A PIN Diode Controlled Variable Attenuator Using a 0-dB Branch-Line Coupler

Kae-Oh Sun, Min Ki Choi, and Daniel van der Weide, *Member, IEEE*

***Abstract*—We describe a simple PIN diode controlled variable attenuator that employs a 0-dB branch line directional coupler. The response of the attenuator was measured between 1.3 GHz and 2.6 GHz. At the center frequency, the attenuation monotonically varied from 0.7 dB to 23 dB with the control voltage, and the distributed branch-line coupler structure resulted in low input reflection. Our attenuator is easier to design, smaller in area than a double hybrid coupled attenuator, and has comparable or better reflection and attenuation performance characteristics.**

***Index Terms*—Attenuator, distributed branch-line coupler, PIN diode controlled variable attenuator.**

I. Introduction

VARIABLE attenuators are used to control power transmission, and they have applications in devices modulators, automatic gain control circuits and radar systems. PIN diodes are commonly used as the control element in variable attenuators because of their speed and ease of design. Many types of variable attenuators using PIN diodes have been presented; π attenuators, resistive line attenuators, bridged-T attenuators, hybrid coupled attenuators, and others [1]. The hybrid coupled attenuator is frequently used when reflected power must be minimized, and a double hybrid coupled attenuator is especially preferred due to its wider bandwidth, though it requires larger area than a single hybrid coupled attenuator.

II. PIN Diode Characteristics and Attenuator Circuit Analysis

A PIN diode is a PN junction diode that has an intrinsic layer between its P-type and N-type layers. The PIN diode behaves as an ordinary PN junction diode at low frequencies, but at high frequencies it behaves as a resistor whose value can be controlled by current. Fig. 1 shows a PIN diode high frequency equivalent circuit. The element C_I is the constant capacitance, which is dependent on the geometry of the intrinsic layer. If the reactance value of C_I is much larger than R_I, the PIN diode can be considered as a pure resistor (when the package inductance, L_p, can be ignored). In our design, we used a MA4FCP200 PIN diode manufactured by MA-COM. The total capacitance of this diode is 0.015 pF and its reactance at 1.9 GHz is approximately 5.6 kΩ, which is large enough to consider it as a pure resistor.

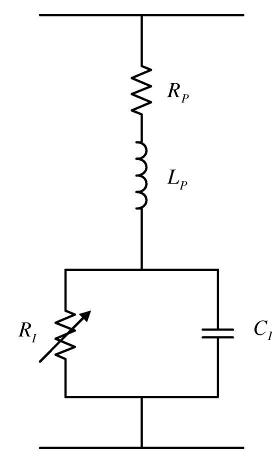

Fig. 1. PIN diode high frequency equivalent circuit.

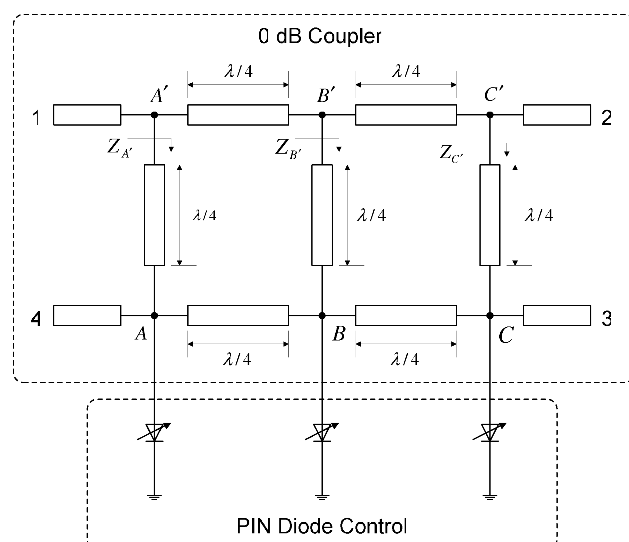

Fig. 2. Attenuator schematic diagram.

Using this resistive characteristic, we constructed a variable attenuator by combining the PIN diode with a 0-db branch-line coupler [2], [3]. Fig. 2 shows the schematic diagram for the variable attenuator. The 0-dB coupler is composed of 50-Ω quarter-wavelength microstrip lines.

Ideally, the resistance of the PIN diodes can be varied from infinity to zero, which means nodes *A*, *B*, and *C* can be floating or, conversely, connected to ground. When the nodes are floating, the whole circuit acts as a 0-dB coupler itself, and the incident power to port 1 is transferred to port 3 without any attenuation or reflection. However, when nodes *A*, *B*, and *C* are grounded,

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The authors are with the Department of Electrical and Computer Engineering, University of Wisconsin, Madison, WI 53706 USA (e-mail: ksun@cae.wisc.edu).

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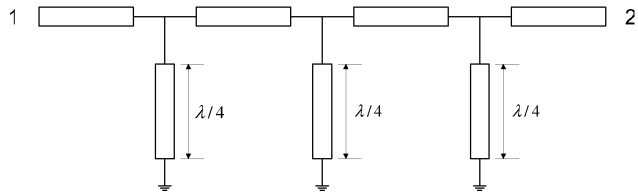

Fig. 3. Equivalent circuit when PIN diodes are turned on.

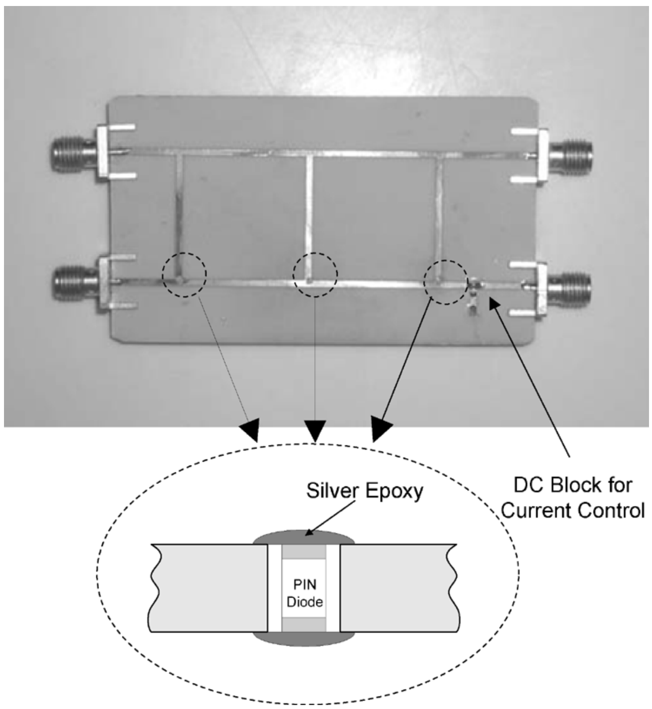

Fig. 4. Layout of the attenuator.

the input resistances Z'_A, Z'_B, and Z'_C as seen from A', B' and C' to the branches, approach infinity.

Applying an even-odd mode analysis for the infinite resistance case, we can get the $ABCD$ matrices as

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_e = \begin{bmatrix} 1 & 0 \\ j & 1 \end{bmatrix}\begin{bmatrix} 0 & j \\ j & 0 \end{bmatrix}\begin{bmatrix} 1 & 0 \\ j & 1 \end{bmatrix}\begin{bmatrix} 0 & j \\ j & 0 \end{bmatrix}\begin{bmatrix} 1 & 0 \\ j & 1 \end{bmatrix} = \begin{bmatrix} 0 & -j \\ -j & 0 \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_o = \begin{bmatrix} 1 & 0 \\ -j & 1 \end{bmatrix}\begin{bmatrix} 0 & j \\ j & 0 \end{bmatrix}\begin{bmatrix} 1 & 0 \\ -j & 1 \end{bmatrix}\begin{bmatrix} 0 & j \\ j & 0 \end{bmatrix}\begin{bmatrix} 1 & 0 \\ -j & 1 \end{bmatrix} = \begin{bmatrix} 0 & j \\ j & 0 \end{bmatrix}. \tag{2}$$

From these equations, the amplitude of the emerging wave at each port in Fig. 2 is $B_1 = B_2 = B_4 = 0$, $B_3 = j$, and all the incident power is transferred to port 3. The power transferred in the zero resistance case can be derived qualitatively. Intuitively, it is clear that all the incident power is transferred to port 2 because the input impedances, as seen from node A', B' and C', approach infinity due to the branches having quarter-wave lengths and each branch being grounded, as shown in Fig. 3. Thus, no power is transferred to port 3 and 4, nor is any power reflected back to port 1.

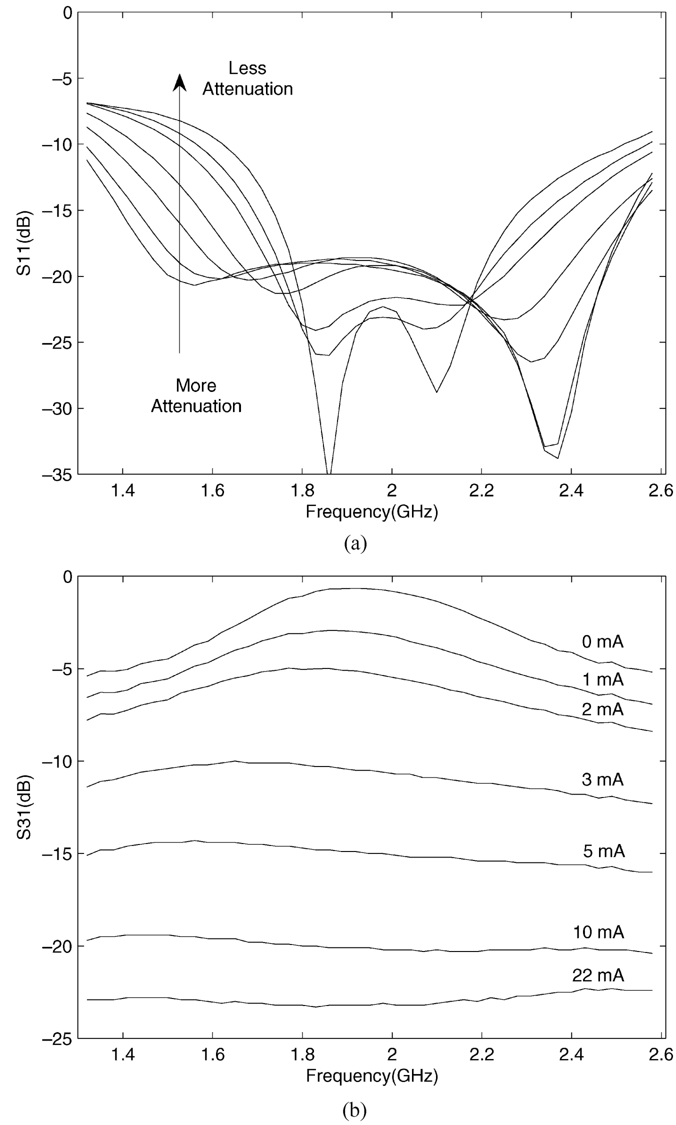

Fig. 5. Measured reflection and attenuation versus control current. (a) Reflection (S_{11}). (b) Attenuation (S_{31}).

III. Fabrication and Measurement Results

The most important performance design consideration is providing a good ground to the PIN diodes when their resistances are minimized. In order to make the shortest path to the ground plane from the microstrip line, we selected a thin board ($\varepsilon_r = 3.38$, dielectric thickness $= 0.2$ mm) and directly inserted the PIN diodes through via holes, as shown in Fig. 4. According to the manufacturer's data sheet, the minimum resistance of the PIN diodes used was 5.2 Ω at 1 MHz and 4.2 Ω at 10 GHz and 10-mA current.

Measured circuit performance is shown in Fig. 5. As seen in Fig. 5(b), the attenuation-control current plot remains relatively flat throughout the whole frequency range, so the bandwidth is mainly determined by the reflection characteristics. S_{11} is shown in Fig. 5(a). Maximum reflected power occurs at minimum attenuation, which corresponds to approximately -7 dB at 1.3 GHz.

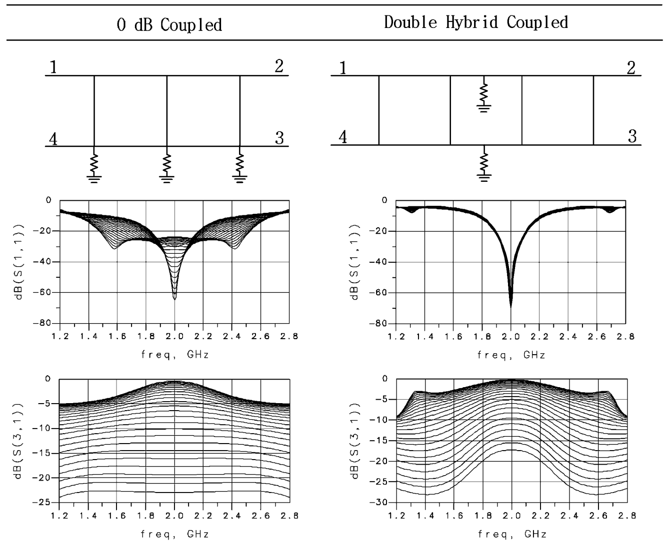

Fig. 6. ADS-simulated performance of our attenuator versus a double hybrid coupled attenuator.

Fig. 6 shows the ADS simulation results of a 0-dB coupled attenuator and a double hybrid coupled attenuator for comparison, disregarding the discontinuities of each junction. In the circuit schematics, port 1 is the input and port 3 is the output. As can be seen in this figure, a 0-dB coupled attenuator has advantages over a double hybrid coupled attenuator, such as smaller size, wider bandwidth (due to the lower input reflection) and larger attenuation range [4].

IV. Conclusion

We have described the design and performance of a PIN diode controlled variable attenuator employing a 0-dB branch-line directional coupler. Due to the low reflected power of the coupler, the attenuator has excellent input and output match characteristics. At 1.9 GHz, it has an attenuation range between 0.7 dB and 23 dB, which could be further improved by using a thinner substrate and PIN diodes with lower series resistances. This modification would result in the control locations *A*, *B*, and *C* (shown in Fig. 2) being nearer to an ideal ground when the PIN diodes are turned on.

References

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