Effects of Parasitic Reactance on Lattice Circuit Slotline Switch

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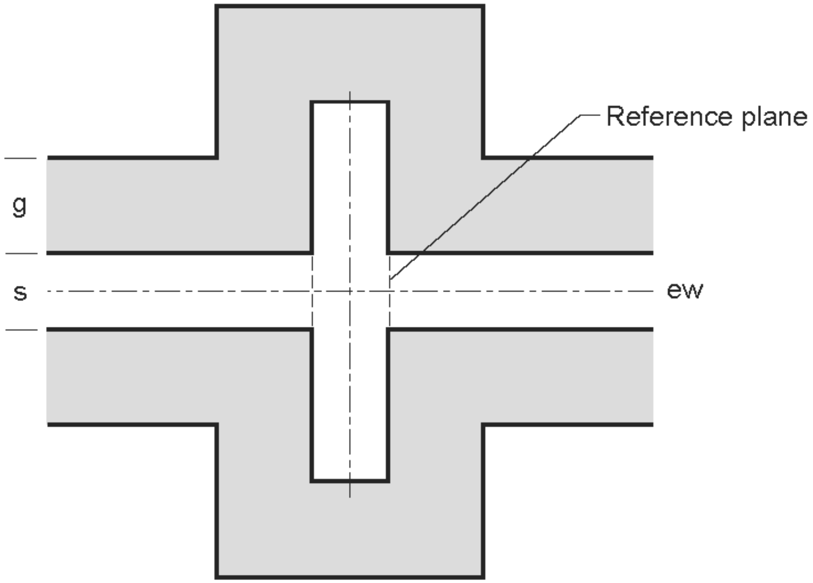
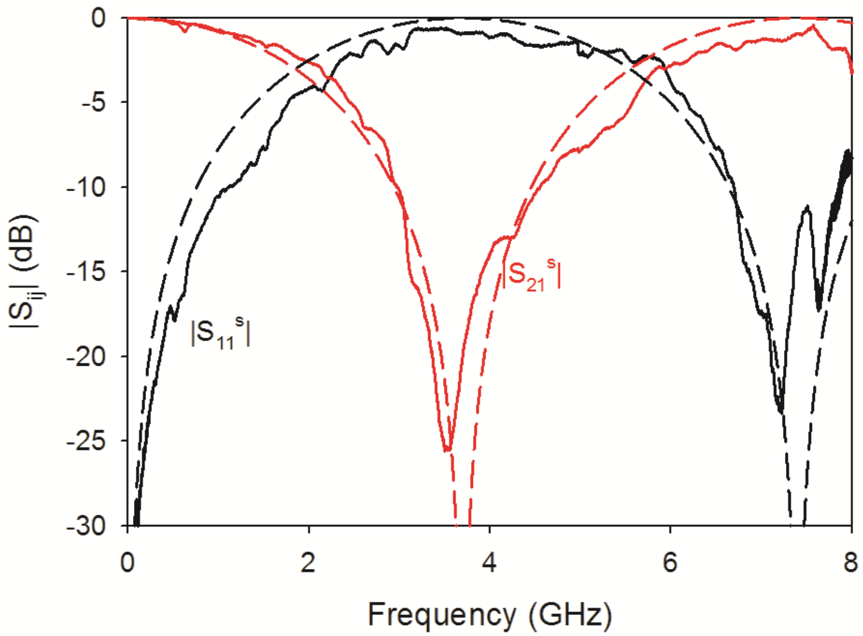
Introduction

- G. E. Ponchak, “Slotline switch based on a lattice circuit,” IEEE Microw. and Wireless Compon. Lett., Vol 26, No. 1, Jan. 2016, pp. 43-45.
  - Reviewers asked me to consider the effects of parasitic reactances
  - In a three page paper, it was not possible
- This paper evaluates the Lattice Circuit Slotline Switch with diode parasitic reactances.
- The Lattice Circuit Slotline Switch is compared to a single shunt diode slotline switch.

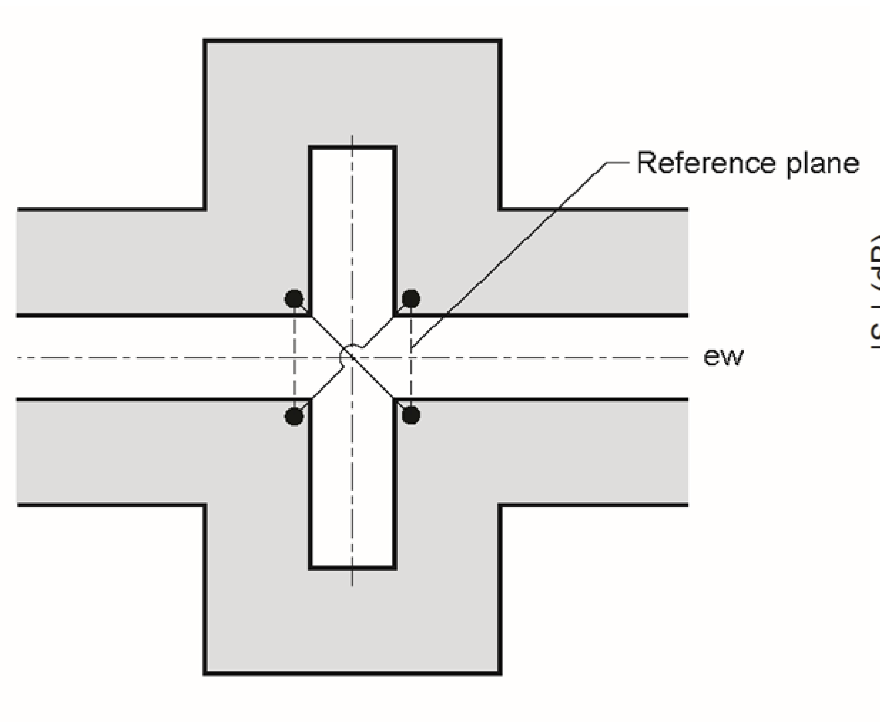
Slotline Short Circuit Terminated Series Stub

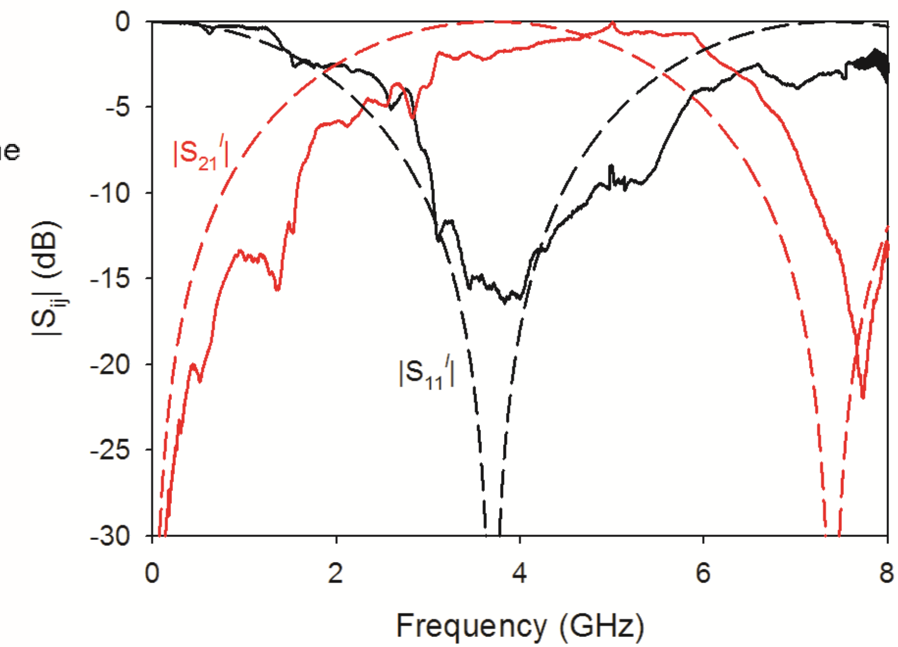




A slotline short circuit terminated series stub acts as a series open circuit when the stub is $\lambda_g/4$ long, reflecting all power at that frequency.

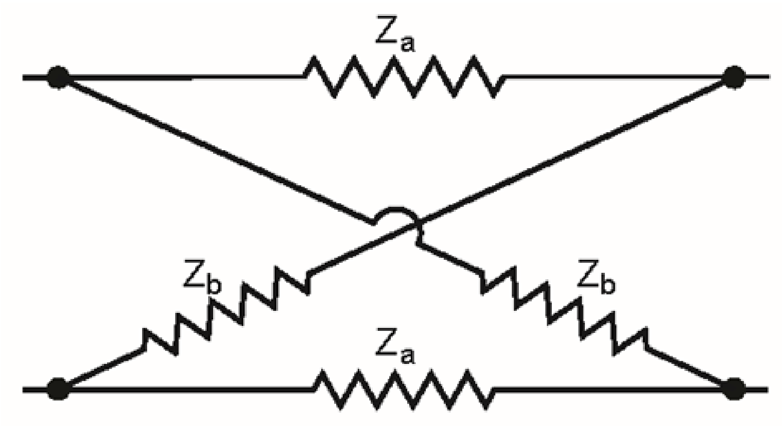
Slotline Short Circuit Terminated Series Stub with Bridge Connection at the T-Junction





A slotline bridge connection at the T-junction short circuits the $\lambda_g/4$ stub and its equivalent open circuit, creating a perfect through line with a 180 degree phase change.

Lattice Circuit Schematic



$$S_{11} = \frac{Z_a Z_b - Z_0^2}{Z_a Z_b + Z_0(Z_a + Z_b) + Z_0^2}$$

$$S_{21} = \frac{(Z_b - Z_a) Z_0}{Z_a Z_b + Z_0(Z_a + Z_b) + Z_0^2}$$

$$S_{11}^s = \frac{jtan(\beta l)}{1 + jtan(\beta l)} \quad S_{21}^s = \frac{1}{1 + jtan(\beta l)}$$

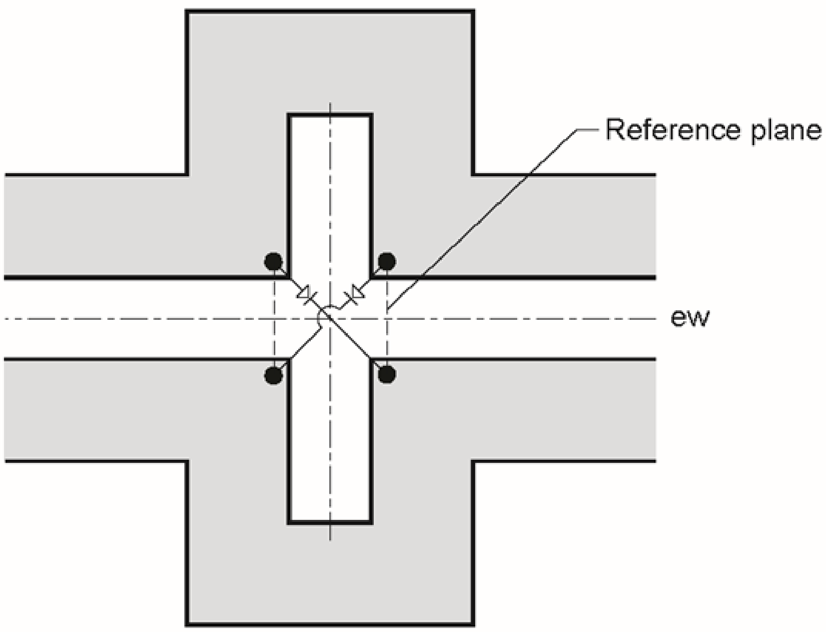
The S-parameters of the Lattice Circuit if $Z_b = \infty$.

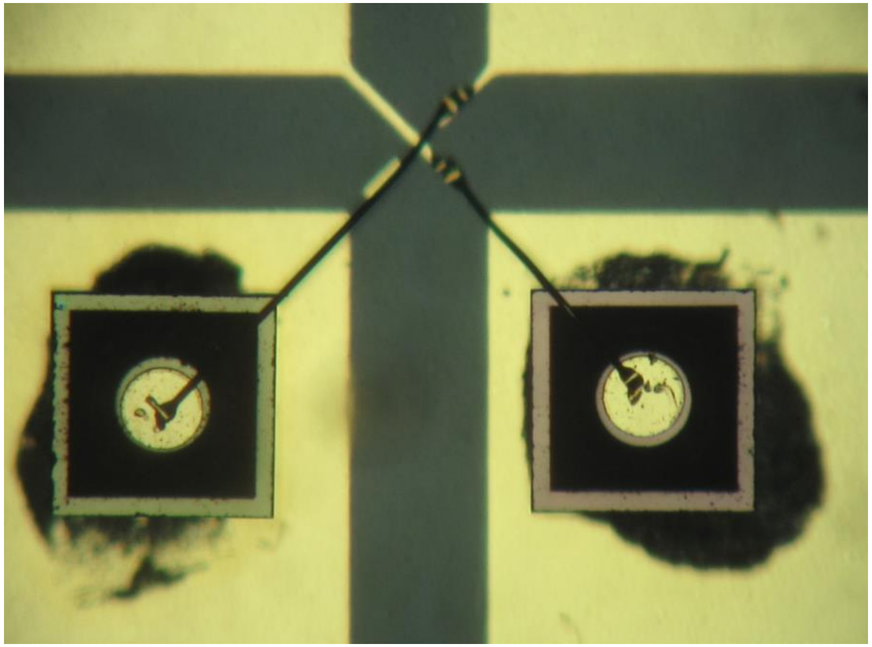
$$S_{11}^l = \frac{-1}{1 + jtan(\beta l)} \quad S_{21}^l = \frac{-jtan(\beta l)}{1 + jtan(\beta l)}$$

The S-parameters of the Lattice Circuit if $Z_b = 0$.

- $\theta = \beta l$
- The above equations assume the diode is either a perfect short or open circuit; No parasitic reactances are considered.

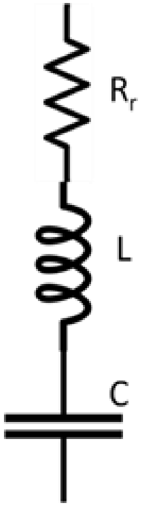
Slotline Switch Based on a Lattice Circuit





- A pair of MACOM MA4P404-132 *pin* diodes across the T-junction comprise the switch.
- When the diodes are reverse biased, the switch is OFF.
- When the diodes are forward biased, the switch is ON.

Pin Diode Model



Reverse biased *pin* diode model

$$Z_r = R_r + j\omega L + {}^{1}/_{j\omega C} = R_r + jX_r$$
$$X_r = -(1 - \omega^2 LC)/\omega C = -1/\omega C_{eff}$$

Forward biased *pin* diode model

$$Z_f = R_f + j\omega L = R_f + jX_f$$
$$X_f = \omega L$$

pin Diode Characterization

- The pin diode (MACOM MA4P404-132) was mounted on a 0.38 mm thick, alumina carrier for one port characterization
- The length of the bond wire from the probe pad to the diode contact was made similar to that used on the slotline, lattice circuit switch.
- A 150 μm pitch ground-signal-ground (GSG) probe was used and an Agilent PNA was calibrated to the probe tip using a GGB Industries calibration standard
- Measurements were made at the same bias conditions as used for the lattice circuit switches (V_r=0 V, I_r=0 mA, and V_f=1.07 V, I_f=37 mA) over the frequency range of 0.01 to 20 GHz.
- S-parameters were converted to Z-parameters.

pin Diode Circuit Element Values

	R_f (Ω)	L(nH)	R_r (Ω)	C(pF)
Reverse Bias	------	0.78	7.0	0.24
Forward Bias	1.3	0.78	------	------

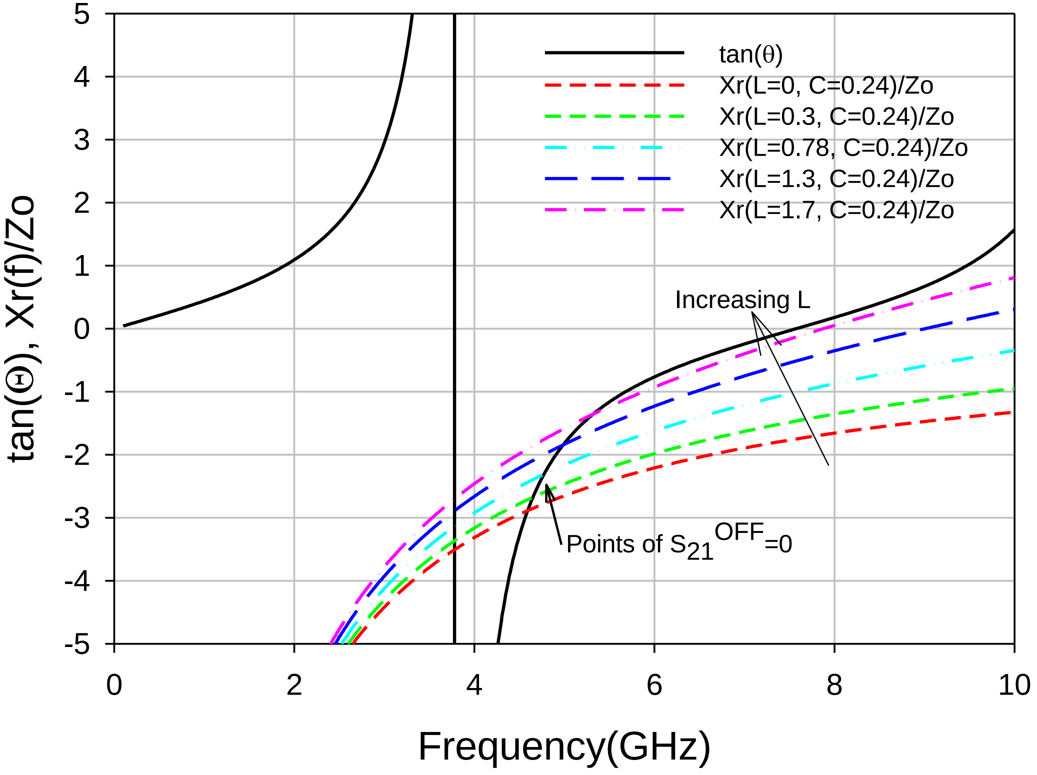
Since the resistances are small, they will be ignored in the analysis.

$$S_{11} = \frac{-(X_i \tan(\theta) + Z_o)}{[Z_o - X_i \tan(\theta)] + j[Z_o \tan(\theta) + X_i]} \qquad S_{21} = \frac{j(X_i - Z_o \tan(\theta))}{[Z_o - X_i \tan(\theta)] + j[Z_o \tan(\theta) + X_i]}$$

- For OFF state switch characteristics, S_{21}=0 if $X_r/Z_o=\tan(\theta)$
- For ON state switch characteristics, $|S_{21}|$=1 and S_{11}=0 if $X_f/Z_o=-\cot(\theta)$

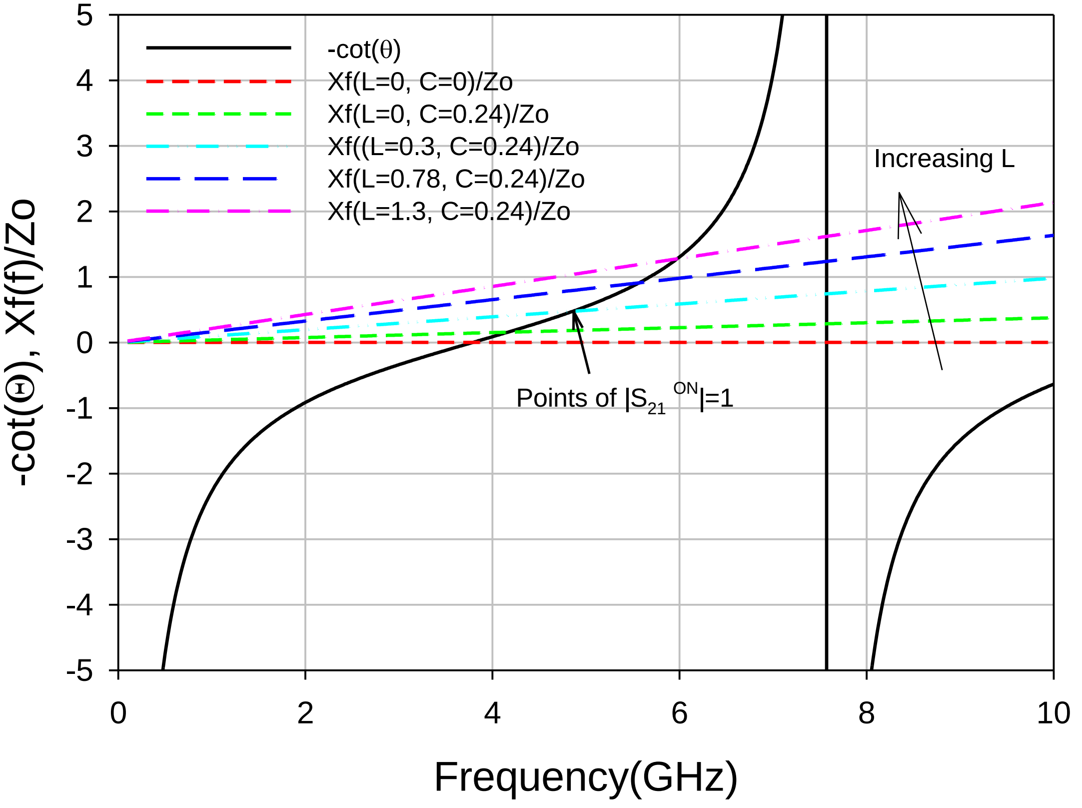
OFF State Requirements

- Diode parasitic reactances increase the frequency of perfect isolation.
- Increasing values of inductance increase the frequency of infinite isolation.
- There is only a frequency at which perfect isolation occurs between $\pi/2 \leq \theta \leq \pi$ if $L \leq 2$ nH.

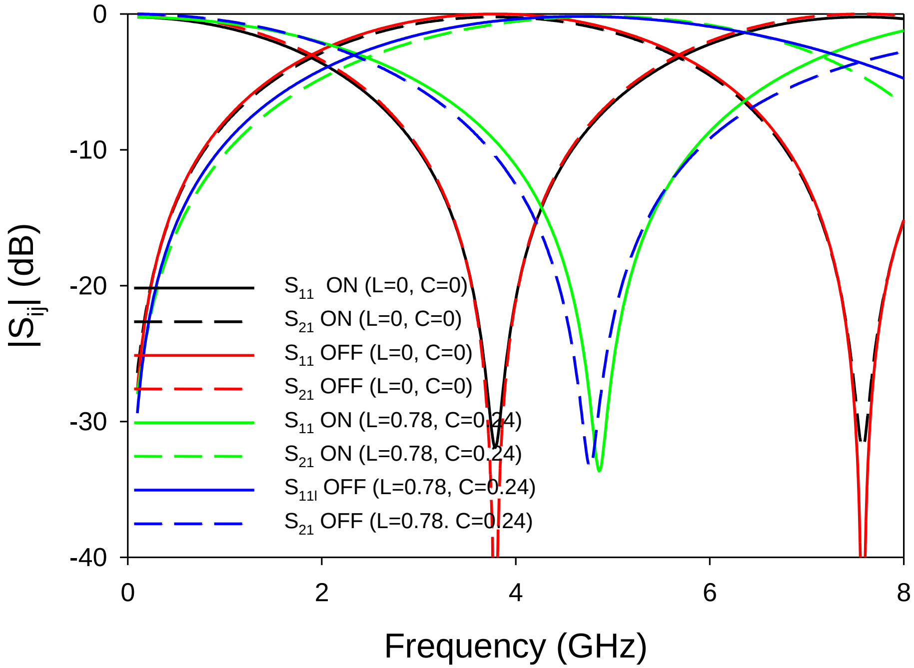


ON State Requirements

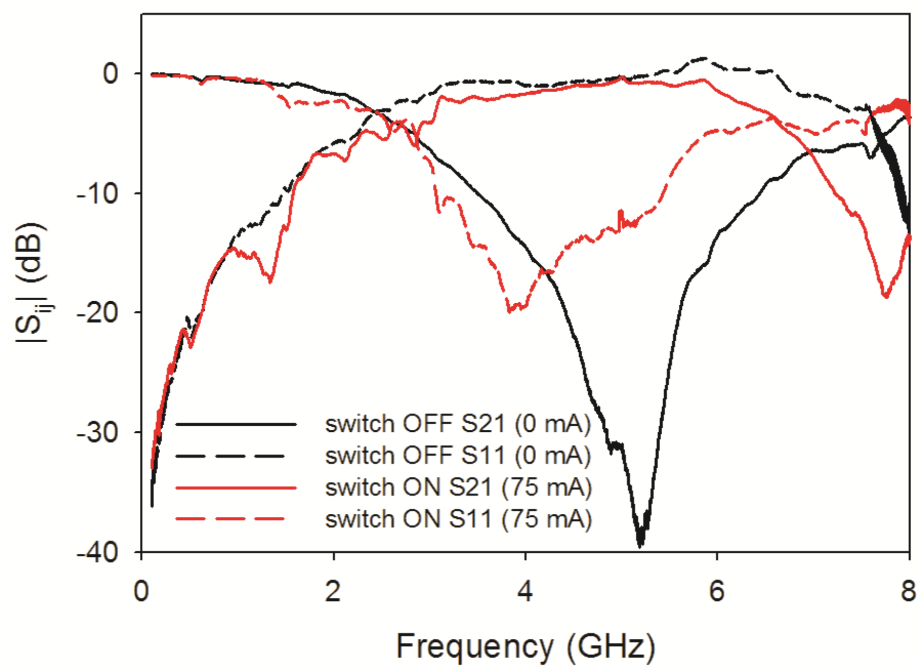
- Diode parasitic reactances increase the frequency of zero insertion loss.
- Increasing values of inductance increase the frequency of zero insertion loss.
- There is always a frequency between $\pi/2 \leq \theta \leq \pi$ at which the insertion loss is zero.



Switch S-parameters with Reactances



Calculated S-parameters with and without the measured diodes reactances.



Measured S-parameters.

- Calculated OFF state parameters match the measured parameters well
- Calculated ON state parameters do not match well, probably due to an overestimate of L.

Optimal Switch Characteristics

Conditions for ideal switch characteristics, $S_{21}^{OFF}=0$ and $S_{21}^{ON}=1$

$$\tan(\theta) = \frac{\omega^2 LC - 1}{\omega C Z_o} \qquad \cot(\theta) = \frac{-\omega L}{Z_o}$$

Leading to:

$$L = \frac{1 \pm \sqrt{1 - 4\omega^2 C^2 Z_o^2}}{2\omega^2 C} \qquad \theta = tan^{-1}({}^{-Z_o}/_{\omega L})$$

- If $2\omega CZo<1$ and $\pi/2<\theta<3\pi/4$, a value of L may be found to obtain ideal switch conditions.
- A solution may be found if ωC is small.

"TRADITIONAL" SLOTLINE SWITCH

- A single pin diode across the slot.
- If diode is reverse biased, the diode impedance is large and has no effect on signal. The switch is ON.
- If diode is forward biased, the diode impedance is small and reflects the signal. The switch is OFF.

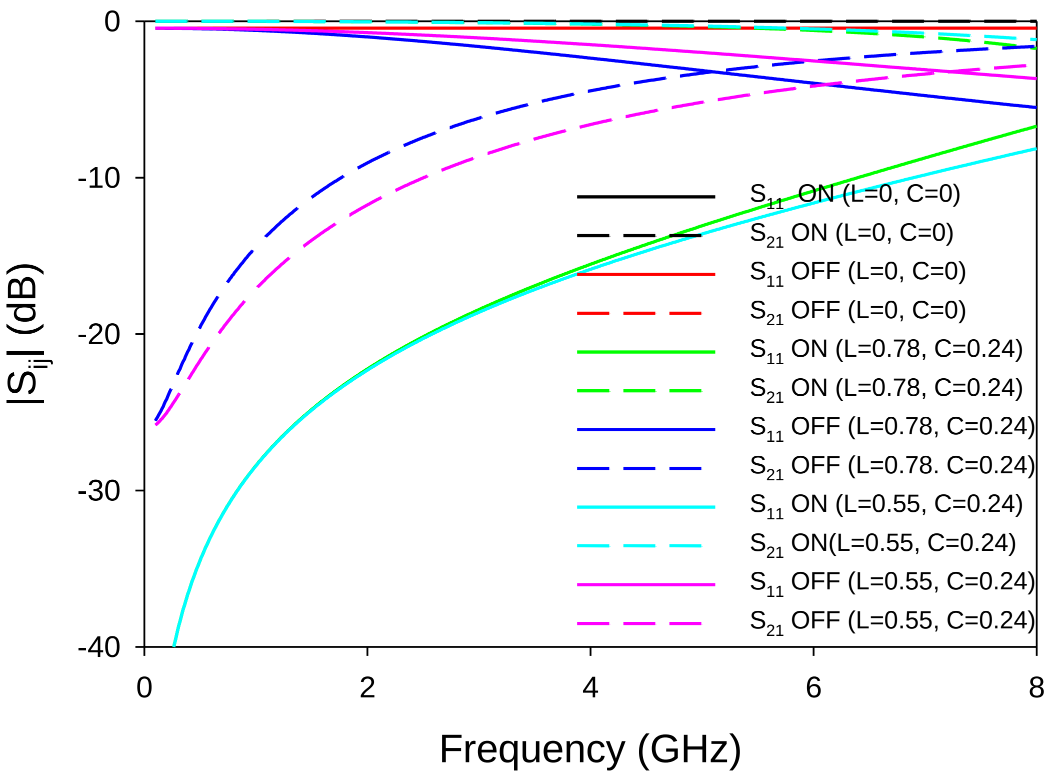
S-parameters are:

$$S_{11} = \frac{-Z_o}{(2R_i + Z_o) + j2X_i} \qquad S_{21} = \frac{2(R_i + jX_i)}{(2R_i + Z_o) + j2X_i}$$

Note that $S_{21}^{OFF}=0$ only if $R_f=X_f=0$

"TRADITIONAL" SLOTLINE SWITCH

- If L=C=0, ideal switch characteristics are achieved over all frequencies.
- If L=0.78 nH and C=0.24 pF, the switch operates well to 2 GHz.
- If L=0.55 nH and C=0.24 pF, the switch operates well to 3 GHz.
- Poor isolation due to forward biased diode reactances.



Conclusions

- The ideal Lattice Circuit Slotline Switch has infinite isolation and perfect impedance match at the design frequency at which the stub is $\lambda_g/4$.
- With parasitic diode reactances, infinite isolation and perfect impedance are possible.
- The newly described Lattice Circuit Slotline Switch has better performance than the "traditional," single diode slotline switch.
  - Note that the reactances of the single diode slotline switch can be minimized by a resonant circuit.