Fixed and Variable Slope CATV Amplitude Equalizers

Compensation of frequency-dependent cable loss is accomplished using an amplitude equalizer

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In CATV systems for audio and video signal transfer by use of coaxial cables, there is a requirement for compensation of a cable's characteristic attenuation [1-5]. In practice, amplitude equalizers with fixed and variable slope of attenuation can be used for this compensation. Fixed slope CATV amplitude equalizers are used for the correction of fixed cable lengths attenuation [1-3]. More important are variable slope amplitude equalizers, because they can be used for compensation of characteristic for different cable lengths [4-5].

The results of design and realization of a few fixed and variable slope CATV amplitude equalizers are presented in this paper. These equalizers are designed for compensation of the cable RF 75-9-09 attenuation characteristic. The equalizers are for the frequency ranges of 40-300 MHz (AE30-XX) and 40-650 MHz (AE65-XX), where XX represents fixed length cable attenuation on the upper cut-off frequency.

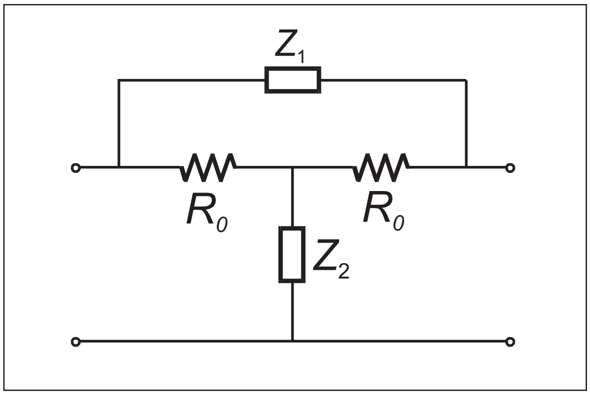
Variable slope amplitude equalizers, AE30-YYZZ and AE65-YYZZ, are designed for compensation of characteristic for different cable lengths where attenuation on the upper cut-off frequency is in the range of YY to ZZ dB.

Equalizer characteristics

In an ideal case, an amplitude equalizer has an attenuation characteristic reciprocal to the cable attenuation characteristic. An equalizer has to fulfill the following conditions [1]:

- The attenuation characteristic for a cascade connected coaxial cable and an amplitude equalizer has a constant value in a given frequency range

$$\alpha = \alpha_c + \alpha_{ae} = K \qquad (1)$$



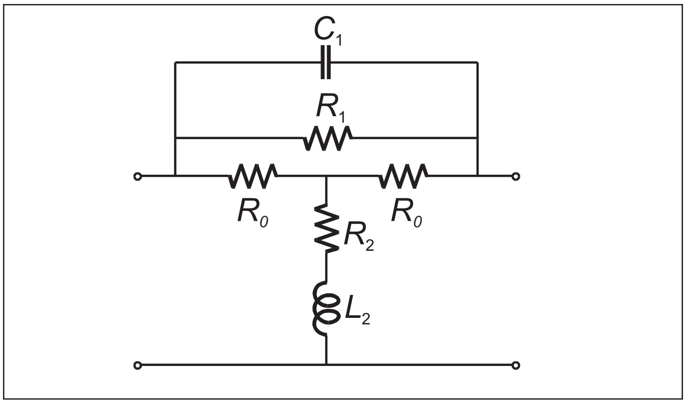
■ **Figure 1. Bridged "T" two-port network.**

where α is the cascade connection attenuation characteristic, α_c is the coaxial cable attenuation, α_{ae} is the attenuation of the amplitude equalizer and K is the given constant.

- The input impedance of the equalizer is real and does not depend on the frequency.

Design of fixed and variable slope amplitude equalizers is uses the symmetrical bridged "T" two-port network given in Figure 1. This network has the best characteristic in designing an amplitude equalizer because of good matching with the characteristic impedance of the cable. Impedances Z_1 and Z_2 can have different number of elements, and resistor R_0 represents the characteristic impedance of the cable (in this case, $R_0 = 75\ \Omega$). In order for the bridged "T" network to have real input impedance, it is sufficient that impedances Z_1 and Z_2 fulfill the duality principle

$$Z_1 Z_2 = R_0^2 \qquad (2)$$

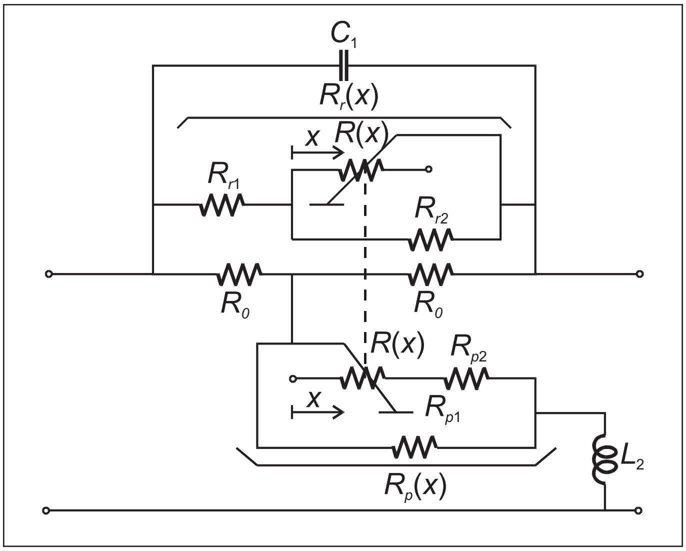


■ **Figure 2. Fixed slope amplitude equalizer.**

Design of fixed slope amplitude equalizers

Figure 2 shows the chosen network for the design of a fixed slope amplitude equalizer with a minimum number of elements. Attenuation in a coaxial cable occurs both in the conductors and in the dielectric [6]. The attenuation in the conductors is

$$\alpha_{cc} = 45.8\times10^{-6}\sqrt{\varepsilon_r f}\left(\frac{1}{d_1\sqrt{\sigma_1}}+\frac{1}{d_2\sqrt{\sigma_2}}\right)\times\frac{1}{\ln\frac{d_2}{d_1}}\left[\frac{dB}{m}\right] \tag{3}$$



■ **Figure 3. Variable slope amplitude equalizer.**

and in the dielectric

$$\alpha_{cd} = 91\times10^{-9}\sqrt{\varepsilon_r}\, f\tan\delta\left[\frac{dB}{m}\right] \tag{4}$$

The total attenuation for the coaxial cable of length l can be rewritten as

$$\alpha_c = (\alpha_{cc}+\alpha_{cd})l \tag{5}$$

In equations (3) and (4), d_1 is the diameter of the inner conductor, d_2 is the inner diameter of the outer conductor, ε_r is the relative dielectric constant, $\tan\delta$ is the dielectric loss tangent, σ_1 is the conductivity of the inner conductor, σ_2 is that of the outer conductor.

If the coaxial cable attenuation characteristic is known, and the value of constant K in equation (1) is given, then the amplitude equalizer element values in Figure 2 can be calculated [4-5]. Equalizers are designed in the 40-300 MHz and 40-650 MHz frequency ranges for the coaxial cable RF 75-9-09 (d_1 = 2.62 mm, d_2 = 9.5 mm, ε_r= 1.062, $\tan\delta$ = 0.00008, $\sigma_1=\sigma_2=5.9\times10^7(\Omega\text{m})^{-1}$).

The initial values for the equalizer are calculated in the program *Mathematica* [7], and final values can be obtained by using the optimization procedure in the programs *Touchstone* or *Libra* [8]. The model for the simulation of coaxial cable characteristics is created in *Touchstone Senior*.

The element values for the designed amplitude equalizers AE30-XX and

Equalizer	R_1 (Ω)	C_1 (pF)	R_2 (Ω)	L_2 (nH)	K (dB)	Δα (dB)	α_{aeu} (dB)
AE30-04	34.14	37.20	164.76	209.25	4.5	0.18	0.67
AE30-06	54.68	27.80	102.87	156.38	6.5	0.36	0.85
AE30-08	79.76	22.05	70.52	124.03	8.5	0.55	1.04
AE30-10	110.71	18.20	50.81	102.38	10.5	0.75	1.25
AE30-12	156.92	13.55	35.85	76.22	13	0.78	1.77
AE30-14	200.00	11.89	28.13	66.88	15	1.03	2.01
AE30-16	264.00	10.56	20.53	59.40	17	1.24	2.23
AE30-18	364.05	9.46	15.45	53.21	19	1.49	2.48
AE30-20	493.65	8.52	11.39	47.93	21	1.76	2.75

■ **Table 1. Element values for AE30-XX equalizers.**

Equalizer	R_1 (Ω)	C_1 (pF)	R_2 (Ω)	L_2 (nH)	K (dB)	Δα (dB)	α_{aeu} (dB)
AE65-04	35.75	16.96	157.34	95.40	4.5	0.23	0.66
AE65-06	57.20	12.69	98.34	71.38	6.5	0.35	0.85
AE65-08	83.30	10.07	67.53	56.64	8.5	0.55	1.04
AE65-10	115.31	8.31	48.78	46.74	10.5	0.76	1.25
AE65-12	164.41	6.18	34.21	34.76	13	0.79	1.78
AE65-14	200.00	5.41	28.13	30.43	15	1.07	2.06
AE65-16	280.98	4.82	20.02	27.11	17	1.28	2.26
AE65-18	364.30	4.31	15.44	24.24	19	1.55	2.53
AE65-20	472.73	3.89	11.90	21.88	21	1.84	2.82

■ **Table 1. Element values for AE65-XX equalizers.**

Equalizer	$R_{r\min}$ (Ω)	$R_{r\max}$ (Ω)	C_1 (pF)	L_2 (nH)	K (dB)	Δα (dB)	α_{aeu} (dB)
AE30-0412	46.38	169.31	13.73	77.26	–6	0.47	2.21
					–13	0.71	1.69
AE30-1220	196.28	507.50	8.46	47.56	–15	0.28	3.26
					–21	1.78	2.78
AE65-0412	48.95	171.53	6.30	35.45	–6	0.72	2.22
					–13	0.71	1.70
AE65-1220	214.70	511.61	3.88	21.82	–15	0.63	3.24
					–21	1.82	2.80

■ **Table 3. Element values for AE30-YYZZ and AE65-YYZZ equalizers.**

AE65-XX are given in Tables 1 and 2. In these tables, K represents the equalizing constant, Δα (dB) is the maximum deviation of attenuation characteristic α with relation to the constant K, and α_{aeu} (dB) is the amplitude equalizer attenuation on the upper cut-off frequency. The equalizing constant is chosen to be 0.5 dB higher than the coaxial cable attenuation at the upper cut-off frequency for the equalizer attenuation in the range 4 to 10 dB.

For higher attenuation (12 to 20 dB), the equalizing constant is 1 dB higher than the coaxial cable attenuation. In this way, the flat attenuation characteristic can be obtained for the cascade connection coaxial cable and amplitude equalizer.

Design of variable slope amplitude equalizers

The symmetrical bridged “T” two-port network, with a minimum number of elements that can be used for the design of variable slope amplitude equalizer, is shown in Figure 3. The attenuation characteristic slope can be varied by changing the values of the two identical variable resistors $R(x)$. These have to be changed in a specific manner. The simple and practical solution for the resistive part of amplitude equalizer with variable resistors in exponential form

$$R(x) = R_{\min} a^{bx} \tag{6}$$

where $0 \le x \le 1$ and a and b are constants, as proposed in [4]. The second condition is fulfilled if

$$R_r(x) R_p(x) = R_0^2 \tag{7}$$

where R_0 is the real characteristic impedance of the coaxial cable and

$$R_r(x) = R_{r1} + \cfrac{1}{\cfrac{1}{R_{r2}} + \cfrac{1}{R(x)}} \tag{8}$$

The equations for calculation of network resistor values [4] are

$$R_{r2} = \frac{B + \sqrt{B^2 + 4AC}}{2A} \quad (9)$$

and

$$R_{r1} = R_{r\min} - \frac{R_{r2} R_{\min}}{R_{r2} + R_{\min}} \quad (10)$$

where

$$A = \frac{R_{\max} - R_{\min}}{R_{r\max} - R_{r\min}} - 1 \quad (11)$$

$$B = R_{\max} + R_{\min} \quad (12)$$

$$C = R_{\max} R_{\min} \quad (13)$$

and $R_{\min} = R(0)$, $R_{\max} = R(1)$, $R_{r\min} = R_r(0)$ and $R_{r\max} = \mathrm{R}_r(1)$.

R_{p1} and R_{p2} can be calculated by using the duality principle

$$R_{p1} = \frac{R_0^2}{R_{r1}} \quad (14)$$

and

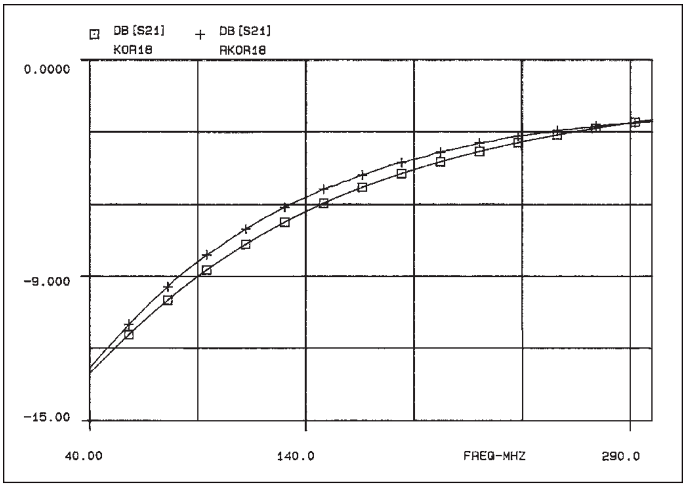
$$R_{p2} = \frac{R_0^2}{R_{r2}} \quad (15)$$

Minimum $R_{r\min}$ and maximum $R_{r\max}$ values are obtained by simultaneous optimization of the cascade connection of the two different amplitude equalizer and two coaxial cables with the same electrical characteristics and different lengths $l_{\min}$ and $l_{\max}$. Equalizers are the same complexity with unknown capacitor of equal capacitance C_1 and different fixed unknown resistors $R_{r\min}$ and $R_{r\max}$. In this manner, optimum values for these elements can be obtained. By choosing the corresponding values for $R_{r\min}$ and $R_{r\max}$ it is easy to calculate values for the other resistors.

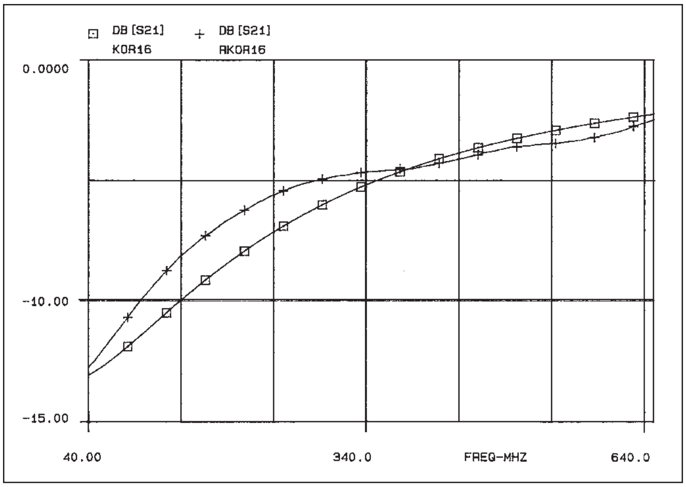
The conclusion from the design procedure is that it is a better solution to divide the attenuation range 4 to 20 dB into two narrower ranges, such as 4 to 12 dB and 12 to 20 dB, than to use one amplitude equalizer for the whole range. In this case two variable amplitude equalizers are used and the attenuation characteristic obtained for the cascade connect-

Equalizer	R_{r1} (Ω)	R_{r2} (Ω)	R_{p1} (Ω)	R_{p2} (Ω)
AE30-0412	37.00	152.50	152.06	36.89
AE30-1220	186.49	472.77	30.16	11.90
AE65-0412	39.57	152.02	142.16	37.00
AE65-1220	204.92	442.34	27.45	12.72

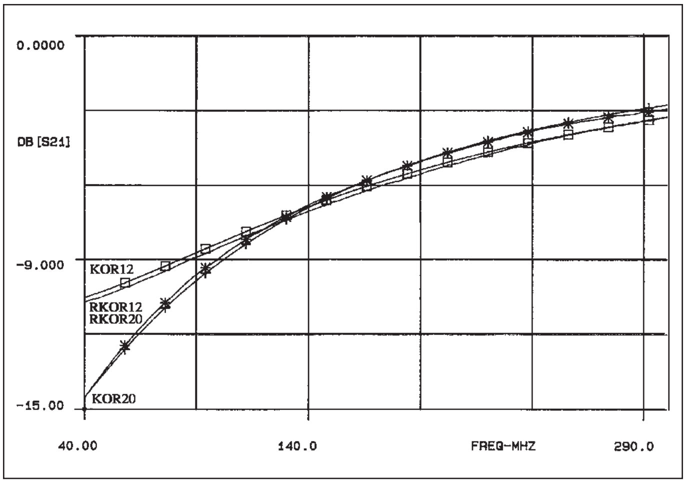
■ Table 4. Resistor values for variable equalizers.



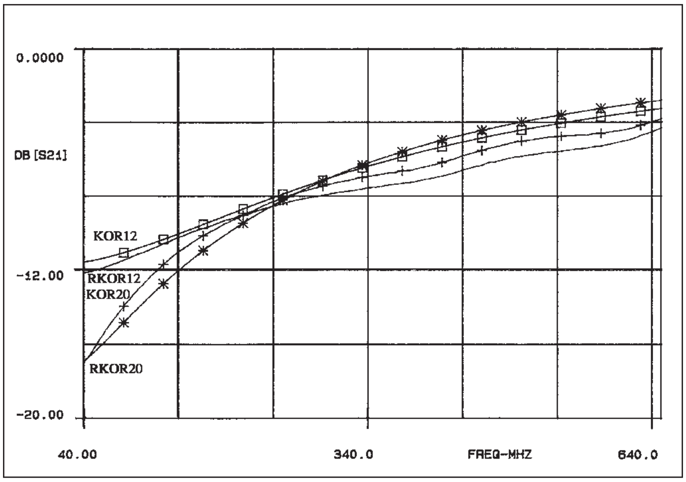
■ Figure 4. Attenuation characteristics for equalizer AE30-18.



■ Figure 5. Attenuation characteristics for equalizer AE65-16.



■ Figure 6. Attenuation characteristics for equalizer AE30-12-20.



■ Figure 7. Attenuation characteristics for equalizer AE65-12-20.

ed cable and equalizer has a small deviation from the constant *K*. Variable slope amplitude equalizers are designed for the coaxial cable RF 75-9-09, and design results are given in Tables 3 and 4. The variable resistor with the exponential characteristic, manufactured by PIHER, is a $2 \times 1\ k\Omega$ double potentiometer with $R_{\min} = 10\ \Omega$.

Two fixed (AE30-18 and AE65-16) and two variable (AE30-1220 and AE65-1220) slope amplitude equalizers are realized. Designed (KORXX) and measured (RKORXX) attenuation characteristics for the above equalizers are presented in Figures 4 to 7.

Conclusion

In this paper, design procedures for fixed and variable slope CATV amplitude equalizers are given. The symmetrical bridged "T" two-port network is used for the design of both types of equalizers. CATV amplitude equalizers can be used for compensation of the cable attenuation characteristic, which increases with frequency. The equalizers presented have a minimum number of elements. A simple and original solution for the changing slope of attenuation characteristic is used. The slope of attenuation characteristic can be varied by changing the values of two identical variable resistors with the same exponential characteristics. The design procedure is verified in several examples. Designed and measured attenuation characteristics for the realized equalizers are shown. These characteristics are in close agreement. ■

References

1. Radler, F. J., "Cable Equalizer Design," *RF Design*, pp 128-133, February 1991.

2. Combes, P. F., *Microwave Transmission for Telecommunications*, John Wiley & Sons, New York, 1991.

3. Weidman, I. H., "Procedure Yields Effective Matched Slope-Equalizer Design," *MSN&CT*, pp 107-115, July 1986.

4. Gmitrovic, M. V., Milovanovic, B. D., and Vukovic, A. M., "Contribution to the Design of CATV Variable

Slope Cable Equalizer," *Proc. of I Conf. TELSIKS*, pp 7-35 to 7-41, Nis, October 1993 (in Serbian).

5. Milosavljevic, Z. D., and Gmitrovic, M. V., "Amplitude Equalizer Design and Realization," *Proc. of XL Conf. ETRAN*, pp 496-499, Budva, 1996 (in Serbian).

6. Combes, P. F., Graffeuil, J., and Sautereau, J. I., *Microwave Components, Devices and Active Circuits*, John Wiley & Sons, New York, 1987.

7. Wolfram, S., *Mathematica: A system for doing mathematics by computer*, USA: Addison-Wesley Publishing Company, Inc., 1988.

8. *Touchstone and Libra User's manual*, HP 851701A Touchstone Family of Software, January 1990.

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