners


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W-Band RF MEMS Double and Triple-Stub Impedance Tuners

T. Vähä-Heikkilä\(^1,2\), J. Varis\(^2\), J. Tuovinen\(^2\) and G. M. Rebeiz\(^1\)

\(^1\) The University of Michigan, Ann Arbor, MI, 48109-2122, USA
\(^2\) MilliLab, VTT Information Technology, P.O. Box 12021, 02044 VTT, Finland

Abstract — Reconfigurable integrated impedance tuners have been developed for W-Band on-wafer noise parameter and load-pull measurement applications. The impedance tuners are based on double and triple-stub topologies and employ 11 switched MEMS capacitors producing 2048 \(2^{11}\) different impedances. Measured \(|\Gamma_{\text{MAX}}|\) for the double-stub tuner is 0.92 and 0.82 at 75 and 100 GHz from 110 measurements out of 2048 possible impedances, and 0.92 and 0.83 for the triple-stub tuner. To our knowledge, this represents the first W-band integrated impedance tuner to date.

Index Terms — RF MEMS, impedance tuner, matching network, noise parameter, load-pull, on-wafer.

I. INTRODUCTION

Impedance tuners based on waveguides are used at frequencies above 50 GHz in noise parameter and load-pull measurements of active devices. In practice, these are large in size and expensive. The maximum achievable reflection coefficient, \(|\Gamma_{\text{MAX}}|\), which can be generated using waveguide tuners is very high (about 0.97) but this is referred to the waveguide flange. For on-wafer measurements, the loss of the connecting waveguide sections and W-band-to-CPW probe can limit \(|\Gamma_{\text{MAX}}|\) to about 0.7-0.8 at 50-110 GHz [1,2]. If a tuner can be integrated inside an RF probe, the loss between the tuner and the DUT can be minimized. Also, measurement automation can be increased with electrically controllable tuners.

In this work, we present the first integrated impedance tuners operating at W-Band (75-110 GHz). The impedance tuners are based on double- and triple-stub topologies and switched MEMS capacitors. The MEMS switches are used since they provide excellent performance compared to mm-wave transistors or varactor diodes [3].

II. IMPEDANCE TUNER DESIGN

The impedance and electrical length of the stubs and connecting t-line are controlled at discrete positions by digital-type RF MEMS capacitors (Fig. 1) as done previously in [4-6]. This method results in more wideband tuning and better impedance coverage compared to standard reconfigurable impedance tuners [7,8]. In the switched capacitor-based tuner, 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 wideband 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 and the lengths of the stubs. There are many variables and several acceptable solutions. The tuners were optimized to have 11 switched capacitors producing 2048 \(2^{11}\) different impedances, and Agilent ADS\(^1\) was used for the optimization procedure. The fabricated impedance tuners are shown in Fig. 2, and the process is similar to [4-6] having the same materials and layer thicknesses.

The switched capacitor is a series combination of a MEMS switch and metal-air-metal (MAM) capacitors (Fig. 3). The size of the MEMS switch is 200 \(\mu\)m x 40 \(\mu\)m x 0.9 \(\mu\)m and the area of the fixed MAM capacitor is 280 \(\mu\)m\(^2\), respectively. The MAM capacitors are realized as a part of the anchor area of the MEMS switch. These are electroplated to 3 \(\mu\)m, and being very stiff, they are not actuated with the bias voltage. The CPW dimensions are 50/50/50 \(\mu\)m (G/W/G) and under the MEMS switches 45/90/45 \(\mu\)m in both designs. The center

conductor was widened under the MEMS switches for a lower pull-down voltage. Measured pull-down voltage was 28 V, and a 36 V bipolar actuation was used for getting a firm down-state contact and avoiding charging in the dielectric layer.

The switched MEMS capacitor total up and down-state capacitances are $C_U = 23 \text{ fF}$ and $C_D = 46 \text{ fF}$ ($X_U = -j78 \Omega$ and $X_D = -j39 \Omega$ at 90 GHz), which results in total capacitance ratio of 2.0. Previous lower frequency designs employed a capacitance ratio of 3.5-4.5 for the entire coverage of the Smith Chart [4-6]. The quality factor of the switched MEMS capacitor is calculated using $Q = \frac{2\pi f C(R_{MEMS}+R_{MAM})^{-1}}{}$ and results in $Q_U = 111$ and $Q_D = 54$ at 90 GHz. This means that the switched capacitors do not contribute a lot to the loss of the tuner circuit. Measured and simulated S-parameters for the tuners are shown in Fig. 4. The T-junctions were simulated with Sonnet\textsuperscript{2}, and the S-parameters for the tuners with Agilent ADS using the equivalent circuits of the switched capacitors (Figs. 3 and 4, and Table I).

Table I

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value (fF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_{MEMS}$ Up-State</td>
<td>24</td>
</tr>
<tr>
<td>$C_{MEMS}$ Down-State</td>
<td>410</td>
</tr>
<tr>
<td>$C_{MAM}$</td>
<td>52</td>
</tr>
<tr>
<td>$R_{BIAS}$ (k\Omega)</td>
<td>&gt; 3</td>
</tr>
<tr>
<td>$L_{MEMS}$ (pH)</td>
<td>6</td>
</tr>
<tr>
<td>$R_{MEMS}+R_{MAM}$ (\Omega)</td>
<td>0.7</td>
</tr>
</tbody>
</table>

III. IMPEDANCE COVERAGE

The tuners can produce 2048 \(2^{11}\) different impedances. Measured (110 points for the 2-stub tuner, and 90 for the 3-stub) and simulated (all 2048 points) impedance coverage for the tuners are shown in Figs. 5 and 6. Measured \(|\Gamma_{\text{MAX}}|\) was 0.93, 0.87 and 0.87 at 75, 90, and 105 GHz for the double-stub tuner from 110 measurements and 0.92, 0.87, and 0.83 for the triple-stub tuner from 90 measurements. The tuners have reasonably good impedance coverage with high reflection coefficients at W-Band frequencies, and demonstrate that stub tuners can be employed at 110 GHz and above.

Fig. 5. (a)-(h) Measured (110 points) and simulated (2048 points) \(S_{11}\) impedance coverage of the reconfigurable W-Band double-stub impedance tuner. The tuner was terminated with 50 \(\Omega\) at Port 2.
Reconfigurable W-Band double- and triple-stub impedance tuners were presented. The tuners were developed for on-wafer noise parameter and load-pull measurement purposes. The electrical tuning of impedance is realized with 11 switched MEMS capacitors, and 2048 \(2^{11}\) different impedances can be generated with the tuners. The tuners are small enough to be integrated inside W-band RF probes.

**IV. CONCLUSIONS**

Reconfigurable W-Band double- and triple-stub impedance tuners were presented. The tuners were developed for on-wafer noise parameter and load-pull measurement purposes. The electrical tuning of impedance is realized with 11 switched MEMS capacitors, and 2048 \(2^{11}\) different impedances can be generated with the tuners. The tuners are small enough to be integrated inside W-band RF probes.

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**REFERENCES**


