P-I-N DIODE BROADBAND PHASE INVARIANT ATTENUATOR

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New investigations in design and measurements of the super-broadband hybrid-type variable phase invariant attenuator are carried out. For power p-i-n diodes in the operational frequency band (0.1…3 GHz) the attenuator has 25 dB attenuation and less than 5 degree phase shift, the VSWR is less than 2.2 at both input and output ports. The results shown that the current-controlled attenuator with correcting inductances is better than the transmission-type phase shift attenuator with the same measurement characteristics.

1. Introduction

The function of a phase invariant attenuator is to change the amplitude in the processing of a microwave signal with minimal impact to the phase characteristic [1]. The variable attenuator is especially one of the most important control circuit blocks composing linealizers, as well as automatic gain control systems. In general, in microwave integrated-circuit attenuators a p-i-n diode or GaAs MESFETs with electrically controllable resistance is assembled [2]. In this paper, the power p-i-n diodes are applied as elements with controllable resistance.

As a rule, p-i-n diode attenuator has a larger phase shift than waveguide attenuator. To the authors' knowledge to date, the best result is about 1 degree/dB attenuation at 9 GHz, but waveguide attenuators may have 0.1 degree/dB [3]. In most cases, however, this phase shift is achieved by adjusting this attenuator on single frequency only.

There is only one theory of attenuator design. It is the theory of phase compensation. When a signal reaches its maximum attenuation, it has a double phase characteristic and returns to insertion loss with an equal and opposite function. The source signal is divided on two signals, one processed from the 0 deg. phase state and another processed from the 180 deg. phase state, and then combined at the output port. Therefore they will cancel the phase errors of each other. In fact, it is two lines that perform a compensation of phase shift.

In the phase invariant attenuator design the traditional preferred media is striplines. But discrete components create a discontinuity within the transmission lines of the device. To minimize the discontinuity many techniques was created, but it degrading performance. So it is required another techniques or media.

2. The compensation circuit

A super-broadband signal is composed of both amplitude and phase elements, but the phase characteristics can be distorted with the variance of attenuation due to the diode resistance characteristics [4]. In many practical cases the essential reduction of the phase shift by varying of attenuation can be reached by appropriate circuit design. The considered phenomenon is physically explained by indemnification of the diodes reactance by the out of phase reactance of correction circuit.

The experimental model of the p-i-n diode attenuator considered in this study is shown in Figure 1. All components are commercially available. The high-frequency part of the circuit was a thin-film hybrid integrated module, and it was fabricated on a polycore substrate with good dielectric properties.

We use p-i-n diodes of 2A705A. Capacity of the diodes is 0.3 pF; inductance is very low and it effect on phase characteristics did not essential. Matching resistance R_9=R_{10}=50 Ohm.

By the way, the choice of a diode is an important thing. Using diodes with a ribbon in a high frequency band has drawbacks, because of the inductance of ribbon adversely affects on the phase. A beam diode is better due to low inductance that provides a significant improvement in performance.

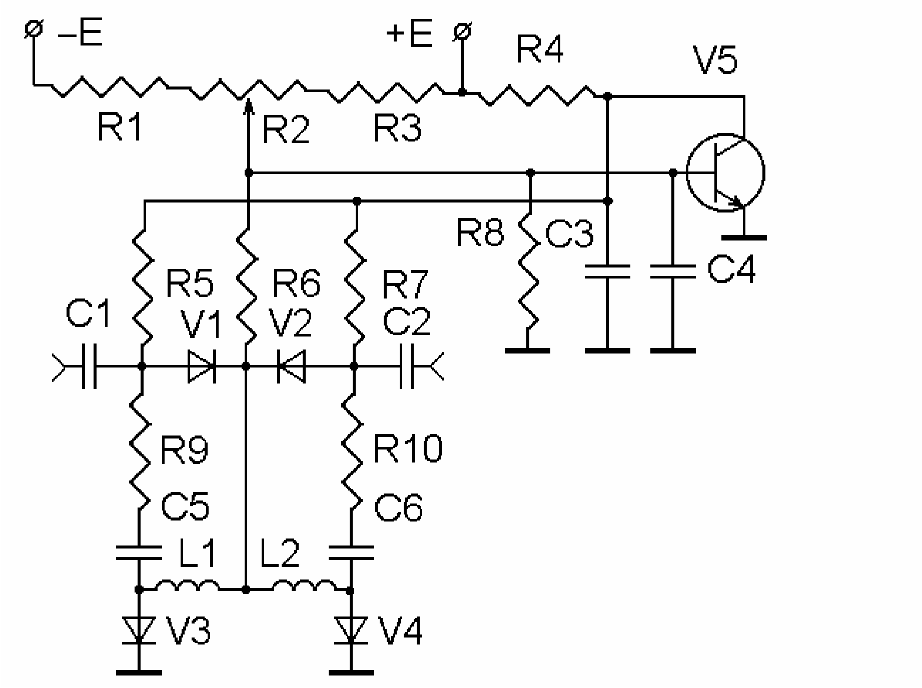

Figure 1. Attenuator circuit

In this circuit, series-connected and shunt-connected diodes operate as attenuator, and series-connected inductances operate as a phase-shift compensation circuit. Combined with the diode's parasitic parameters, they form a low-pass filter and thus compensate for the phase shift variation when the attenuation is adjusted.

The attenuator operates as follows. When the movable contact of R2 is at its left position on the figure, the diodes V3 and V4 are closed and have a maximum resistance. The diodes V1 and V2 of the series arm are open and have minimum resistance, and the transistor V5 is closed by a negative voltage on its base. In this case the attenuation is minimum. When the movable contact is shifted to the right, the voltage at the cathodes of the diodes V3 and V4 is increased and the diodes opened. In order to increase the attenuation with a minimum phase shift, the diodes V1 and V2 should be closed more rapidly than the diodes V3 and V4 should be opened. This can be achieved using the transistor V5.

Even with the improvement in the microwave part, it is the control circuitry that provides the absolute accuracy for the overall device. The control section of the phase invariant attenuator is designed as independent part.

Typical performance achieved using the described techniques is more simply than in paper [1] with digital control for single-section broadband phase invariant attenuator with 32 dB of dynamic range.

3. Characteristics

The optimal inductance (L1=L2=0.65 nH) and the optimal diode control during continuous adjustments of attenuation (Figure 2) allow achieving interesting phase frequency characteristics as shown in Figure 3. The phase shift, defined as phase differences $\Delta\varphi_i=\varphi_i(f)-\varphi_0(f)$, $i=1,\ldots,4$ was measured for different attenuations within the range k_i=1,2...26 dB and in frequency band 0.1...3 GHz. Figure 3 shows that the maximum phase shift variation within the attenuation range up to 24 dB does not exceed 5 degrees in a frequency band of 0.1...2.5 GHz. In other attenuation ranges the phase shift changes much less. The maximum attenuation is 40 dB, the VSWR in full range of frequencies and attenuations is always less than 2.2.

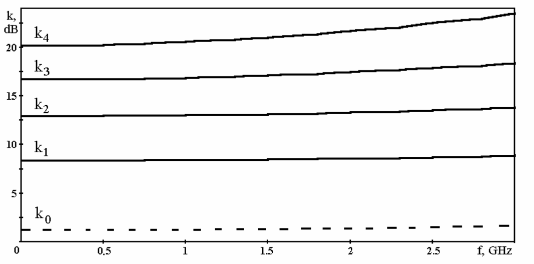

Figure 2. Measured attenuation characteristics as function of frequency

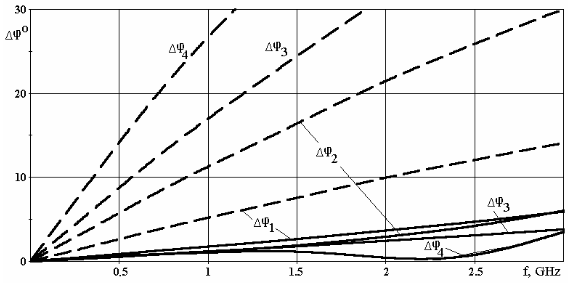

Figure 3. Measured phase characteristics of attenuator as function of frequency

The phase error can be explained by the large parasitic diode parameters. To decrease the phase error, further study in evaluating the diode parameters is necessary.

4. Conclusions

As a rule, the phase stability has only been reached in the attenuation range smaller than 60% of maximum attenuations. For increasing the attenuation level, the attenuators can be cascaded and the resulting phase shifts remain reasonably stable. Cascading multiple phase invariant attenuators improves phase and amplitude characteristics, as well as increases dynamic attenuation range.

As simple attenuators, used as components for control circuit blocks, the output current of the attenuation controller must be small and, thus, the dynamic range of the attenuator is comparatively small. However, the phase shift characteristics are small and interesting. Therefore for increasing the dynamic range the attenuators should be cascaded.

This paper describes problems encountered and solutions devised to produce a minimum phase change versus attenuation for an impedance-matched electronically variable attenuator. The low phase shift attenuator is shown to overcome some disadvantages of the existing phase shift attenuator. The presented attenuator has been designed such that less than 5 degrees phase shift is obtained for attenuations up to 30 dB, the VSWR less than 2,2 at both input and output ports.

Thus, the phase invariant attenuator provides improved performance at lower cost. The use of the correction circuits permits to achieve a more constant phase shift via regulation of the transfer factor by a simple method.

References

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