Gain Equalizer Flattens Attenuation Over 6-18 GHz

This equalizer technique is useful at microwave frequencies and easily implemented with microstrip circuitry

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Physical transmission lines have frequency dependent attenuation that increases its loss as the operating frequency increases. This phenomenon can pose severe problems in broadband systems, which should be compensated to get a flat attenuation response with frequency. A gain equalizer is a passive component that flattens the linear increase in attenuation (or decrease in gain) with frequency that may be exhibited by a component or subsystem. Cable loss equalizers may be used in certain EW systems, as CATV amplitude equalizers or amplifier gain equalizers, and in other applications with frequency-dependent loss.

A topology for such an equalizer is suggested in this article, and the development of an equalizer that flattens about 11 dB attenuation slope of a coaxial cable in the 6-18 GHz range is presented. The circuit was developed for microstrip construction, using the linear simulation package Touchstone®.

Coaxial cable characteristics

Coaxial cable offers a dispersionless medium for propagation of electromagnetic energy in the TEM-mode. Cable attenuation depends on physical charactersitics of cable and length. Insertion loss of coaxial transmission line comprises conductor loss (α_c) and dielectric loss (α_d), given by:

$$\alpha_t = (\alpha_c + \alpha_d)\, L \quad (1)$$

where L is the length of the cable and α_c, α_d are given by:

$$\alpha_c = 45.8\times10^{-6}(\varepsilon_r f)^{1/2}[1/(d_1\sigma_1) + \cdots \cdots + 1/(d_2\sigma_2)][1/\ln(d_2/d_1)] \text{ dB/m} \quad (2)$$

and

Cable parameters:	
d_1 = 1.02 mm	d_2 = 2.98 mm
ε_r = 1.7	$\tan\delta = 64\times10^{-6}$
L = 16100 mm	
Attenuation (dB/100 ft.):	
5 GHz —	23 dB
10 GHz —	33.3 dB
20 GHz —	48.5 dB

■ **Table 1. Cable parameters and loss for Micro-Coax UT-141LL.**

$$\alpha_d = 91\times10^{-9}\, \varepsilon_r^{1/2} f \tan\delta \text{ dB/m} \quad (3)$$

where

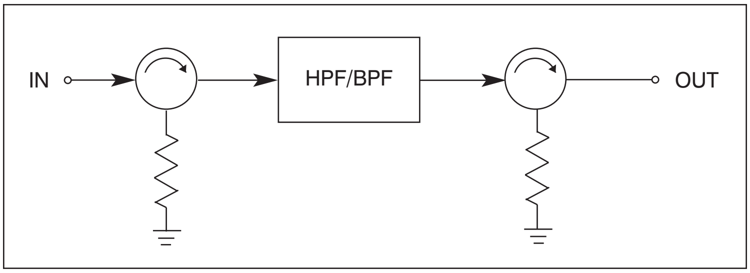
d_1 is the diameter of the inner conductor
d_2 is the diameter of the outer conductor
σ_1 and σ_2 are their respective conductivities
ε_r is relative dielectric constant
$\tan\delta$ is the loss tangent

Physical and electrical properties of UT-141LL coaxial semirigid cable from Micro-Coax are given in Table 1. This cable exhibits a linear increase in attenuation (in dB) with frequency.

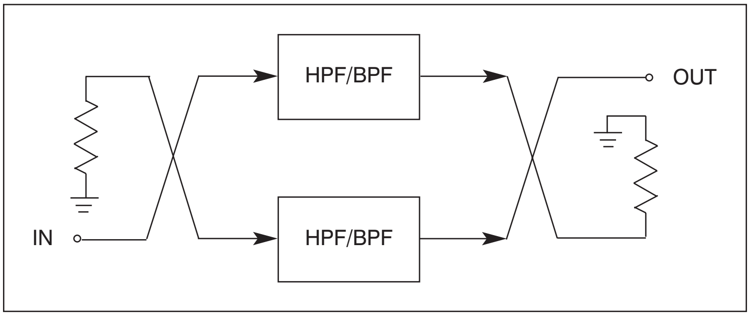
Cable loss equalizer

A cable loss equalizer is a passive two-port network that has attenuation characteristics opposite to that of the cable. An equalizer network should fulfill the following requirements over the desired frequency range:

- Approximately flat attenuation characteristics for a cascade connected coaxial cable



■ **Figure 1. Isolators can be used to ensure a good input and output match.**



■ **Figure 2. Lange couplers can be used with two filters to obtain good input and output match over an octave band.**

- Minimum insertion loss at the highest frequency of operation
- Good input/output match

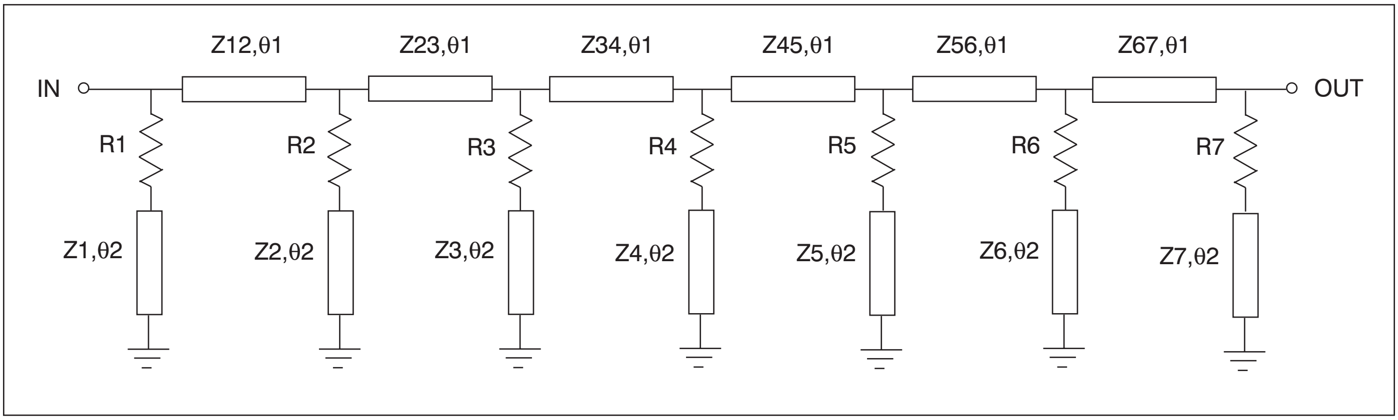
The stopband attenuation slope of a reactive highpass filter (HPF) or bandpass filter (BPF) can be suitably designed to flatten the frequency *vs*. attenuation slope of coaxial cable. It satisfies the first two requirements mentioned above, but good input/output match is not possible with reactive filters, since they are typically designed to reflect the the signals in the stopband region.

One way to overcome this problem is to use two isolators as shown in Figure 1. Isolators ensure good input/output VSWR in the stopband region of the filter. Another technique is to use Lange couplers [1] and two reflective equalizers (filters), as shown in Figure 2. Lange couplers offer good input/output match over an octave band.

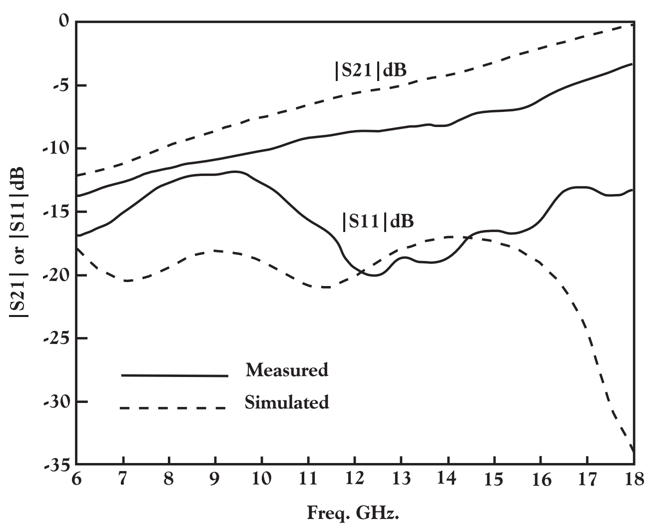
Basically, a cable loss equalizer is an absorptive filter (HPF or BPF) operated in the stopband region. The design of lumped element equalizer networks suitable for frequencies in the VHF/UHF range have been reported in the literature [2, 3, 4]. Practical difficulties in the realization of lumped element networks at microwave frequencies require distributed network topologies. A direct-coupled bandpass filter [5] topology has been used in the realization of the equalizer described here. Resistors are connected in series with short stubs, as shown in Figure 3. The resistors absorb forward and reflected signals at lower frequencies. Series transmission lines and short stubs are of quarter wavelength at 18 GHz. The short stubs offer maximum impedance at 18 GHz, thereby offering minimum attenuation for the signal at the highest frequency of operation.

A computer program was written to compute element values for the direct-coupled BPF. Using this program, seven-section 0.1 dB ripple Chebyshev BPFs were designed, centered at 18 GHz and having different fractional bandwidths (0.89, 1.33, etc.). It was observed that a circuit designed for less than the required bandwidth is sufficient, because the bandwidth is broadened by the addition of the resistors to the shunt stubs. After a few simulation trials, a seven-section BPF was determined to be the optimum for the design requirements. It should be noted that the highest frequency of operation is 18 GHz only, not the entire passband of the BPF. The circuit was realized on a 10-mil RT-Duroid 5880 substrate using a microstrip configuration. Thin film resistors were used in series with the shunt stubs. The circuit was developed using Touchstone, and was optimized for good input/output VSWR, minimum insertion loss at the highest frequency of operation, and the desired attenuation slope characteristics.

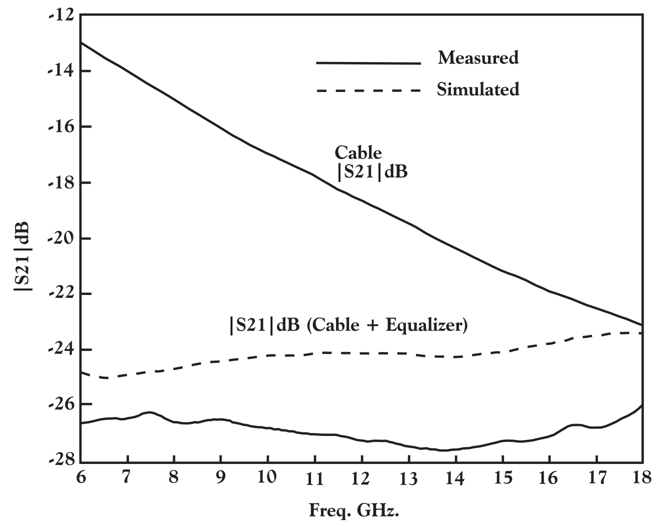
Insertion loss and return loss performance of the cir-



■ **Figure 3. Cable Loss Equalizer topology using series stubs and resistively-loaded shunt stubs. *Zx* is the line impedance and θ1, θ2 are the electrical lengths.**



■ **Figure 4. Insertion loss and return loss performance of the equalizer circuit.**



■ **Figure 5. Cable attenuation and cable plus equalizer performance.**

cuit is shown in Figure 4. Cable attenuation and the cable-with-equalizer performance are shown in Figure 5. Attenuation of the equalizer cascaded with the cable is about 26.5 dB, with flatness of ±1 dB. Input/output return loss is better than 10 dB in the 6-18 GHz band. Deviation of the measured performance from the simulated results can be attributed to the center frequency shift due to parasitic elements associated with the resistors, microstrip conductor losses and connector mismatch losses. Circuit performance can be improved by considering the high frequency equivalent circuits of the thin film resistors in the design simulation. The attenuation characteristics can be adjusted by varying the resistor values to a limited extent. The final circuit parameters are given in Table 2.

Conclusion

A practical circuit topology for the development of cable loss equalizers has been suggested for operation at microwave frequencies. A microstrip circuit was developed using a linear simulation package, and performance of an 11 dB attenuation slope equalizer for the 6-18 GHz frequency range was presented. The equalizer's microstrip configuration makes realization easy and offers good performance repeatability. ■

Circuit parameters:

Z1 = Z7 = 62.1 ohms	Z3 = Z5 = 59.0 ohms
Z2 = Z6 = 62.6 ohms	Z4 = 58.0 ohms
Z12 = Z67 = 46.4 ohms	Z34 = Z45 = 54.9 ohms
Z23 = Z56 = 52.2 ohms	
R1 = R7 = 330 ohms	R3 = R5 = 330 ohms
R2 = R6 = 68 ohms	R4 = 33 ohms
θ1 = θ2 = 90 degrees	

■ **Table 2. Circuit parameters of the cable loss equalizer.**

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