Attenuator with Small Phase Shift for Ultra-Wideband Pulse Subsurface Geo-Radar

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Abstract. The paper reports on the realization and measurements of the super-broadband hybrid-type current-controlled variable low phase shift attenuator for ultra-wideband pulse subsurface geo-radar. In the operational frequency band (0,1–2100 MHz) the attenuator has 30 dB attenuation and less than 4 degree phase shift, the VSWR is less than 2,2 at both input and output ports. The results demonstrate that the performance of the attenuator with correcting circuits is better than the transmission-type phase shift attenuator with the same measurement specifications.

INTRODUCTION

In multi-channel systems aimed for power addition in microwave amplifiers, antenna arrays, signal auto-phasing, controlling capacity level, etc. the independence of the phase shift response concerning effect in connection to the control of the signal amplitudes is required. It means that, for exact reproduction of the signal form stringent specifications as the group delay time characteristics over a wide dynamic range and in operational frequency band are needed [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 integrated [2]. In this paper, p-i-n diodes are applied.

Generally, p-i-n diode attenuators have a larger phase shift than waveguide attenuators. For example, to the authors' knowledge to date, the best published spurious phase shift for p-i-n diode attenuators is about 1 degree/dB attenuation at 9 GHz, but waveguide attenuators may have 0,1 deg./dB [3].

A superbroadband signal is composed of both amplitude and phase elements, but the phase characteristics can be distorted with the variance of attenuation due to the several problems. As we observe in [4], the phase characteristic is variable with the varying attenuation because of the diode resistance characteristics.

In many practical cases research has shown that an essential reduction of the phase shift by regulating the transfer factor 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, or indemnification of the phase shift by creation of the additional channel of the signal transfer.

ATTENUATOR

The experimental model of the p-i-n diode attenuator considered in this study is shown in Figure 1. This circuit was fabricated on a polycore layout as shown in Figure 2.

All components are commercially available. As elements with controllable resistance p-i-n diodes of 2A517A have been used. Inductance and capacity of the diodes are L=0,1 nH, C=0,3 pF, respectively. The high-frequency part of the circuit represented as a thin-film hybrid integrated module and is assembled on the substrate with good dielectric properties.

In this circuit, series-connected p-i-n diodes operate as attenuators, while a shunt-connected diode operates as a phase-shift compensation circuit.

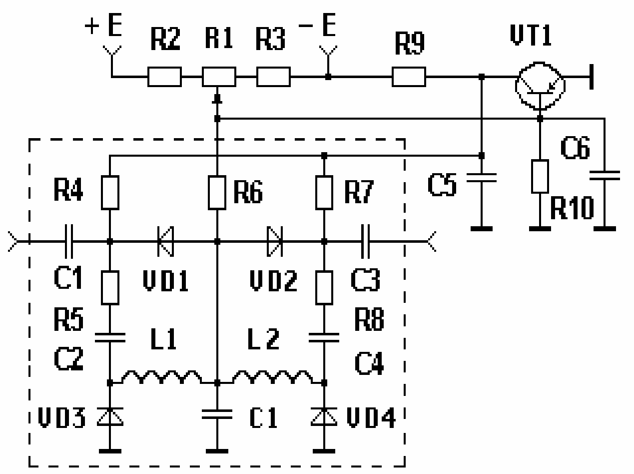

Figure 1. Attenuator circuit

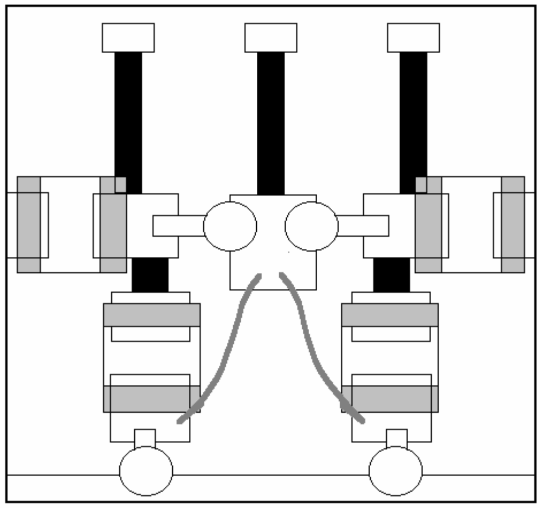

Figure 2. Attenuator layout

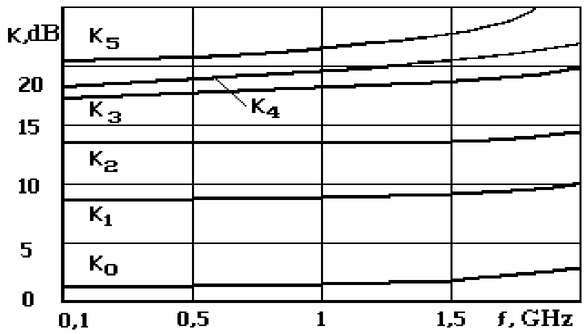

Figure 3. Measured amplitude characteristics of attenuator as function of frequency

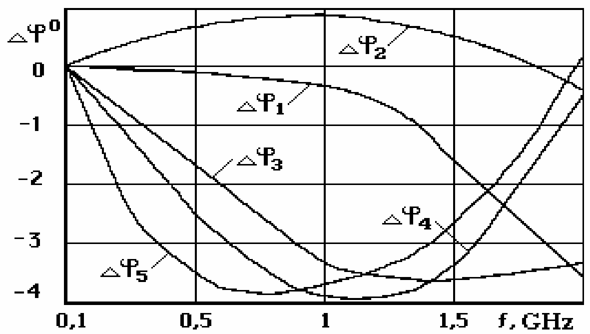

Figure 4. Measured phase characteristics of attenuator as function of frequency

Phase stability provide the inductance L1, L2 and capacity C1. 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 R1 is at its left position on the diagram, the diodes VD3 and VD4 of the parallel arm of the attenuator are closed and have a maximum resistance. The diodes VD1 and VD2 of the serial arm are open and have minimum resistance, and the transistor VT1 is closed by a positive 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 VD3 and VD4 is low and the diodes are open. In order to increase the attenuation with a minimum variation in phase, the diodes VD1 and VD2 of the in-series arm should be closed more rapidly than the diodes VD3 and VD4. This can be achieved using the transistor VT1. The optimal diode control during continuous adjustments of attenuation (Figure 3) allows achieving interesting phase frequency characteristics as shown in Figure 4.

DISCUSSION

The phase shift, defined as phase differences $\Delta\varphi_i=\varphi_i(f)-\varphi_0(f)$, i=1,5 was measured for different attenuations within the range 1,5...24 dB and in frequency band 0,1...2 GHz. Figure 4 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...1 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.

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.

In the electrically controllable attenuator described above the change in transmission phase versus attenuation was reduced by a factor of 10 through application of this principle.

As a rule, the phase stability has only been reached in the attenuation range smaller than 50% to 60% of maximum attenuations in dB. For increasing the attenuation level, the attenuators can be cascaded and the resulting phase shifts remain reasonably stable.

CONCLUSION

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 4 degrees phase shift is obtained for attenuations up to 30 dB, the VSWR less than 2,2 at both input and output ports.

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.

Thus, the use of the correction circuits permits to achieve a more constant phase shift via regulation of the transfer factor by a simple method. It permits to come nearer to potential achievable characteristics that open wide opportunities of improving the quality parameters of devices.

REFERENCES

1. O.V. Stoukatch, "The Devices with Independence a Phase Shift from Transfer Factor", *Proceedings of PIERS 1997 – Progress in Electromagnetics Research Symposium,* Vol. 2, p. 734, Hong Kong, 1997.
2. Won-Tae Kang, Ik-Soo Chang, Min-Soo Kang, "Reflection-Type Low-Phase-Shift Attenuator", *IEEE Transactions on Microwave Theory and Techniques*, Vol. 46, No. 7, pp. 1019-1021, July 1998.
3. S. Walker, "A Low Phase Shift Attenuator", *IEEE Transactions on Microwave Theory and Techniques*, Vol. 42, No. 2, p. 182, February 1994.
4. O.V. Stoukatch, "New Structures of Controllable Attenuators", Proceedings *High Power Microwave Electronics: Measurements, Identification, Application* MIA-ME'99, pp.IV.21-IV.23, Novosibirsk, Russia, September, 1999.