Next Generation Adjustable Q-Band Gain Equalizers

By: Joe O'Neil – Engineering Manager

Introduction

Growing demand for higher communication bandwidths has led to considerable development of systems operating at millimeter-wave frequencies. These systems have, in turn, stimulated research and development efforts up to 50 GHz components such as Traveling Wave Tubes, (TWTs), solid-state amplifiers, and phase shifters. These novel components often suffer from bandwidth limitations due to variations in the gain-frequency response. Gain equalizers are used to correct the gain-frequency response of complex communication systems to increase serviceable bandwidth. Spectrum Control offers a variety of gain-frequency correction with field-adjustable gain equalizers for 26 to 40 GHz frequencies, but above 40 GHz, the options have not been available.

In response to these new markets and technological trends, Spectrum Control has recently developed field-adjustable gain-equalizer technology optimized specifically for applications in the Q-Band of 40 to 50 GHz.

To introduce gain equalization at Q-Band frequencies, critical qualities such as versatility and high dependability must be met. The technology must utilize precise and stable mechanisms as small adjustments have larger impacts in these higher frequency applications. Spectrum Control has almost 50 years of experience developing all types of fixed, adjustable, and field-adjustable gain equalizers with broadband coverage for various military and commercial applications.

Design of Q-Band Equalizer Package

Gain equalizers are classified by the type of correction they provide, namely slope, parabolic, and ripple equalizers (Figure 1).

Equalizers can also be divided into fixed (tubular) and adjustable (rectangular) models based on the end user's ability to modify the shape of the gain correction and the gain-equalizer form factor (some examples of which are shown on page 1).

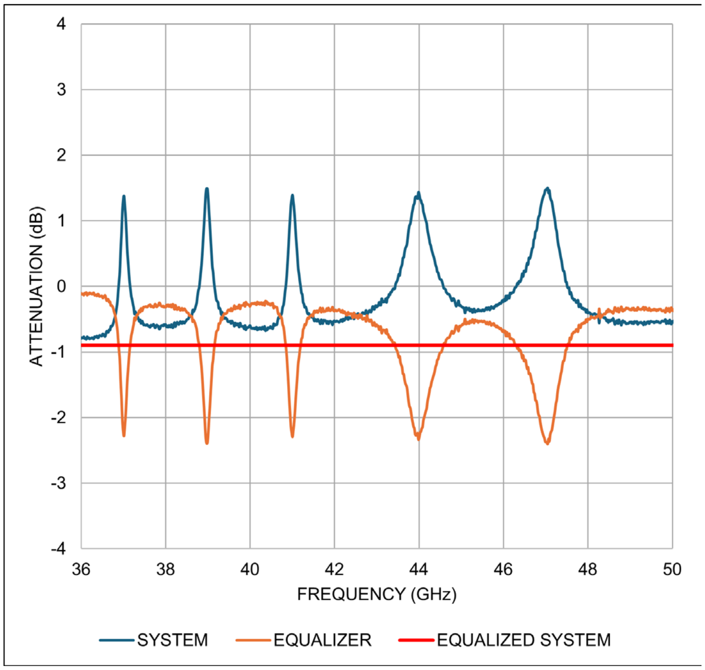

Figure 1: *Gain-frequency correction in a complex communication system.*

Use of existing gain-equalizer technology was limited at higher frequencies by the higher mode cut-off in the 2.92mm transmission lines, tuning filters, and other coaxial elements, which had been proportionally scaled for optimal operation below 40GHz. The first step in realizing a Q-band equalizer was the development of a rectangular package with a long coaxial transmission line. The coaxial line accommodates the placement of multiple tuning elements while maintaining low reflection characteristics up to 50 GHz. This helps support various types of correction curves with minimum additional parasitic loss. In addition, the transmission line is robust, concerning environmental stress conditions as described by MIL-STD-202 standards.

To achieve low reflection characteristics, the design of a 1.7”-long coaxial transmission line and its transitions to 50 GHz with 2.4 mm connectors was optimized with the help of a 3-D electromagnetic simulator. 2.4 mm Connectors were chosen to push the cut-off frequency of the coaxial transmission line above 50 GHz. The length of the compensation step between the center conductor and outer conductor of the 2.4 mm bead was optimized to reduce coupling capacitance, providing low Insertion loss and VSWR as illustrated in (Figure 2). The developed package allowed installation of up to 9 tuning elements and the use of 2.4 mm connectors, as shown in (Figure 3).

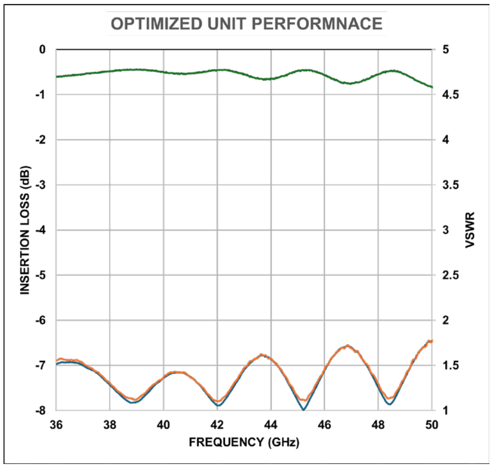

Figure 2: *Optimized Performance using a compensating step.*

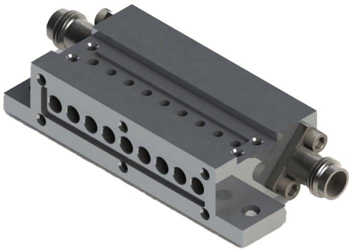

Figure 3: *The equalizer’s rectangular package.*

50 GHz Tuning Elements

Equalization of the gain-frequency response is addressed by frequency- and amplitude-adjustable tuning elements that resonate at uncoupled frequencies. By carefully selecting the full-width half-maximum (FWHM) bandwidth, the resonance frequency, and the magnitude of the loss (or quality factor) from every individual tuner element, it is possible to build various types of complicated correction curves see figure 4. The slope and parabolic type equalizers for 40 to 50 GHz applications require the use of medium and wide-band tuners with FWHM bandwidths of ~1 and ~3 GHz, respectively. Narrow-band tuners with a FWHM bandwidth

An example of a Q-band parabolic equalizer constructed using five medium/wide tuning elements (tuners) is shown in Figure 5. The resonant frequency and the magnitude of the individual tuners are set to oppose the gain bumps in the equalized system. The modification of tuning elements to operate up to 50 GHz was complicated by the need to scale most of the piece parts down, while still meeting the demanding requirements of precise and robust operation of the tuning screws.

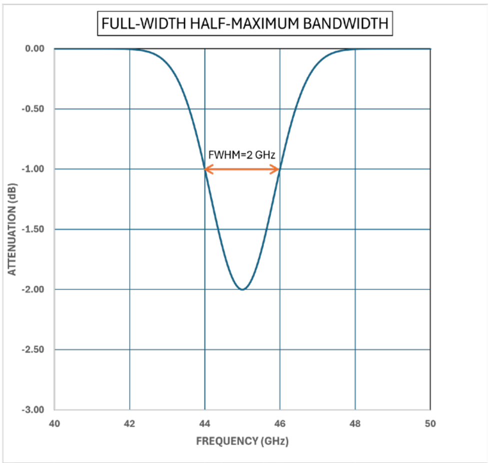

Figure 4: *Example of a 2 GHz bandwidth tuner centered at 45 GHz.*

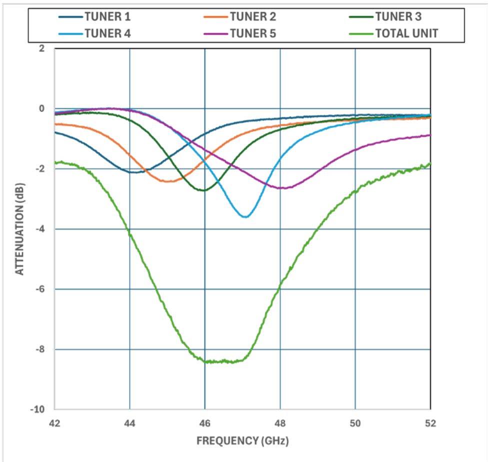

Figure 5: *Example of a Q-band parabolic equalizer’s performance.*

A 3-D electrical model used for development of a 50 GHz tuner is illustrated in Figure 6. The dimensions of the coupling cavity, length and diameter of the resistive element and the locations of the tuners were all optimized for maximum versatility and highest TEM- mode frequency of operation.

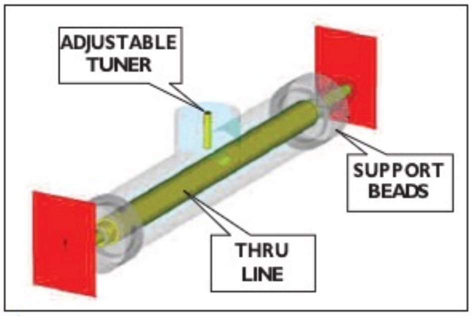

Figure 6: *3-D electrical model used in the 50 GHz tuner development.*

Experimental Data

The new technology was demonstrated across the entire 40 to 50 GHz band using a fully adjustable 4, 6, and 8 dB parabolic-slope equalizers (see Figure 7), as well as a 3 dB negative-slope equalizer (see Figure 8).

Most parabolic curves to 10 dB and linear slopes up to 5 dB are achievable across the broader 36 to 50 GHz band or within a selected sub-band using the package in Figure 4. In addition to the linear and parabolic equalizers as described above, this technology can also be applied successfully to narrow-band ripple equalizers (200 MHz). Spectrum Control can also customize the package and number of tuning elements to meet unique equalization goals.

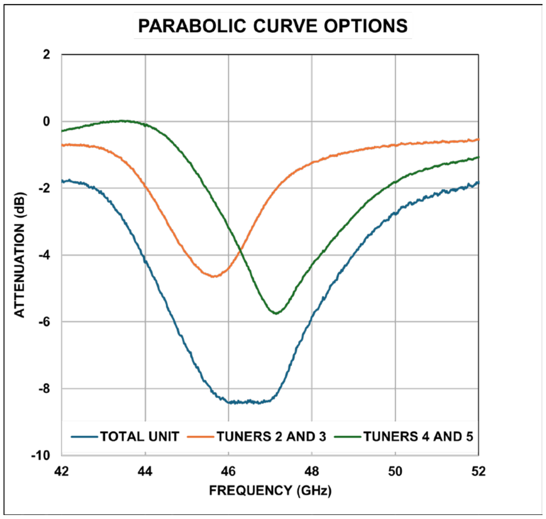

Figure 7: *Examples of Q-Band Parabolic equalizer profiles.*

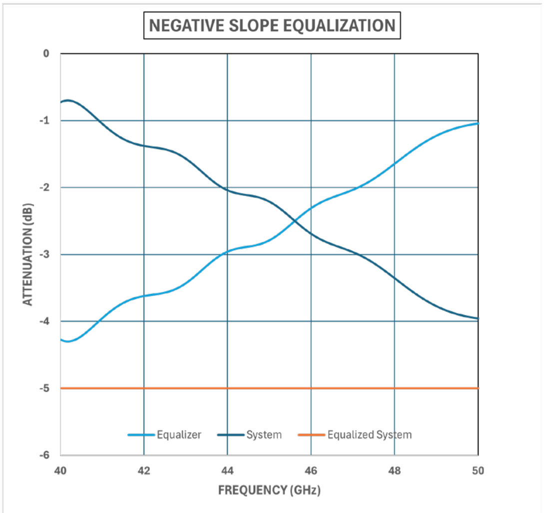

Figure 8: *A 3 dB negative-slope equalizer's performance.*

Conclusion

Spectrum Control's latest adjustable Q-band gain-equalizer technology effectively addresses critical bandwidth flattening needs in the increasingly important 40 to 50 GHz range. The developed adjustable slope, parabolic, and ripple equalizers offer enhanced performance, reliability, and adaptability, positioning this technology as a robust solution for emerging higher frequency applications. Ongoing efforts aim to extend frequency coverage and introduce additional tuning flexibility to accommodate future RF system requirements.