Voltage-Controlled PIN Diode Attenuator with a Temperature-Compensation Circuit

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***Abstract*—This paper presents a voltage-controlled PIN diode attenuator and its temperature-compensation circuit composed of a thermistor and simple operational amplifier circuits. After carefully investigating the temperature characteristics of PIN diode attenuators, we designed voltage-controlled PIN diode attenuators showing the linear attenuation characteristics of 16 dB with input voltage within the operating temperature range. The fabricated attenuator has demonstrated the improvement of attenuation variation from 15 to 0.5 dB in the temperature range from −15 to 65 °C.**

***Index Terms*—Attenuator, PIN diode, temperature compensation.**

I. Introduction

PIN diodes have been widely used in control of RF/microwave signals, e.g. switching, limiting, phase shifting, attenuating, etc. Especially, PIN diode attenuators are used extensively in automatic gain control and RF leveling applications [1].

Typically, PIN diode attenuators have been controlled by the bias current. This is caused by the fact that PIN diode is current controlled device and the attenuation level is dependent on the value of the PIN diode's RF resistance, which is primarily established by the forward bias current [2]. Because of difficulty in making current source, the attenuator bias circuit is very complex. Also, additional voltage-current converter is necessary. Consequently, there have been increasing demands for voltage-controlled PIN diode attenuators [3].

In order to design voltage-controlled attenuator using PIN diodes, it is necessary that the attenuation level should be varied linearly with input voltage and the temperature variation be minimized. However, it is known that voltage-controlled attenuators are seriously affected by temperature variation, resulting in an attenuation spread of several decibels [4].

In this paper, we present a voltage-controlled PIN diode attenuator with a temperature-compensation circuit. The proposed compensation circuit controls the forward voltage in order to keep the attenuation constant with temperature. The fabricated attenuator has demonstrated the improvement of attenuation variation from 15 to 0.5 dB in the temperature range from −15 to 65 °C. The performance of the fabricated attenuator using proposed configuration will be described.

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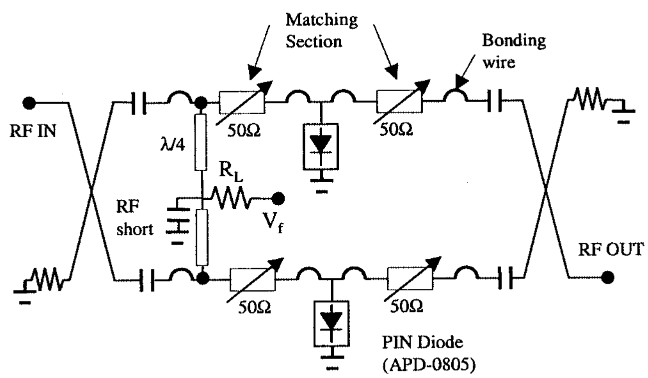

Fig. 1. PIN diode attenuator circuit diagram.

II. PIN Diode Attenuator Design

Fig. 1 shows the circuit configuration of a Ku-band double hybrid coupled attenuator considered in this study. The R_L is load resistor for driving attenuator using voltage source V_f. The PIN diode selected is an Alpha's APD0805-000 chip. The APD0805-000 has low capacitance of 0.05 pF and 8 μm I-region thickness.

The matching section consists of series microstrip lines which compensate the bonding wire inductance and the diode's parasitic capacitance. The PIN diode attenuator was manufactured as a hybrid integrated circuit on 15-mil-thick alumina substrate $(\varepsilon_r = 9.8)$ in a microstrip structure.

All circuit-level simulation and layout were done using HP-Eesof's Libra harmonic balance software. After completing simulation and layout, the attenuator is constructed using thin-film process [5].

For exact measurement, the test fixture is specially designed [5]. Two attenuator carriers are mounted in this test fixture because the attenuator we are considering requires the attenuation range of 16 dB.

Fig. 2 shows measured attenuation characteristics at the three temperature points of −15 °C, +25 °C, and +65 °C, as a function of input voltage. This data was taken at 12.5 GHz center frequency. The measured results show linear characteristics from −12 to −28 dB. But, the attenuation value for constant input voltage increases with the increase of temperature because the forward voltage drop of the PIN diode decreases with the increase of temperature.

From Fig. 2, it can be seen that the attenuation can be kept constant in the temperature range by adjusting the forward voltage of the attenuator. The forward voltage has to be varied from 0.57 to 0.7 V to achieve constant attenuation of 10 dB in the temperature range between −15 and 65 °C, as shown in Fig. 2.

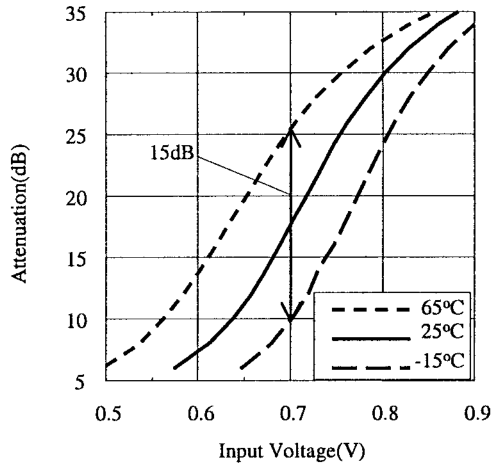

Fig. 2. Measured attenuation versus dc bias voltage (V_f) over temperature range.

III. Temperature Compensation Circuit

The attenuation variation against temperature of the voltage-controlled PIN diode attenuator can be compensated by decreasing forward voltage with an increase of temperature, as mentioned in Section II. In this section, the operation principle and design method of the temperature-compensation circuit, which is simply composed of a thermistor and operational amplifiers, are investigated.

Fig. 3 shows the schematic diagram of the temperature-compensation circuit. The circuit consists of two operational amplifiers, a negative temperature coefficient (NTC) thermistor (R_{TH}) and some fixed resistors.

The operation principle of the temperature-compensation circuit shown in Fig. 3 is as follows.

1) When the ambient temperature rises, the resistance of R_{TH} becomes smaller.
2) The offset voltage V_{offset} also decreases, where R1 and R2 should be adjusted to tract the temperature variation of the PIN diode forward voltage drop. Thus, V_{offset} can effectively cancel the forward voltage drop of the attenuator diode.
3) The input control voltage $V_{control}$ is injected to inverting amplifier (OPAMP1). The resistor Rc is used for scaling from input voltage value to real attenuator's control voltage (in this paper, 1-dB attenuation per 10-mV input voltage).
4) The output of inverting amplifier and offset voltage are injected to differential amplifier (OPAMP2). Therefore, the differential amplifier output voltage V_f has forward voltage variation over operating temperature range.

Using this compensation circuit, we fabricated the stable attenuator over temperature range. Fig. 4 shows the measured characteristics of attenuator module including temperature-compensation circuit. The temperature range is setted from -15 to 65°C and attenuation level are fixed at -12 dB. At center frequency, a maximum attenuation error of 0.5 dB has been realized over operational temperature range.

Fig. 5 shows attenuation characteristics of the final PIN diode attenuator over operating temperature range as a function of

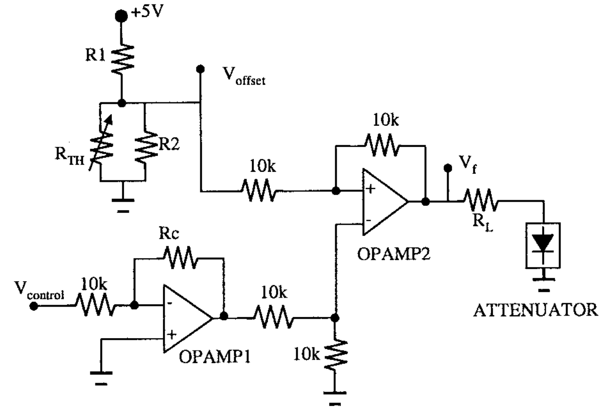

Fig. 3. Temperature-compensation circuit schematic diagram.

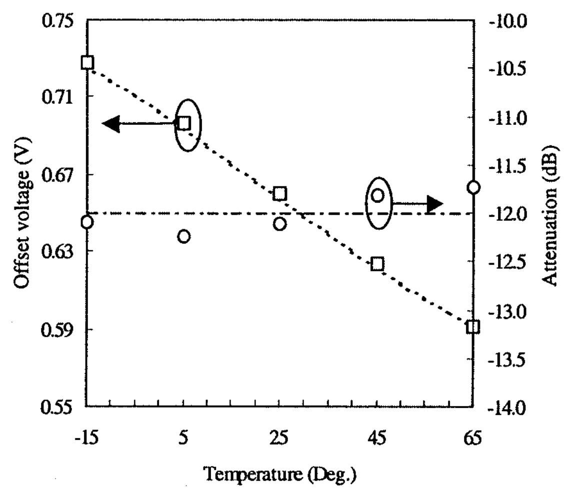

Fig. 4. Measured offset voltage (V_{offset}) and attenuation (in decibels) over temperature range. Lines are for simulated characteristics.

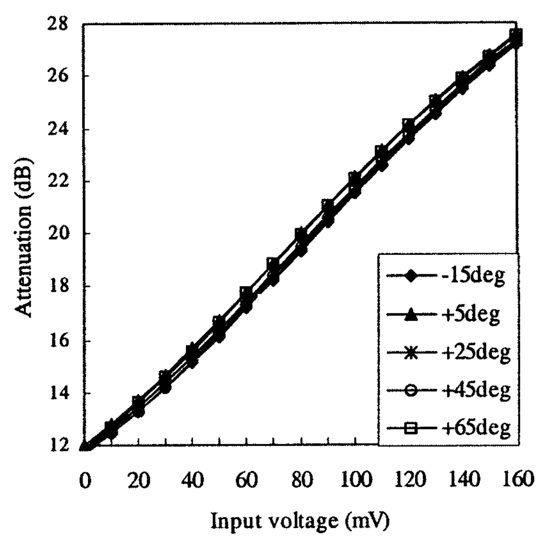

Fig. 5. Measured attenuation characteristics of the attenuator over temperature range as a function of linear input voltage.

linear control voltage $(V_{control})$. The fabricated attenuator has demonstrated the stable linear attenuation characteristics between -12 and -28 dB in the temperature range from -15 to

65 °C. Owing to temperature-compensation circuit, the attenuation value can be controlled by linear voltage from zero voltage with a slope of 0.1 dB/mV.

IV. Conclusion

In this paper, the study of the effect of temperature on voltage-controlled PIN diode attenuators and the temperature-compensation method of these attenuators has been presented.

A temperature-compensation circuit using a thermistor is now suggested to compensate the temperature variation of a voltage-controlled PIN diode attenuator. With the temperature-compensation circuit, the attenuation variation has been improved from 15 to 0.5 dB in the temperature range between -15 and $+65$ °C. It has been demonstrated that the presented temperature-compensation circuit is effective for correcting attenuation variation of a voltage-controlled PIN diode attenuator in a wide temperature range.

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