Coplanar Stripline Single Pole Single Throw Switch

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***Abstract*— Coplanar stripline (CPS) series-connected spurline resonators are terminated with diodes, which can have a voltage applied to them, creating either a short circuit or open circuit. By connecting two spurline resonators in series separated by a quarter-wavelength transmission line, and when the diodes are reverse biased, the total circuit passes the RF power unimpeded. When the diodes are forward-biased, the circuit is a bandstop filter. This creates a CPS RF series switch with an insertion loss of 0.1 ± 0.1 dB, a reflection coefficient of −30 dB, and an isolation of 20 dB. The switch was simulated, fabricated, and measured for both single-element and two-element configurations.**

***Index Terms*— Coplanar stripline (CPS), p-i-n diode, spurline resonator, switch.**

I. Introduction

COPLANAR stripline (CPS) has good characteristics and advantages for RF circuits and systems; it facilitates easy integration of series and shunt passive components and diodes without the need for through wafer via holes. It also supports a balanced signal, which is important for modern RF circuits and systems [1], [2]. Even with these advantages, it is rarely used as evidenced by the small number of papers published in the literature compared to microstrip and the dual of CPS, coplanar waveguide (CPW). The reason for this is that the even mode of CPS is easily excited [3], [4], [5], [6], [7], and no easy method of suppressing it has been described, such as airbridges or bond wires as used for CPW. Instead, only a few unique methods for suppressing the even mode on specific elements have been demonstrated. For CPS series stubs connected in T-junctions, a very noneloquent method was demonstrated [8]. A method to suppress the even mode on CPS spurline resonators using airbridges or wirebonds was presented [9]. Other than these two specific methods, more general methods have not been published.

However, if CPS is to be widely used, more CPS circuit components must be developed. A component required in many applications is a switch to turn ON and OFF the power to certain circuit elements. CPS switches are typically implemented by placing a diode across the slot [10], [11]; when the diode is reverse-biased, it is an effective open circuit and does not affect the RF power propagating on the CPS, and when the diode is forward-biased it is an effective short circuit across the slot and reflects the RF power propagating on the CPS. This switch has the advantage that it is small, but the p-i-n diode parasitic reactances make it virtually impossible to achieve the theoretical characteristics, especially at higher frequencies. A graphene film across the slot or across a gap in the two CPS strips has been proposed and modeled [12]. A CPS switch based on a lattice network that connects and disconnects a series impedance, which is an effective open circuit, has been demonstrated [13], [14], [15]. This switch had an insertion loss of 0.1 dB and an isolation of 25 dB over a narrow bandwidth, but it is physically large. A CPW switch based on a spurline resonator, with a p-i-n diode switching between an open circuit terminated stub and a short circuit terminated stub, achieved 1 dB insertion loss and 19 dB isolation [16], [17]. A spurline resonator switch was later demonstrated in microstrip configuration [18]. The advantage of these switches is that they are in line and smaller than the lattice circuit switch. A CPS reconfigurable bandpass filter has been demonstrated with a notch frequency that could be turned ON and OFF, thus achieving a switch, but this circuit was meant to be a bandpass filter and was comprised of multiple diodes that introduced significant parasitic reactances that severely degraded the component's use as a switch, which had an insertion loss of 3 dB and an isolation of 11 dB [19].

In this letter, a CPS series switch is introduced that uses the concept of the switched spurline resonator in the same way that was done in the CPW switch described above. The switch uses the even mode suppression technique to achieve good open-circuit terminated stub and passband characteristics, as well as good short-circuit terminated stub and stopband characteristics [9], effectively achieving good switching characteristics.

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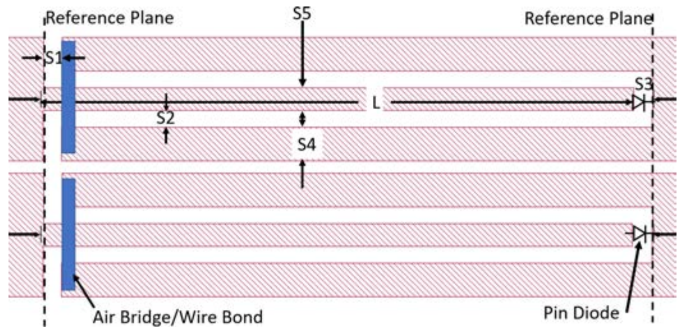


Fig. 1. Line drawing of CPS spurline resonator switch.

II. Spurline Resonator Based Switch

Fig. 1 shows a line drawing of a CPS single stub spurline resonator-based switch. The circuit is fabricated on 0.762 mm

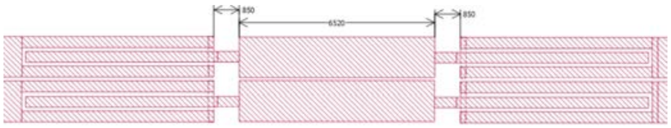


Fig. 2. Line drawing of two-stub CPS spurline resonator switch.

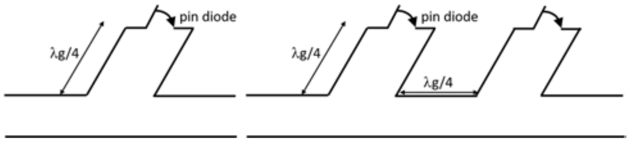
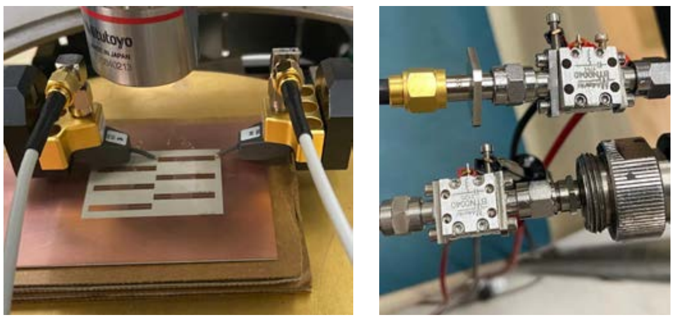


Fig. 3. Schematic of one and two element switch.



(a) (b)

Fig. 4. (a) Setup for single-element switch with (b) bias voltage applied through two bias tees.

TMM10i with 35 μm thick copper cladding and a relative permittivity of 9.8. Gold ribbon bonds 50.8 μm wide and 12.7 μm thick are used for the airbridges, which are about ten skin depths at the frequency of the switch. The CPS slot width is 150 μm and the strip width is 1350 μm. The spurline dimensions are S1 = S2 = S3 = 130 μm, S4 = 370 μm, S5 = 360 μm, and L = 6370 μm. L is a quarter wavelength at the design frequency of f_o = 3.25 GHz and S1 and S2 are chosen to be easily fabricated. MACOM MA4P404-132 p-i-n diodes are used. In the modeling, they have a reverse bias capacitance of 0.1 pF and a resistance of 5 Ω, and a forward bias resistance of 0.2 Ω. The wirebonds for connecting the diodes are modeled with a 0.1 nH inductance.

A drawing of a two stub spurline resonator is shown in Fig. 2. The dimensions of the two-stub resonator are the same as the single stub resonator, with the total length between the two stubs optimized using Sonnet software to be 8220 μm long. This consists of two 850 μm length sections of width 350 μm on either end of a length 6520 μm section of width 1350 μm. Note that the line between the two spurline resonators is λg/4 and when the diodes are forward-biased, or the resonators appear as open circuits, the two-element switch is equivalent to a gap-coupled bandstop filter [20]. The schematic of the switches is shown in Fig. 3.

III. Measurement Procedure

Measurements of the switch were completed on a probe station. The fabricated switch was placed on two stacked sheets of cardboard to minimize the effect of the metal wafer chuck and measured using Form Factor + ACP40 GS probes with 250 μm pitch. The probes were connected to a vector network analyzer (VNA) using coaxial cables, with bias tees (Marki BTN0040-1711) between the VNA and coaxial cables.

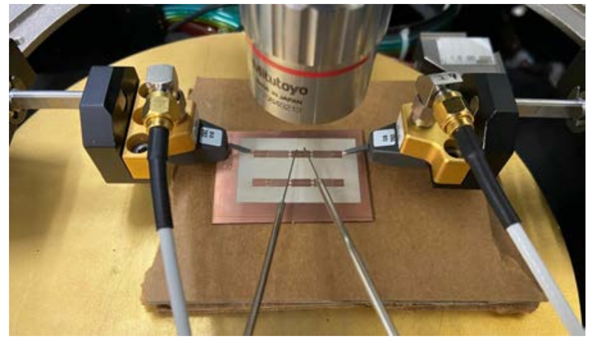


Fig. 5. Two-element switch test setup with dc bias probes.

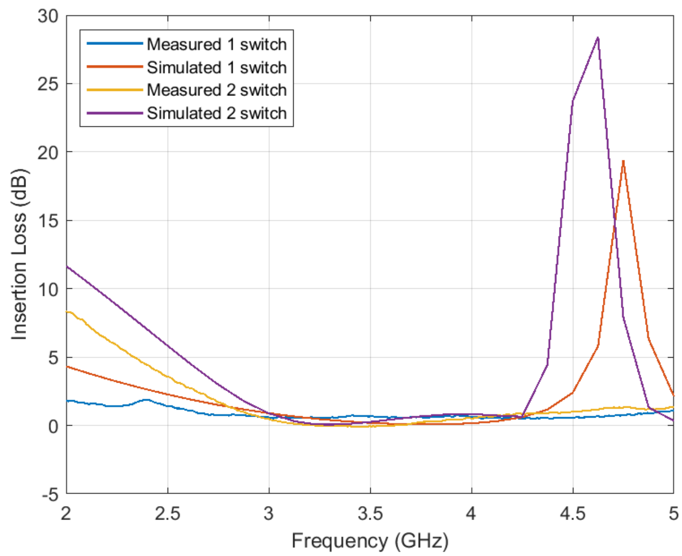


Fig. 6. Measured and simulated insertion loss of the one and two-element switches when the switches are ON.

For the single-element switch, the diodes were biased from a dc power supply using the bias tees, as shown in Fig. 4. For the two-element switch, the diodes are biased using needle probes connected to the CPS section between the two sets of stubs as shown in Fig. 5, and the bias tees are grounded. For both setups, the dc bias voltage is set to 1.0 V.

An open-short-load-through coaxial calibration was performed from the ends of the coaxial connectors, which were connected to the probes during measurement. The measured thru line insertion loss is 1.2 dB at the center frequency, 3.25 GHz, from which the added loss of the probes and CPS feed line is determined. The maximum reflection coefficient is –17 dB.

IV. Measured and Simulated Results

Both the single-element and two-element switches were simulated, fabricated, and measured with the input port on the left-hand side and the output port on the right-hand side. In the simulations, the actual measured values of the circuit lengths were used, which varied from the designed dimensions by ± 50 μm. Fig. 6 shows the measured and simulated

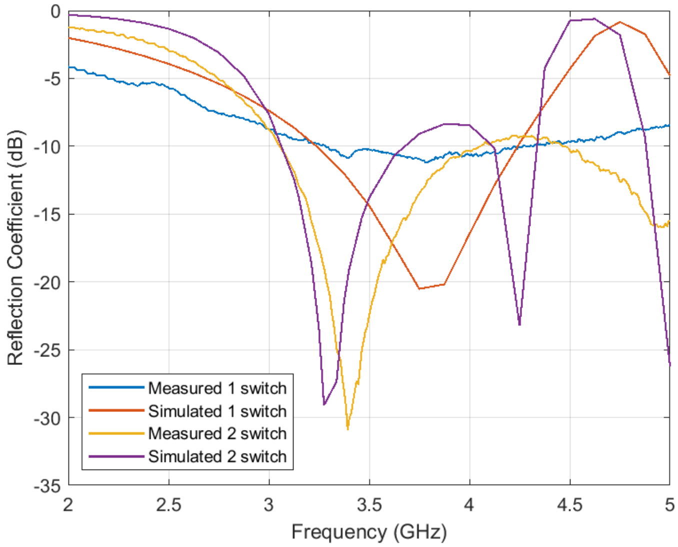


Fig. 7. Measured and simulated reflection coefficient of the one and two-element switches in the ON-state.

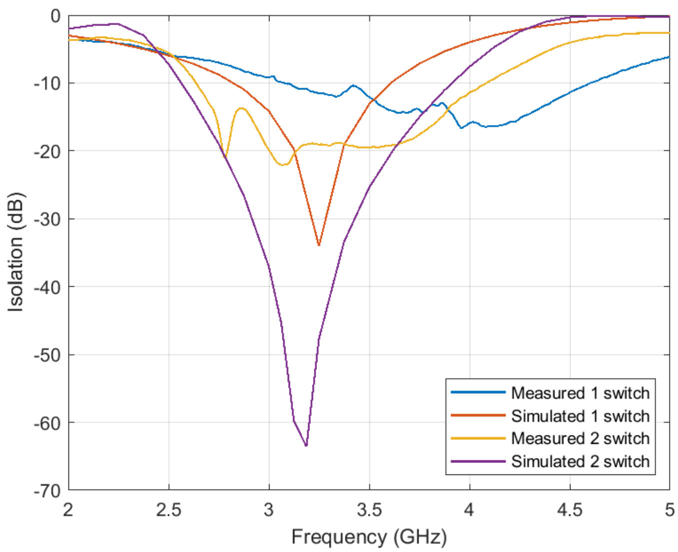


Fig. 8. Measured and simulated isolation of the one and two-element switches when the switches are OFF.

insertion loss of the two switches. Fig. 7 shows the measured and simulated reflection coefficient of the switch in the ON state, and Fig. 8 shows the isolation of the switches in the OFF state. There is good agreement between the measured and simulated results, with the measured results showing additional loss across the entire response originating from fabrication imperfections and unaccounted conductor loss in the spurline resonators. Other variations between the simulations and measurements may be due to the permittivity of the cardboard which varies between 1.8 and 2.6 [21], [22], which was simulated as air, and the fact that cardboard is inhomogeneous. Finally, the loss tangent of cardboard varies between 0.015 and 0.025 [21] or 0.042 and 0.068 [23]. Unfortunately, neither paper stated the humidity in the room, which greatly affects the permittivity.

These results show how the switch passes RF signals centered around 3.25 GHz when the diode is reverse biased, which

TABLE I

MEASURED DATA OF THE SINGLE AND DOUBLE ELEMENT SWITCHES

	On State IL (dB)	Bandwidth
1 Stub	0.5±0.1dB	26%
2 Stub	0.1±0.1dB	27%
[13]	0.1	39%

creates an open circuit and transferred to a short circuit by the $\lambda/4$ stub, but blocks these signals when the diode is forward biased, which creates a short circuit which is transferred to an open circuit by the stub.

The two-element switch with the $\lambda g/4$ line between the two resonators has a smaller insertion loss, a higher isolation, and a larger isolation bandwidth than the single element switch. The results are summarized in Table I. The variation in the insertion loss is due to a ripple in the through line measurement which is used for calibration or correction. The bandwidth is defined as |reflection coefficient| and isolation greater than 10 dB. Note the diodes are forward biased when the switch is in the ON-state in [13] so the current flows through the bond wire and diode resistance, which increases the insertion loss. For the switches described in this letter, the diodes are reverse biased when the switch is in the ON-state, so there is no current flow through the resistances. The switch in [13] had a higher isolation, but the switch in [13] is not inline and therefore harder to use in a circuit than the switch described in this letter.

V. CONCLUSION

In this letter, a CPS switch using a switched spurline resonator is introduced. The switch was simulated, fabricated, and measured for both single-element and double-element designs. The even-mode suppression allows the switch to achieve both good open-circuit and short-circuit characteristics. The addition of a second switch improves the isolation and creates an integrated switch/bandpass filter. It is noted that the center frequency of the switch differs between the ON state and OFF state due to the different diode reactances for forward and reverse bias. This work increases the utility of CPS transmission lines in RF circuits by developing a device that controls the flow of RF signals on a CPS transmission line and with a smaller size than [13]. It must be noted that the bandwidth of the switch is limited by the spurline resonators since at twice the resonant frequency the stubs have the opposite characteristics as the stubs at f_o.

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