TWO-WAY CABLE PLANT CHARACTERISTICS

Richard Citta and Dennis Mutzabaugh

ZENITH RADIO CORP.

ABSTRACT

Two-way cable plant characteristics, specifically of the return plant, are needed to aid cable operators and cable engineers in understanding the problems encountered in a return plant. This is extremely important with the advent of two-way interactive services being included in franchise contracts.

Data from twelve operating two-way plants was gathered and correlated, resulting in a "composite" or typical return plant. From this "composite", five major characteristics were constructed and analyzed. These five characteristics are: white noise floor, the tunneling effect; ingress, unwanted external signals; common mode distortion, the difference products resulting from forward plant rectification; impulse noise, specifically 60 Hz power line contributions; and amplifier nonlinearities.

INTRODUCTION

The five characteristics of a return plant (white noise, ingress, common mode distortion, impulse noise and amplifier nonlinearities), will be discusssed individually with data taken from one or more of the twelve analyzed cable plants illustrating a particular characteristic. Following the discussions of each characteristic, a sampling of the twelve return plant measurements will be presented. In conclusion, a return plant "composite" will be constructed depicting the characteristics of a "typical" return plant.

RETURN PLANT CHARACTERISTICS

White Noise

The white noise of a return plant, like the forward plant, is based on the thermal noise of a 75 ohm terminating resistor, the bandwidth under consideration, the amplifiers noise figure and the number of amplifiers. The noise floor of a return plant differs from the forward plant in one fundamental concept: noise funnelling.

A 75 ohm terminator in the plant generates thermal noise. This noise is carried through each return distribution amplifier, which adds its own noise, and bridged to the trunk. Noise figure is a method of measuring amplifier noise contribution. The return trunk amplifiers carry this distribution noise to the headend, also adding their own noise. Since all distribution has a 75 ohm terminator, each distribution leg adds its own noise to the trunk system. This "addition" of noise from each distribution leg is called "noise funnelling". Since each amplifier, both trunk and distribution, contributes its own noise to the return system, the total number of amplifiers in a cable plant is used to calculate the return plant noise floor. This is different from the forward plant noise floor calculations, where only the longest cascade is required.

A common plant design uses a 0 db or unity gain design scheme. If this scheme is assumed, then the white noise floor of a return plant can be calculated using equation (1).

$$\text{WN floor (dbmv)} = -59 + 10\log(BW/4\text{Mhz}) + nf + 10\log(N) \quad (1)$$

where

- -59 = noise generated by a 75 ohm resistor in a 4Mhz bandwidth in dbmv.
- BW = bandwidth other than 4Mhz.
- nf = amplifier noise figure (assuming the same for all amplifiers).
- N = total number of amplifiers in the cable system.

The following example illustrates the use of equation (1):

Example:

A cable plant with 14,000 subscribers consists of 642 amplifiers with a noise figure of 7 db. Assuming a unity gain design and a noise bandwidth of 100Khz, calculate the return plant white noise floor.

$$\text{WN floor} = -59 + 10\log(100\text{Khz}/4\text{Mhz}) + 7 + 10\log(642)$$
$$\text{WN floor} = -59 - 16.02 + 7 + 28.08$$
$$\text{WN floor} = -39.94 \text{ dbmv}$$

Fig. 1 shows the return plant spectrum of an actual cable plant with the specifications described in the above example. The results of equation (2) correlate well with the measured data. The nominal or reference level shown is a typical return plant operating level of 20 dbmv. If a return signal is at 20 dbmv then the carrier to noise ratio, C/N, is 59.94 db.

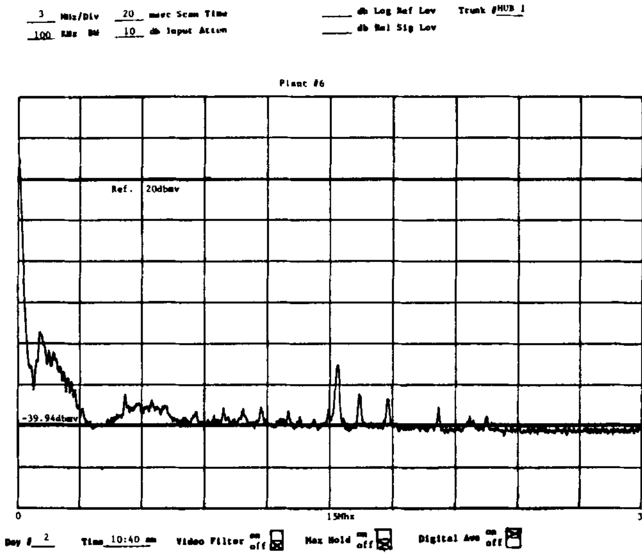


Fig. 1

The cable plant of fig. 1 is a very "clean" plant. Fig. 2 shows a return plant that is quite different. In Fig. 2 the lower graph is an 8-hour average of spectrum analyzer sweeps taken every six seconds with 100Khz bandwidth. The upper graph is an average of 8 one-hour interval quasi-peaks. The quasi-peak is the peak value of each frequency, during the one-hour interval, of a ten-sweep average. This method retains the peak value of time varying signals but eliminates impluse noise. The specifications of this plant are 31,000 subscribers, 2312 amplifiers with a noise figure of 9 db, and a unity gain design. Using 100Khz as a bandwidth and these specifications, equation (1) yields a white noise floor of -32.38 dbmv with a C/N of 52.28 db.

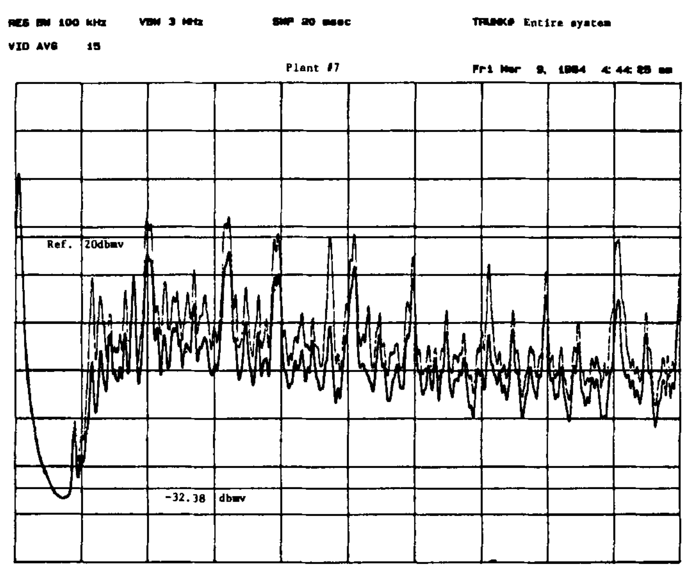


Fig. 2

The calculated white noise floor is significantly lower than the measured noise floor. The graph shows numerous extraneous signals. These signals and their associated sidebands raise the noise floor of the return plant above the calculated noise floor. The C/N appears to vary from 25 db at 6Mhz to 32 db at 24Mhz. These extraneous signals are the result of ingress and common mode distortion.

Ingress

Ingress is defined as unwanted external signals entering the cable plant. These signals enter the plant at weak points in the cable system. The most common weak points are drops and/or faulty connectors where shield discontinuities or breaks reduce the ground shield effectiveness. The common ingress sources found in a return plant are amateur radio operators, citizen's band operators, local AM broadcast, local shortwave and international shortwave. Fig. 3 shows the locations of these possible ingress sources on a return plant spectrum. It is clear that any return plant communications system may be adversely affected by these unwanted signals.

In fig. 3 the solid bars indicate shortwave bands, the crosshatched bar citizen's band, the diagonal bars amateur radio bands and the dotted bar AM broadcast.

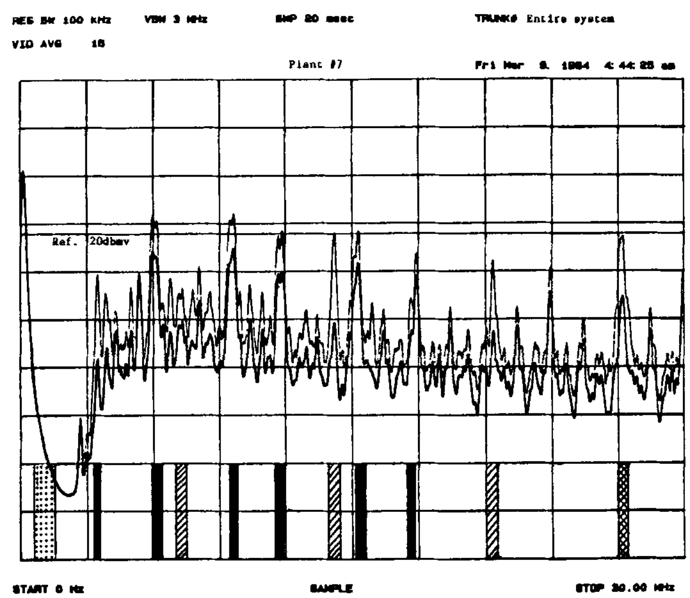


Fig. 3

Amateur radio and citizen's band ingress are a result of local operators transmitting near a cable plant in close proximity to bad connectors and/or poor shielding. Entry points for these ingress types are not difficult to locate if code operated switches are available.

AM broadcast and shortwave, especially international shortwave, are another matter. Field intensities for these signals are constant in almost the entire plant distribution. Consequently, determining the entry points of these signals becomes much more difficult.

Five major international shortwave bands appear in the return plant: 5.95-6.2Mhz, 9.5-9.775Mhz, 11.7-11.975Mhz, 15.1-15.45Mhz, and 17.7-17.9Mhz. Fig. 4 and fig. 5 show the spectra of two of these shortwave bands.

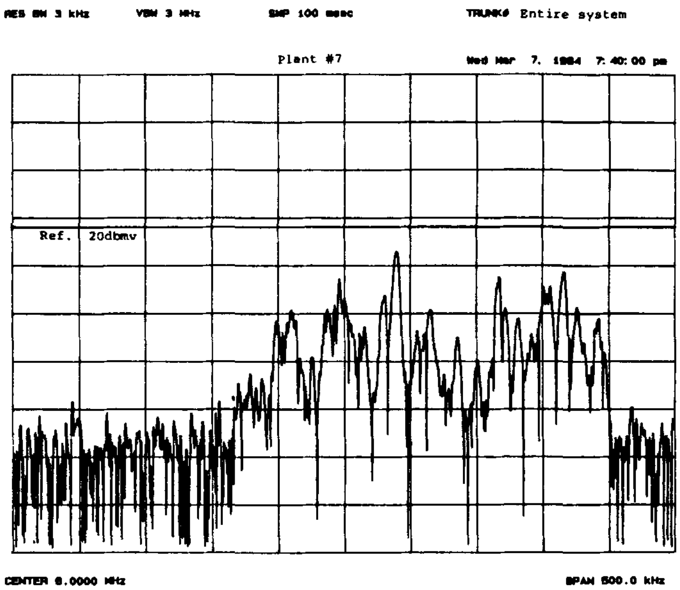


Fig. 4

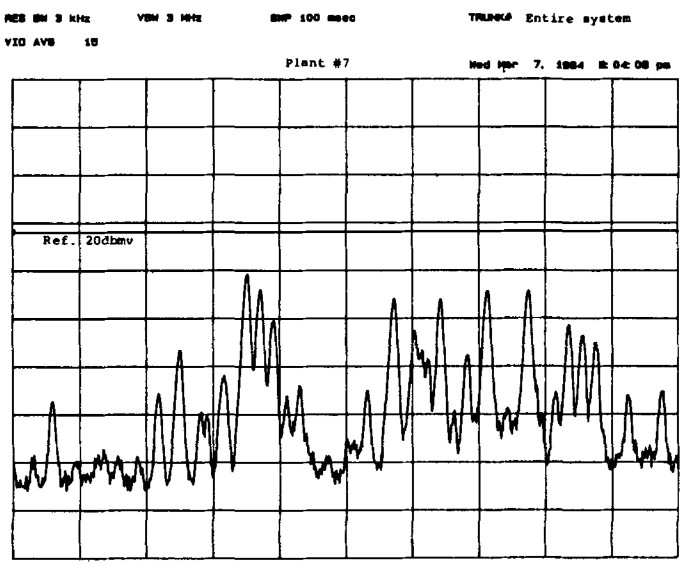


Fig. 5

An interesting characteristic of international shortwave signals worth noting is its time variation. These shortwave signals, commonly originating in Europe and the Far East, reach the United States via the "skip" phenomenon. This "skip" is accomplished by signals reflecting off atmospheric layers. The "skip" area is usually located midway between the source and receiving points.

Temperature has a positive gradient effect on the reflective atmospheric layers. As these layers are warmed by the sun, they rise, increasing the reflecting height, causing the receiving point to increase in distance from the source. The opposite is also true. In general, the shortwave bands vary in the following manner: 5.95-6.2Mhz, active at night, decreasing in the daytime; 9.5-9.775Mhz, activity varies several times during the day and night; 11.7-11.975Mhz, 15.1-15.45Mhz and 17.7-17.9Mhz, active during the day, decreasing at night. Fig. 6 was taken from the same cable plant as fig. 4 but at a different time during the day. Fig. 4 shows active international shortwave while fig. 6 shows no activity.

Fig. 6 shows another characteristic in a return plant: common mode distortion.

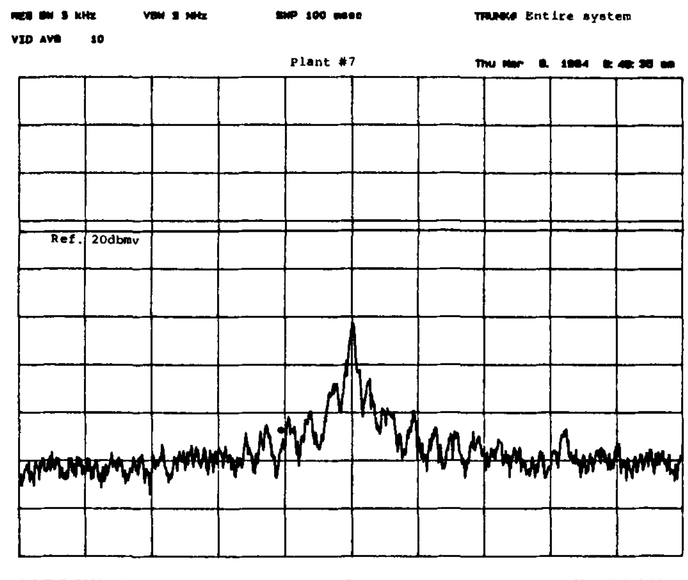


Fig. 6

Common Mode Distortion

Common mode distortion, also known as common path distortion, is the result of nonlinearities in the cable system that are not a result of active devices. This nonlinear function is generated by corrosion in the cable plant connectors, commonly in distribution, when oxide forms between two metal surfaces, creating a point contact diode. This diode may appear in the ground portion of the connector, thereby producing common mode distortion and allowing ingress to penetrate the plant, or it may appear in the center conductor, producing only common mode distortion.

The effect of this diode creates problems in both the forward and return plants. When the forward plant signals drive this diode, sum products of the driving signals may appear in upper channels of the forward plant, producing unwanted frequency beats. In the return plant the difference products are present and their effect is more dominating.

In all systems a majority of the forward or driving signals are 6Mhz apart. When these signals drive a nonlinearity, the difference products will always appear at 6Mhz and its harmonic multiples. A return plant with common mode distortion produced by these difference products has a spectrum consisting of frequencies at 6Mhz, 12Mhz, 18Mhz, 24Mhz, 30Mhz, etc. This phenomenon was discussed and published by Reichert in 1982.[1] Fig. 7 indicates where these signals reside.

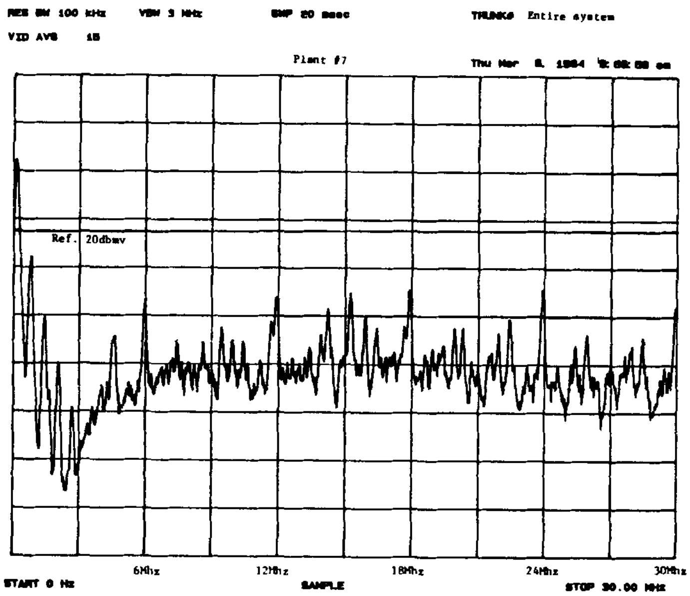


Fig. 7

Fig. 3 also has common mode distortion present but the 6Mhz and the 12Mhz are dominated by international shortwave signals. Fig. 8 shows the common mode distortion at 6Mhz with symmetrical sidebands. These sidebands are at 15,734Hz intervals, which are the harmonics of the video horizontal sweep.

Fig. 9 and fig. 10 show the spectra of the 12Mhz and the 18Mhz common mode distortion products.The frequency area just below 12Mhz and 18Mhz are sections of the international shortwave bands.

These nonlinear effects seen in the return plant can be the result of one faulty connector or many faulty connectors. The actual number is indeterminant. These nonlinear transfer functions vary from diode to diode. Consequently, the resultant effect on the return plant can be generated by one, several or many connectors, depending on the extent of corrosion. This makes maintenance very difficult and time consuming without code operated switches.

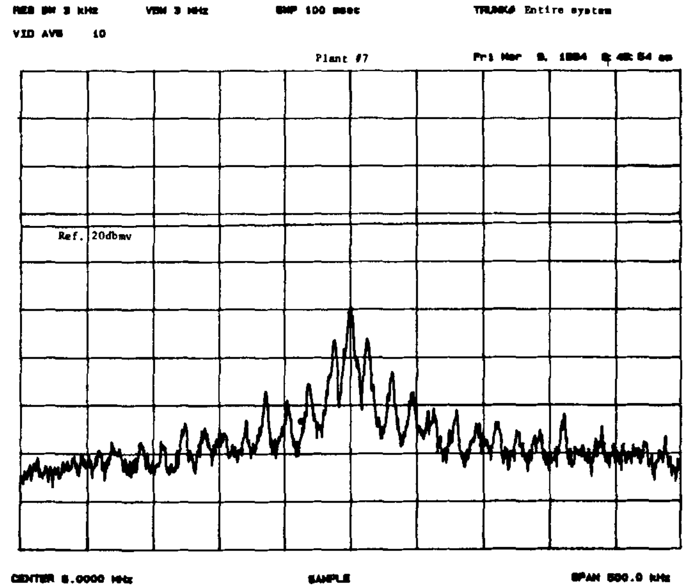


Fig. 8

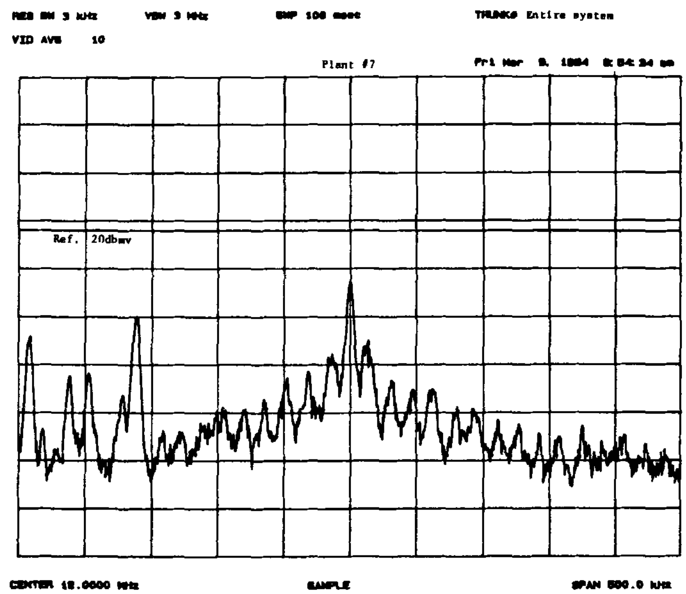


Fig. 9

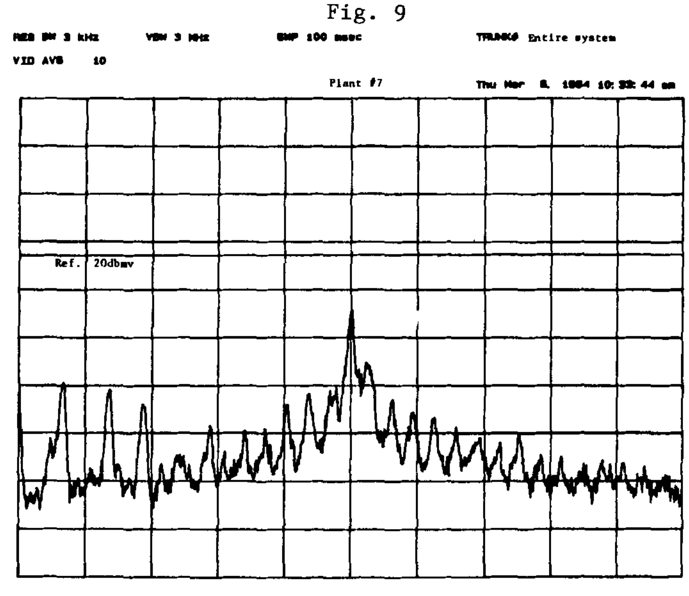


Fig. 10

The amount of common mode distortion can vary from day to day and even hour to hour in the same cable plant. In some systems, the common mode distortion level remains relatively constant, while in others it may vary a great deal. Since common mode distortion is a nonlinear exponential effect, slight variations in forward levels will cause significant changes in common mode levels. Fig. 11 and fig. 12 show how 6Mhz common mode distortion can vary in the same plant. Speculation has it that weather conditions, such as temperature, humidity and wind velocity, play a major role in physically altering the point contact diode structure of the connector thereby affecting the nonlinear tansfer function.

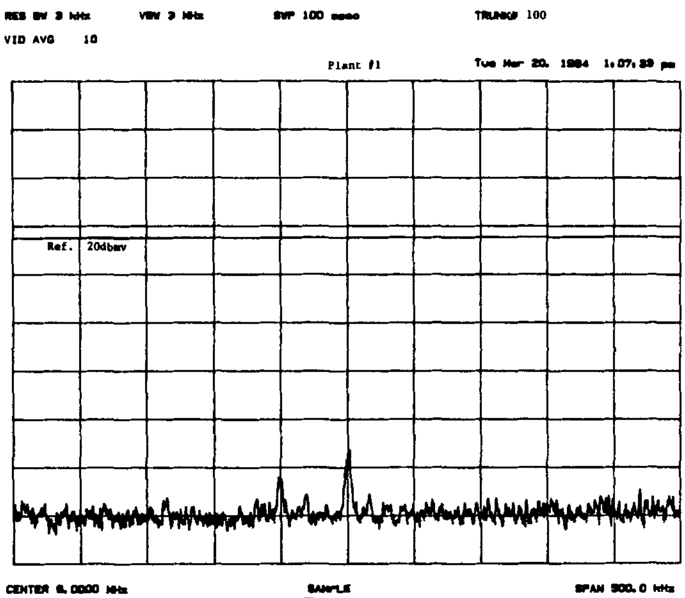


Fig. 11

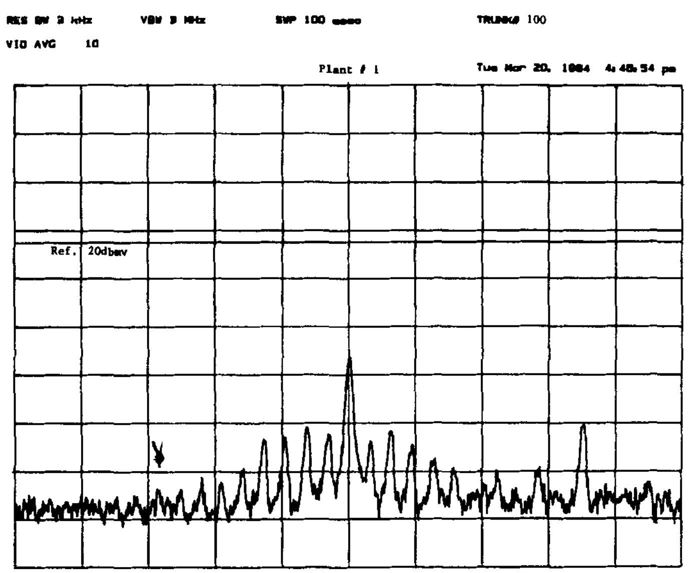


Fig. 12

When common mode distortion is present, it is either time invariant or slowly time varying. A characteristic of a return plant that is randomly time variant is impulse noise.

<u>Impulse Noise</u>

By far the dominant source of impulse noise in a return plant is 60Hz high voltage lines. There are two types of discharge noise that are associated with high voltage lines: corona and gap noise. Corona is a result of high voltage energy actually discharging into the air. This is primarily on 300Kv or higher lines and it is random in nature. Temperature and humidity play a vital role in this phenomenon. The other type of discharge, gap noise, is a direct result of a system fault. This fault is usually a bad or cracked insulator. When the voltage on the line rises to near the peak level, either positive or negative, a discharge through the insulator's discontinuity takes place. This can occur on 100Kv lines as well as 300Kv lines. Since discharge takes place on both peaks, the spectrum of this discharge has impulses at 120Hz intervals. This discharge or arc has a duration in the microsecond region with very sharp rise and fall times. Consequently the spectrum can extend into the tens of megahertz range at 120Hz intervals. If the discharge time is fairly constant, then the frequency spectrum takes on a sin x/x distribution.

There are two ways this interference can enter a return plant. One way is through bad connectors, entering the plant by the same mechanism as shortwave ingress. The other way is due to insufficient ground of the cable shield.

Fig. 13 compares the average peak power of a return plant with its average power. The upper graph is the average peak power which is dominated by gap noise power.

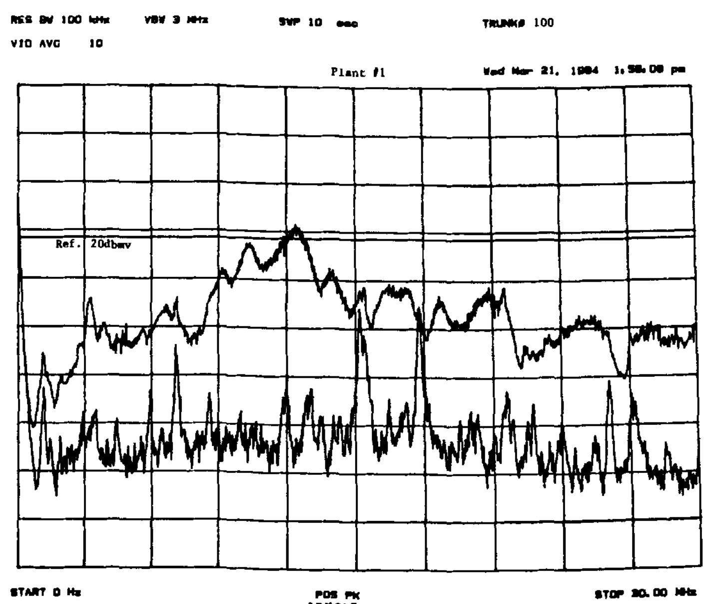


Fig. 13

The spectrum analyzer used in these measurements uses a positive peak detector for measuring the average peak power. A digital average algorithm is used on the data taken from ten sweeps. This measurement technique captures impulses in the return plant which appear at a relatively constant rate. Because this technique weighs each signal by a certain fraction, it eliminates impulses that occur only once or twice during the ten sweeps. The lower graph uses the same digital average algorithm except a sampling detector is used. It is evident from fig. 13 that at a specific frequency the average peak power caused by gap noise can be as much as 40 db higher than the average power. This difference must be understood if the return plant is to be used as a communications link.

The discharge through a faulty insulator is not exactly of a certain duration nor does it occur exactly at 8.33ms intervals. This is because of the unknown conditions at the faulty insulator. If it is "dirty" with debris or moisture, the discharge will not occur at exactly the peak voltage but it may occur within a certain "window" around the peak. This causes multiburst and/or high density discharges. Fig. 14 is a time domain graph at a center frequency of 9.54Mhz. Notice the voltage spikes appearing in pairs and the high density pulses appearing at lower levels slightly prior to these pairs. This is an example of multiburst gap noise. It is interesting to note that the central moment of these pulses appears at 8.33ms intervals.

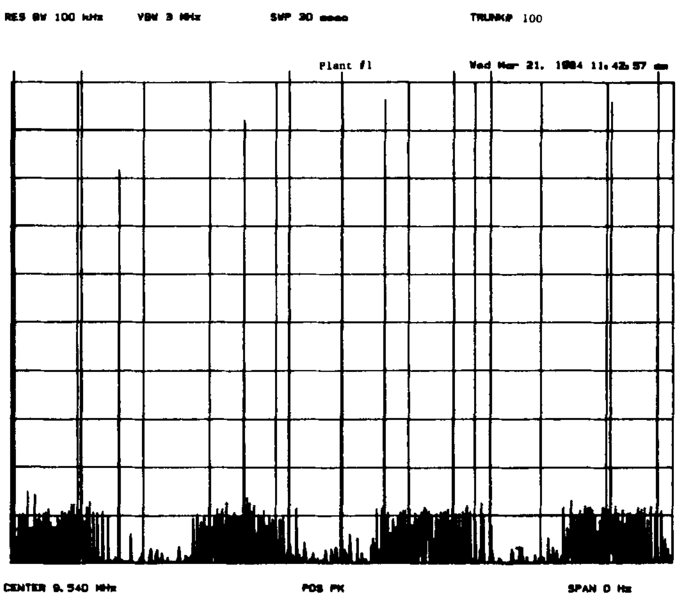


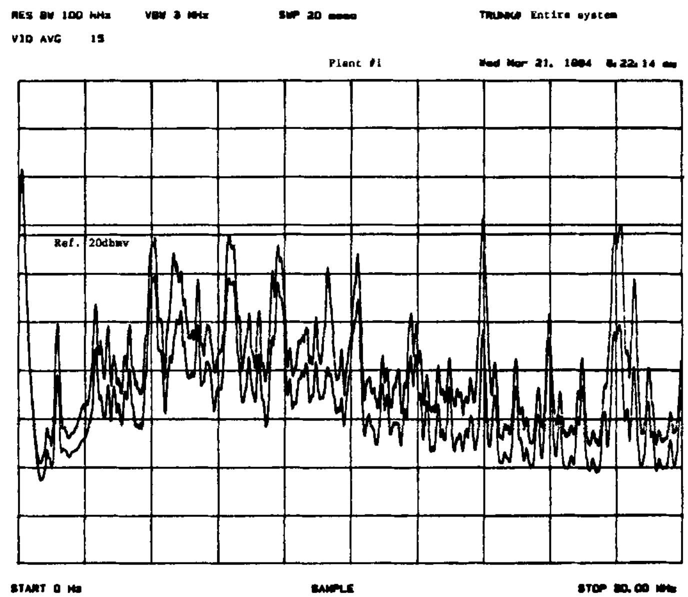
Fig. 14

Amplifier Nonlinearities

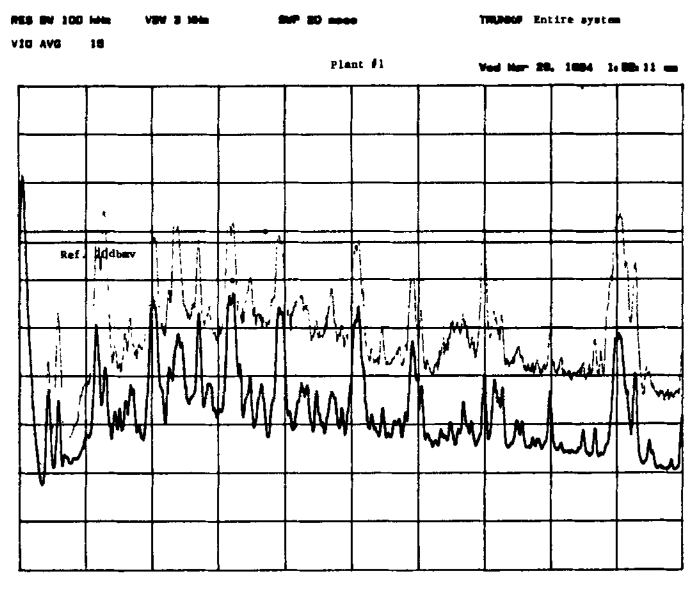
A problem that is not very common in a return plant but nonetheless can exist is amplifier nonlinearities or oscillations. Pulse regenerative oscillations are the most common types found, and they are the result of a marginally stable amplifier either driving a reactive load or terminating a reactive line. In either event mistermination of the transmission line is the cause of the instability. A spectrum of this problem is a comb of frequencies within the return plant frequency band. The frequency spacing is related to the distance of the mistermination from the amplifier in question.

RETURN PLANT DATA

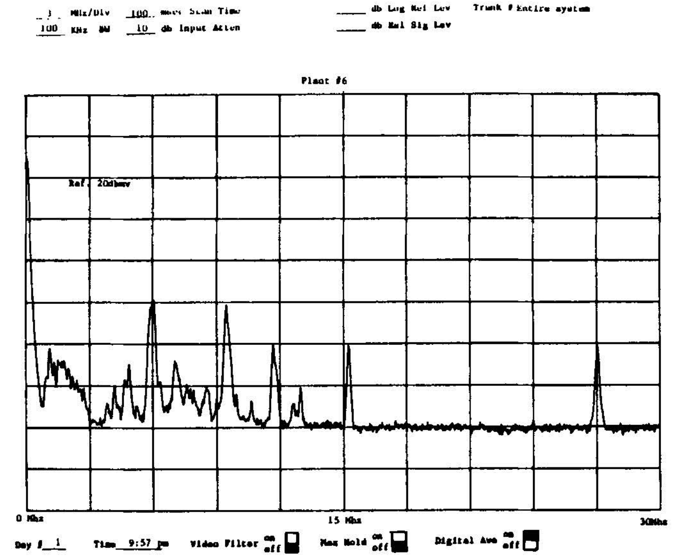
Figures 15 through 20 are return plant spectra of five of the twelve cable plants that were analyzed. Single plots are spectra taken at the time indicated. Double plots, except for fig. 16, are twelve-hour averages. On these plots the upper graph is the average of the quasi-peaks and the lower graph is the total average. Fig. 16 is a six-day average of plant #1. Plant size in both number of subcribers and total number of amplifiers is provided.



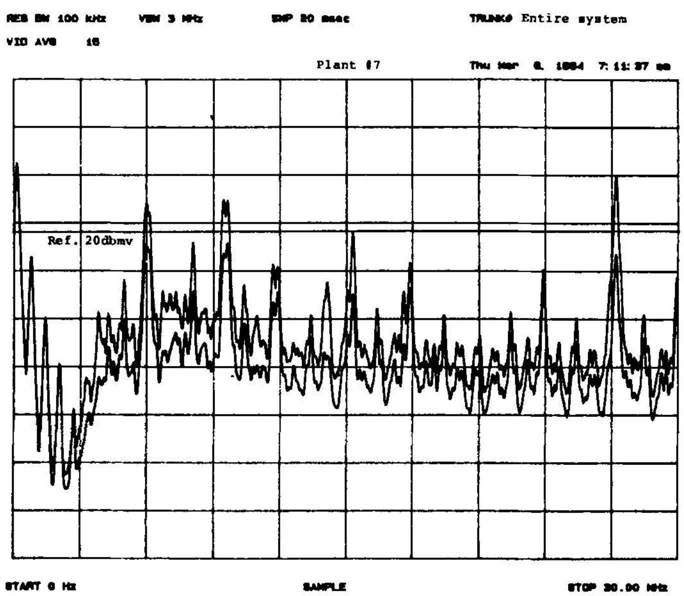
13,000 subs Fig. 15 444 amps



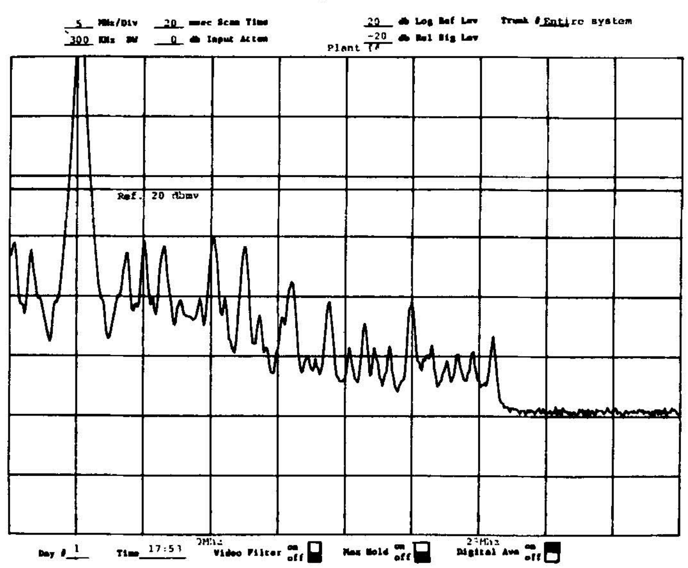
13,000 subs Fig. 16 444 amps



14,000 subs Fig. 17 642 amps



31,000 subs Fig. 18 2312 amps



30,000 subs Fig. 19

Plant #2

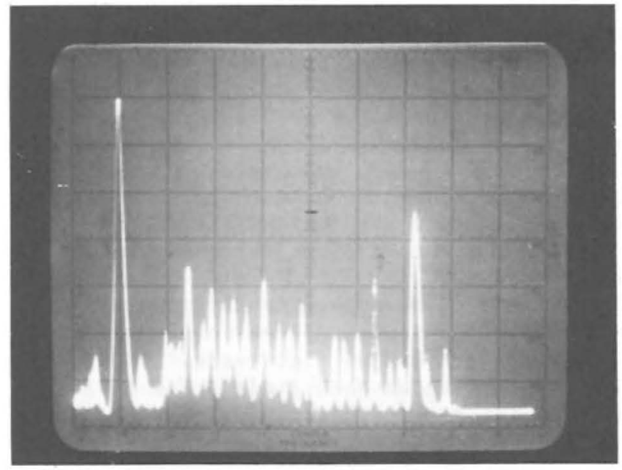


Fig. 20

Conditions:
5Mhz/div
300Khz res BW
20Mhz center frequency
57 dbmv reference
32Mhz pilot at 22 dbmv ref.
7,000 subs

The data presented in this section is a representative sample of the data accumulated from the twelve cable plants.

CONCLUSIONS

Spectrum Summary

There are five characteristics of a return plant: white noise, ingress, common mode distortion, impulse noise and amplifier nonlinearities. If amplifier problems are eliminated, then ingress and common mode distortion can be thought of as long term problems and impulse noise as a short term problem. The long term problems also affect the noise floor of a return plant. The sidebands of common mode distortion raise the noise floor of the return plant, and if international shortwave is present, it produces an apparent tilt in the noise floor. Impulse noise, unless extremely high, does not appreciably affect the noise floor. These problems can be attributed to faulty or corroding connectors in the cable system.

Fig. 21 is a "composite" of the twelve cable plants that were measured and analyzed. This "typical" plant is the average of the common mode distortion products, ingress sources and white noise sources of the twelve cable plants. The horizontal tick marks indicate the maximum values reached by ingress or common mode distortion products.

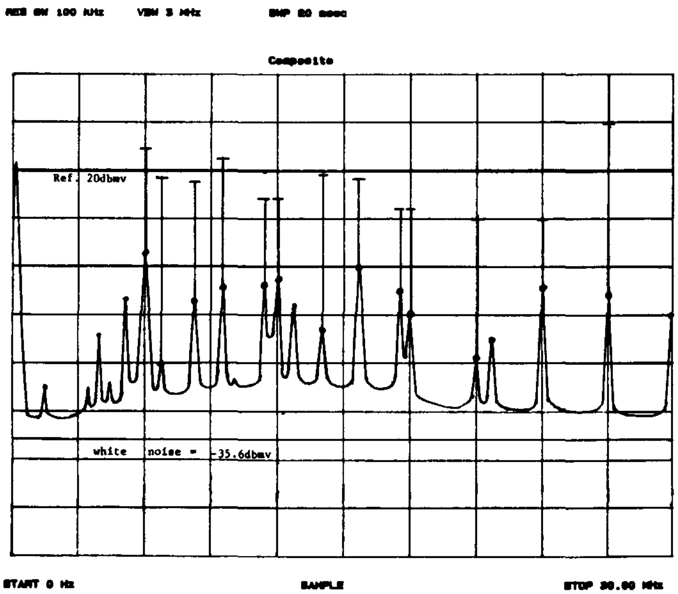


Fig. 21

Maintenance

The amount and type of maintenance vary from plant to plant. By far, the most efficient means of locating trouble spots in a cable system is the code operated switch system. Using COS's, the cable operator can quickly search the system to find the faulty connectors. If code operated switches are not used, then the labor intensive "sniffer" technique must be used.

In general, it is much more labor intensive to incorporate return plant maintenance procedures than it is to use forward plant maintenance procedures. Much more ingress, common mode distortion and impulse noise can be tolerated in the forward plant than in the return plant.

Fig. 17 is cable system that uses return plant maintenance procedures, and figs. 15, 16, 18, 19 and 20 are cable systems that incorporate a forward plant maintenance schedule.

Communication Viability

If two-way communication links are to be used in return plants, then the type of communication system used must be balanced with the amount of maintenance required to guarantee reliable service. If a wide band system is used, i.e. return video, then a substantial amount of maintenance will be required. If wide band data transmission is used then the return maintenance will be somewhat less.

It is possible to use the return plant for data communication with only forward plant maintenance and with little or no return plant maintenance. If narrow band data transmission is employed, i.e. bandwidth less than 100Khz, then the return carriers can be "slotted" into the "holes" of the return plant spectrum. By avoiding the common mode distortion and ingress frequencies, long term reliability is possible. If the bandwidth is narrow, then impulse noise susceptibility is reduced and short term reliability is possible.

If these criteria are met, then reliable, practical, two-way cable communications can be achieved with no substantial increase in maintenance costs.

REFERENCES

1. Reichert, H. J. Jr., "CATV System Return Path Interference", NCTA 31st Annual Convention-Technical Papers, May 3-5, 1982.