

# 2-22 GHz Continuously Variable Attenuator Has Low IMD and Flat Response

By Alexander Chenakin and AP.S. "Paul" Khanna  
Phase Matrix, Inc.

To achieve a continuously variable attenuation range and low distortion, this design uses a combination of fixed and variable attenuator modules

Attenuators are well-known electronic circuits, widely used for signal level control in a variety of applications. One particular application is a front-end device for

microwave test and measurement instruments such as frequency synthesizers, spectrum and network analyzers, oscilloscopes, etc. In these applications, the device is primarily used to extend the dynamic range of the instruments by reducing and optimizing signal levels to detectors and mixers. Key figures of merit for this application include high attenuation range, low intermodulation products, low insertion loss, and flat response over a wide frequency range.

Relay-based electromechanical step attenuators traditionally provide a superior performance and are widely utilized in test and measurement instruments. Nevertheless, their slow switching speed, short life time, and high cost encourage the use of electronic solid-state devices [1].

PIN-diode digital switched bit attenuators are normally preferred to analog ones because they offer better linearity, higher power handling, and lower insertion loss [2-4]. Distortion generated by the attenuator is low because the power is absorbed by resistive components rather than PIN-diodes themselves. The required resolution and attenuation range characteristics are provided by cascading the individual attenuator cells. In spite of its simplicity, the approach leads to a high insertion loss by rapid accumulating of the loss of individual cells.

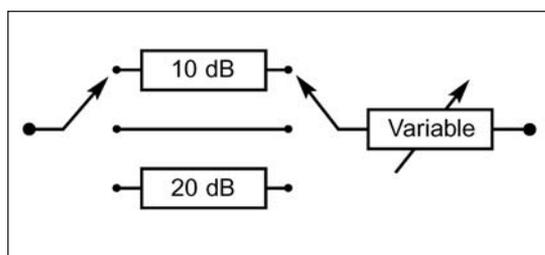


Figure 1 · Block diagram of the attenuator, with a switchable 0 (thru), 10 and 20 dB fixed module, and a >10 dB variable module.

When a fine level resolution is required, continuous analog attenuators become preferred over the step ones [5]. The main problem associated with the analog attenuators is a limited attenuation range. The intermodulation distortion characteristics are usually worse as well.

The problem is overcome by combining the step and continuous attenuators in one design. This approach relaxes the requirements for the both attenuators that results in a simple and robust construction. We report here a combined attenuator design, which provides a low insertion loss, low intermodulation distortion, and flat frequency response over the 2 to 22 GHz range.

## Attenuator Design

The attenuator block diagram includes two modules as shown in Figure 1. The first module is a 3-step digital attenuator, which employs two SP3T switches routing signals through 0, 10, and 20 dB branches respectively. The second module provides the remaining 10 dB continuous attenuation (with a required margin) to fill in the gaps.

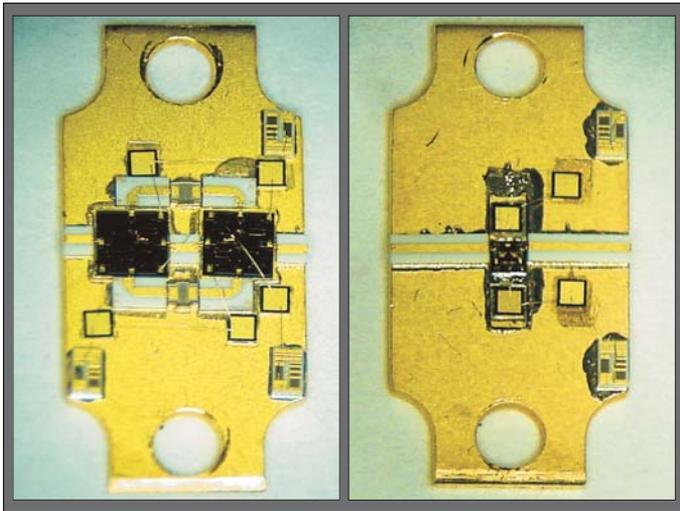


Figure 2 · The switched step (left) and continuous (right) attenuator modules.

The main advantage of this scheme is the limited step size and attenuation range required from the step and continuous attenuators respectively. Both attenuators are operated within their optimum range, which results in enhanced performance and reliability.

The attenuator modules are built from commercially available MMIC devices using a hybrid chip-and-wire assembly technology. The parts are placed on a kovar carrier and wired up as shown in Figure 2. The step attenuator branches (seen at the center of the left photo) and interconnecting transmission lines are printed on 10 mil alumina substrates.

An attenuator driver circuit is built on a separate printed circuit board. The modules and driver PCB are placed in an aluminum housing featuring input and output SMA connectors as shown in Figure 3.

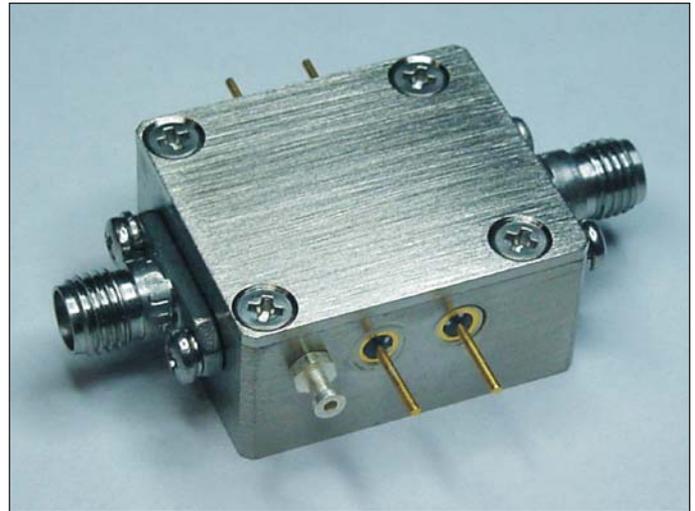


Figure 3 · The complete attenuator assembly, comprising the two attenuator modules and driver circuitry.

### Measurement Results

At first we characterized the step and continuous attenuator modules individually. The measured step attenuator insertion loss is shown in Figure 4. The module demonstrates a flat response from 2 to 22 GHz where it starts degrading. A rolloff at 2 GHz is due to integrated on-chip blocking capacitors. It should be noted that the actual module performance is slightly better since the indicated plot includes flatness irregularities and residual loss of the used test fixture and coaxial-to-microstrip transitions.

The continuous attenuator response is reported in Figure 5. The moderate attenuation range requirements (10 dB) result in a reasonably flat attenuation curve family as depicted below.

The frequency response of the combined attenuator

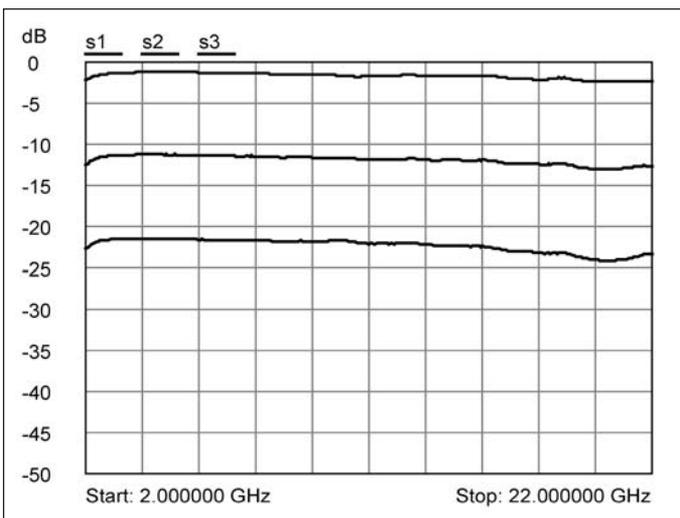


Figure 4 · 0-10-20 dB step attenuator response.

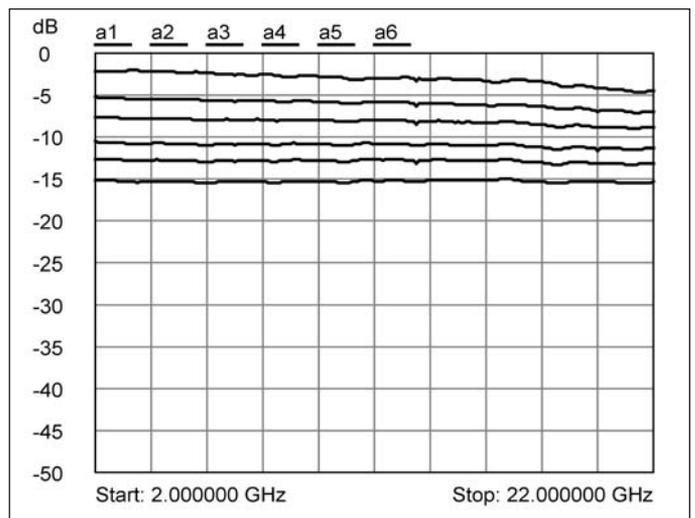


Figure 5 · Continuously variable attenuator response.

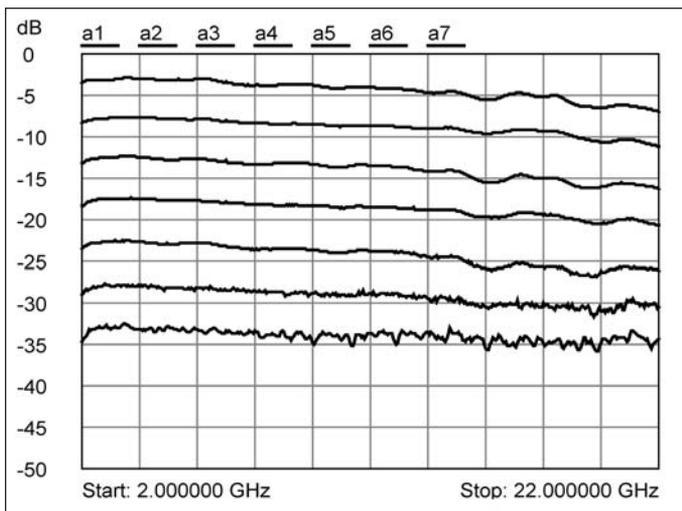


Figure 6 · Combined attenuator response.

assembly is shown in Figure 6. The plot represents a family of attenuation curves at different step and continuous attenuator settings. The combined attenuator demonstrates about 30 dB attenuation range with  $\pm 2$  dB flatness in the frequency range between 2 and 22 GHz.

The attenuator intermodulation distortion measurements are presented in Figure 7. The measurements were taken at 20 dB input step attenuator setting and minimum insertion loss of the continuous attenuator cell respectively. The attenuator output  $IM_3$  products at +15 dBm incident power (per tone) do not exceed  $-60$  dBc level at 17 GHz.

It is worth mentioning that the continuous analog attenuator is always operated in a linear regime by optimizing its input signal level with the input step attenuator. The measured input and output return loss do not exceed  $-12$  dB at all attenuation settings. The attenuator and driver circuit requires  $\pm 5$  VDC supply with 40 mA current consumption.

## Conclusion

A 2-22 GHz voltage controlled variable attenuator has been developed and characterized. Operating its step and continuous cells in optimum range enhances the attenuator performance. Measured results confirm the robustness of the design for test and measurements as well as other applications where a broadband, low distortion operation is required.

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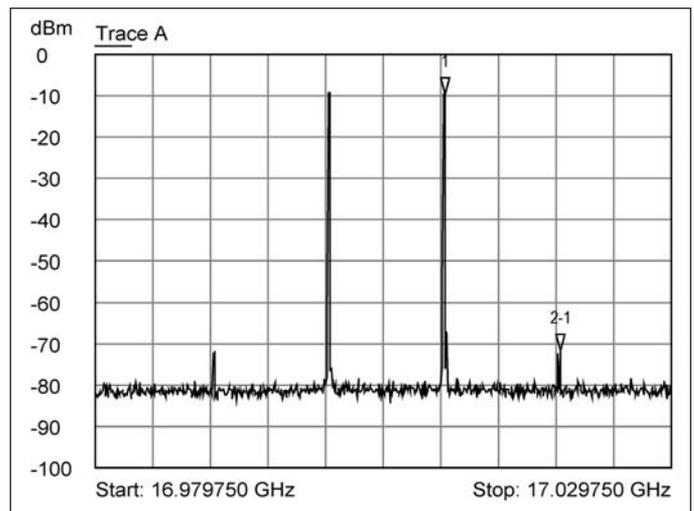


Figure 7 ·  $IM_3$  products with +15 dBm per tone

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## Author Information

Dr. Alexander Chenakin is Manager, Advanced Development at Phase Matrix, Inc., 109 Bonaventura Dr., San Jose, CA 95134. He can be reached by e-mail at achenakin@phasematrix.com.

Dr. A.P.S. "Paul" Khanna is Director of Engineering at Phase Matrix, and can be reached by e-mail at pkhanna@phasematrix.com.

The company Web site is: [www.phasematrix.com](http://www.phasematrix.com).

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