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CATV 홈 네트워크의 특성 분석

(Characteristics and Analysis of CATV Home Networks)

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요 약

홈 CATV 네트워크는 동축 케이블과 이상적인 특성을 만족하지 못하는 신호 분배기로 구성되며, 케이블 설치시 원치 않은 묶임이나 구부러짐 그리고 케이블 연결 부위의 문제점 등이 발생할 수 있다. 또한 케이블 커넥터의 배치에 따라 발생할 수도 있는 이러한 문제점은 신호 누설의 원인이 될 수 있고, 네트워크의 성능을 악화시키는 원인이 되기도 한다. 본 논문에서는 RG-59, RG-6 동축 케이블 등과 같은 차폐 케이블이나 신호 분배기 에서의 신호 누설 및 전파 문제를 분석하고, 이상적인 CATV 홈 네트워크 구축 방법을 설명한다.

Abstract

Home CATV networks comprise coaxial cables and signal splitters which have less than ideal characteristics. Home network testing facilities use long lengths of coaxial cables, often undesirably coiling and bending the cable, stressing joints on connectors. Cable connectors, cable placement, bending and flexing can cause leakage of signals and can result in undesired signal paths in a system causing deteriorated performance. The purpose of this paper is to bring to light the issues of signal leakage and radiation from shielded media such as RG-59 and RG-6 coaxial cables, furthermore signal splitters have less than ideal characteristics.

Keywords : CATV, Home Network, Coaxial Cable, Coaxial Connector, Signal Splitter

Ⅰ. Introduction

Home network testing facilities use long lengths of coaxial cables, often undesirably coiling and bending the cable, stressing joints on connectors. Cable connectors, cable placement, bending and flexing can cause leakage of signals and can result in undesired signal paths in a system causing deteriorated performance. The purpose of this paper is to bring to light the issues of signal leakage and radiation from shielded media such as RG-59 and RG-6 coaxial cables, furthermore signal splitters have less than ideal characteristics. Test setups simulating home networks must be carefully considered in light of these effects.

Ⅱ. CATV Home Network

1. A Home Network Topology

Figure 1 shows a representative home network topology which can be constructed as a test setup.

As a home network, the room ports may be physically separated by a considerable distance,

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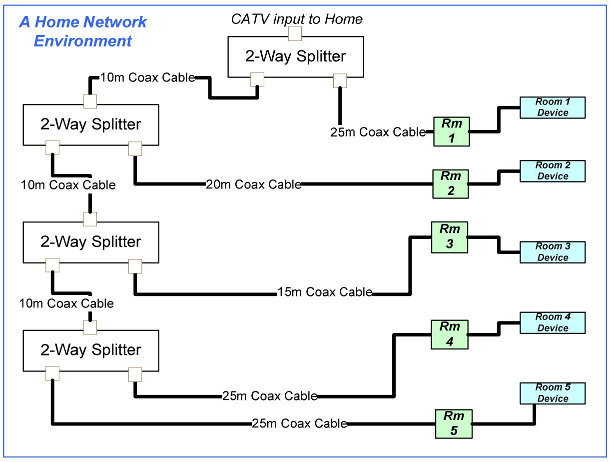

그림 1. 홈 네트워크 토폴로지
Fig. 1. A home network topology.

although this is not guaranteed. On the other hand, as a test setup, the “room” connections may be physically very close together. Cables are likely to be coiled up and bundled, and there may be undesired direct electrical connections between the “shield” sides of connectors while the intended signal path might be greatly attenuated by coax length losses and by splitter losses[1].

2. Components of the network

Home networks comprise lengths of coaxial cables terminated in Type F connectors. Networks further include signal splitters and the home consumer devices which are located in the various rooms.

2.1 Coaxial cables

Coaxial cable is constructed from a nominally round inner conductor surrounded by a larger diameter coaxially dispose cylindrical outer conductor which is separated from the inner conductor by a dielectric material. The cable has a characteristic impedance equal to the square root of the ratio of the cable inductance per length to capacitance per length. Thus the relative diameters of the conductors and the electrical properties of the dielectric define the cable characteristic impedance. Said another way, when the cable is terminated in a load resistance equal to the cable characteristic impedance (a matched load), the ratio of the voltage between the two conductors to the current through the conductors equals the characteristic impedance. Bending or flexing coax changes the relative geometric dimensions and the characteristic impedance. Shield foil may tear or form oxide, and shield braid may separate. These can cause the shielding effectiveness to deteriorate, and oxide action can behave like a non-linear semiconductor junction and cause signal components to mix and signals to distort.

2.2 Losses in Coax Cable Conductors

Coaxial cables rely on the flow of charges in conductors as much as on the passage of electromagnetic fields through the dielectric medium, thus the ensuing losses are due to both conductors and dielectrics[2]. Electromagnetic fields will penetrate conductors, but with a field amplitude that falls off exponentially according to $\exp(-z/\delta_s)$, where z is the distance into the conductor and δ_s is the skin depth. The general expression for the skin depth for a good conductor is

$$\delta_s = \sqrt{\frac{2}{\omega\mu_0\sigma}} \tag{1}$$

where σ is the conductivity of the conductor. The resistance per unit length of round wire of diameter b and conductivity σ is

$$R_s = \frac{1}{\pi b\delta_s\sigma} = \frac{1}{\pi b}\sqrt{\frac{\omega\mu_0}{2\sigma}} \tag{2}$$

Notice that the resistance per unit length R_s increases as the square root of frequency ω. The ohmic losses of a round wire depend on the current shape

$$R_{ohmic} = R_s\int_{z_0}^{z_1} I^2(z)dz \tag{3}$$

where $I(z)$ is the current normalized to the rms maximum value.

2.3 Coaxial Transmission Lines

Coaxial transmission lines are concentric conductors separated by an insulator. The dimensions, construction and conductivities of the inner and outer conductors along with the dielectric properties of the insulator characterize the performance of the coaxial lines[3]. The capacitance C_L and inductance L_L per unit length of coaxial cable can be expressed in terms of the outer diameter d of the inner conductor, the inner diameter D of the outer conductor as well as by the complex permittivity $\varepsilon = \varepsilon_0 \varepsilon_d$ and permeability μ of the insulating material between d and D

$$C_L = \frac{2\pi\varepsilon}{\ln\left(\frac{D}{d}\right)} \tag{4}$$

Since ε is complex, C_L can be seen to be of the form of a lossless capacitance term C_L in parallel with a conductance term G_0. The inductance per unit length is

$$L_L = \frac{\mu}{2\pi} ln\left(\frac{D}{d}\right) \tag{5}$$

The characteristic impedance of a transmission line is

$$Z_0 = \sqrt{\frac{j\omega L_L + R_c}{j\omega C_0 + G_0}} \tag{6}$$

which for low loss coaxial lines simplified to

$$Z_0 = \frac{\eta_m}{2\pi} ln\left(\frac{D}{d}\right) \tag{7}$$

The constant η_m is the characteristic impedance of medium between the two conductors. For coaxial lines C_L and L_L are give by (4) and (5), while the conductor resistance R_c is derived from (2),

$$R_c = \frac{1}{\pi d \delta_{si} \sigma_i} + \frac{1}{\pi D \delta_{so} \sigma_o} \tag{8}$$

Expression (8) recognizes that the inner conductor (subscript i) conductivity σ_i may be different from the outer conductor (subscript o) conductivity σ_o and that the respective skin depths are therefore also different. When the dissipation factor D_g is small, and μ_d = 1, then

$$k_g = k\sqrt{\varepsilon_r} \tag{9}$$

and the approximate attenuation expression, in nepers/m, including conductor losses is

$$\alpha_g = k\sqrt{\varepsilon_r}\left(\frac{D_\varepsilon}{2}\right) + \frac{R_c}{2Z_0} \tag{10}$$

Expression (10) can be rewritten in more common engineering terms in dB/m as

$$A_g = 0.09102\sqrt{\varepsilon_r}\, D_\varepsilon f + \frac{2.747}{Z_0}\left(\frac{1}{d\sqrt{\sigma_{Si}}} + \frac{1}{D\sqrt{\sigma_{So}}}\right) \tag{11}$$

where f is in MHz and dimensions d and D are meters. In engineering catalogs for transmission lines A is sometimes stated in dB per 100 feet(30.48 meter) and dimensions d and D are given in inches. Conductivity is likewise customarily given as K which is defined as the ratio to $\sigma_{CU} = 5.7 \times 10^7$ S/m, the conductivity of bulk copper. With those customary units (11) can be written with A in dB per 100 feet,

$$A_g = 2.774\sqrt{\varepsilon_r}\, D_\varepsilon f + \frac{0.437}{Z_0}\left(\frac{1}{d\sqrt{K_i}} + \frac{1}{D\sqrt{K_o}}\right)\sqrt{f} \tag{12}$$

for dimensions d and D in inches and frequency f in MHz.

In the practical case, the effective conductivity in ratio to bulk copper conductivity K_i and K_o will be about 0.4 to 0.5 for coaxial lines having stranded inner conductor and a braided shield even for pure copper conductors. The shielding effectiveness of braided coaxial lines is somewhat limited, the total power external to a one meter length of coaxial transmission line having a braided outer conductor is only about 40 to 50 dB below the power transmitted through that line. The effectiveness of solid outer conductors is far better, approaching 70 dB or so, but performance is ultimately limited by the practical construction of coaxial connectors.

Figure 2 shows the attenuation of several types 50 ohm (dashed lines) and 75 ohm (solid lines) coaxial cables as a function of frequency. The attenuation tends to vary predominantly with the square root of

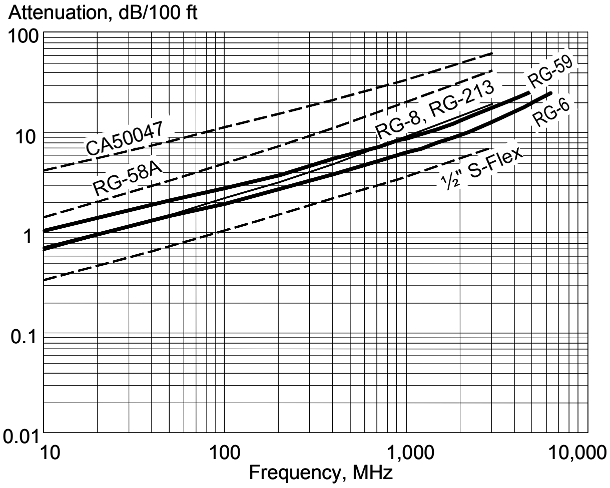

그림 2. 동축 케이블에서의 다양한 감쇠 형태
Fig. 2. Attenuation of several types of coaxial lines.

frequency at the lowest frequencies, where losses are primarily associated with conductors as seen in expression (11). As frequency increases the loss asymptotically approaches proportionality with frequency as dielectric losses begin to dominate. The standard coaxial transmission medium for CATV systems is 75 ohm cable. Figure 2 shows (in solid) the attenuation characteristics of RG-59 and RG-6, two popularly used CATV service coaxial cables.

Cable loss for RG59 is approximated by

$$Loss59 = 0.12 + 7.98\sqrt{f_{GHz}} + 0.79 f_{GHz} \text{ dB/100ft} \quad (13)$$

An approximate model for RG6 coax cable is

$$Loss6 = 0.04 + 5.3\sqrt{f_{GHz}} + 0.8 f_{GHz} \text{ dB/100ft} \quad (14)$$

The term proportional to frequency is due to dielectric losses, and the term in square root of frequency is due to conductor losses in the cable. The constant term is the loss at DC. All of these losses, when stated in decibels, are proportional to the cable length. By direct measurement of phase delay $(2\pi fl/cv_c)$ from nearly DC to 12 GHz, the group delay is found as the derivative of phase delay divided by 2π, or

$$Delay = \frac{1}{cv_c} \quad (15)$$

and l is the cable length and c is the speed of light.

Ⅲ. Experimental Results

3.1 Comparison of cable attenuation with radio wave propagation attenuation

Guided signals, like on coaxial transmission lines, and propagated signals follow different attenuation behaviors. Radiated signal energy in free space expands geometrically, hence attenuation between two antennas follows an inverse square law, with distance d, captured by a $n10\log(d)$ behavior, and in free space n=2. Scattering and multipath propagation might conspire to increase the propagation exponent to 3 or more, but basically the $\log(d)$ remains. Cable attenuation, in contrast, is exponential! The behavior is $A_g d$.

Initially, geometric expansion of waves provides much greater attenuation than exponential losses. However, the exponential curve soon overtakes the geometric behavior as seen in Figure 3. Clearly, cable does not always provide the smallest attenuation, and the cross-over depends on the type of coax used, as well as on the value of n.

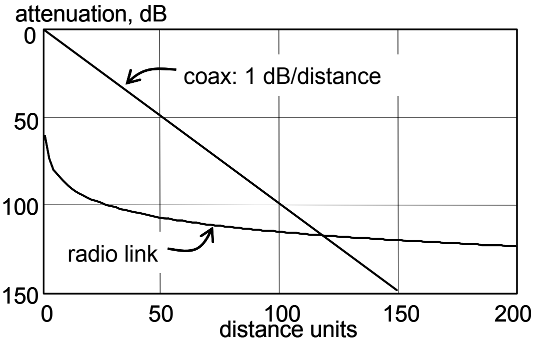

그림 3. 동축 케이블 가이드와 라디오 채널의 감쇠
Fig. 3. Coaxial cable guided and radio channel attenuations.

3.2 Coaxial Connectors

Coaxial cable connectors are a “weak point” in maintaining signal integrity in a coaxial cable network. When properly designed and properly installed connectors maintain the inductance per length and the capacitance per length. That is, the maintain the characteristic impedance of the line.

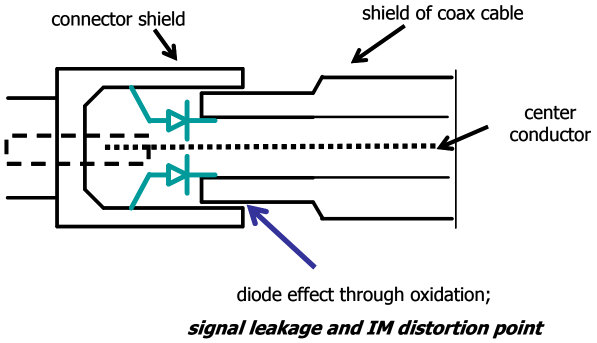

그림 4. 불완전한 케이블 커넥터의 연결
Fig. 4. An imperfect cable - connector junction.

More often than not, connectors are poorly installed and not well maintained. The connection between the cable shield and the barrel of the connector is pressed on and may oxidize and/or corrode causing undesired effects such as a diode effect at the junction of the cable and connector, see Figure 4.

The Type-F connectors used in CATV home networks do not maintain a constant 75 ohm characteristic impedance across the length of the connector. Furthermore, the connection between the coax shield and the connector shield physically is far from ideal. Thus, connectors can leak radiation and are not stable after multiple connect-disconnect cycles. In a scenario comprising a long length of coax that is bundled and coiled to “save space” in a test set up, there could be significant direct coupling between the two ends of the cable in addition to the desired coupling through the cable.

3.3 Signal Splitters

A ideal signal splitter divides the input signal into equal portions at the splitter outputs. Furthermore, the ideal splitters has zero coupling between any two output ports. Splitters are designed to operate up to some defined frequency which is often below about 2 GHz. When operated out of band, the input-to-output (I-O) attenuation is often much higher than in the CATV bands. The isolation between output ports (O-O) deteriorates outside the CATV bands. Since home networks often include paths that traverse splitters in the O-O configuration, like between any two rooms in Figure 1, we rely on the lessened isolation for our desired signal path.

Since splitters are not rated in our band of interest, all of the signal paths through various splitter ports can take on a large range of values from splitter to splitter of a given model, and across different splitter manufacturers. In particular, and in the O-O path, some splitter exhibit nulls in the frequency band of interest. Pulse based systems have an inherent advantage in that the pulse energy is distributed over the entire pulse bandwidth. A narrow band null does no more than reduce the signal energy, but does not drop out data bits. The actual loss is averaged by a power spectral density of the signal. That is, if the splitter is characterized by $S_{12}(f)$(or equivalently $S_{21}(f)$), so the power transfer coefficient is proportional to $|S_{12}(f)|^2$ since $S_{12}$is proportional to a normalized voltage transmission coefficient. If were present the time averaged Power Spectral Density(PSD) of the signal as $C(f)$ W/MHz then the relevant splitter loss in decibels can be calculated from

$$L_{avg} = 10\log\left(\int C(f)|S_{12}(f)|^2 df\right) \tag{16}$$

The integration is over the entire signal spectrum. In practice it is sufficient to perform an average of the splitter $|S_{12}(f)|^2$ between the lower and upper -3dB points of the signal, and report the value in decibels.

Thus sharp/deep nulls in the splitter characteristic do not cause drop-outs, just a reduction in the average power transferred. The “loss-averaging” effect of a wide band signal is one of the significant advantages that a system has over carrier based systems (like OFDM), which drop out the carriers in the nulls with data losses, in these applications. In characterizing the effects on OFDM systems one would have to use the splitter loss at each and every tone-carrier frequency individually.

In 3- and 4-way splitters the O-O characteristic between any two output ports might be dramatically different. This is because some of these splitters are designed like cascaded 2-way splitters. Referring to

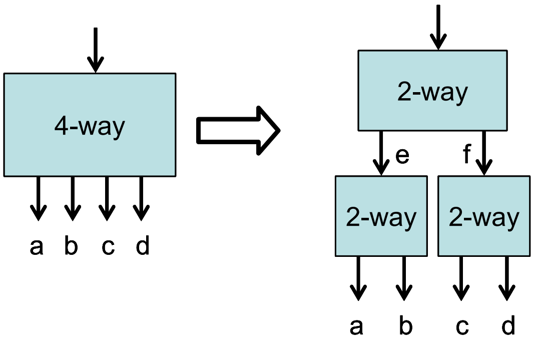

그림 5. 동일한 4-way 분배기 형태
Fig. 5. A 4-way splitter with equivalent

Figure 5, the O-O paths of a 4-way splitter can have dramatically different losses. The path from "*a*" to "*b*" or from "*c*" to "*d*" is equivalent to a single O-O path through a 2-way splitter. However, "*a*" to "*c*" incurs the I-O path loss from "*a*" to "*e*", then an O-O path loss from "*e*" to "*f*" and finally an I-O path loss from "*f*" to "*c*". Remedial action in a network might include the swapping of connections to improve signals dramatically

Ⅳ. Conclusions

Home network testing facilities use long lengths of coaxial cables, often undesirably coiling and bending the cable, stressing joints on connectors. Cable connectors, cable placement, bending and flexing can cause leakage of signals and can result in undesired signal paths in a system causing deteriorated performance. Inputs to the system and outputs from the system can be physically located close together on a test setup. As a result, undesired low attenuation signal paths can result which interfere with the desired intended testing path. These effects have been observed in practice. Good engineering practices would include:

(1) Good quality coaxial cables should be used, and properly fitted with good quality connectors.

(2) Coax should not be excessively bent or crimped.

(3) Coax should not be coiled bundled.

(4) Coax cable inputs and cable outputs should be physically and electrically isolated.

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