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Recommended Practices

for

Measurements

on

Cable Television Systems'

2nd edition (revised 1993)

SUPPLEMENT on UPSTREAM TRANSPORT ISSUES

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Publisher's note:

This supplement is best used in conjunction with the most recent edition of the notebook, *NCTA Recommended Practices for Measurements on Cable Television Systems*. The authors assume that the reader seeks measurement procedures, not arbitrary rules. Users must know their system's base operating parameters. It is vital that you are aware of the proper alignment procedures and level adjustments for your particular headend before using any of the NCTA recommended practices for measurements.

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Executive Summary

The goal for this Section of the *NCTA Recommended Practices for Measurements on Cable Television Systems* is to provide step-by-step procedures that allow cable television operators to successfully setup and manage their upstream plant. This document is also intended to assist equipment vendors in understanding upstream transport issues.

Chapter 1 addresses **definitions** necessary to form a clear understanding of the basis for the measurement procedures offered.

Chapter 2 discusses the **upstream plant setup** and a method of noise funneling prediction.

Chapter 3 presents the **fundamental measurements** necessary to **verify the performance** of the upstream plant.

Chapter 4 provides the tools to assist with **diagnosis and troubleshooting** the upstream plant.

Chapter 5 collects ideas unable to be addressed in this section's first release. The hope is that they be considered during a subsequent update.

Acknowledgments

Many thanks to the Recommended Practices Subcommittee UPSTREAM TRANSPORTATION ISSUES Working Groups 1 through 6 for laying down the groundwork for this Section of the *NCTA Recommended Practices for Measurements on Cable Television Systems*. Key contributors to this section are shown below. We greatly appreciate their leadership and dedication. In addition to those whose names appear, a significant number of well qualified industry engineers provided valuable counsel. While this list is too long to be included, the key persons are grateful to them for sharing their expertise and sounding board availability.

Dick Shimp (ComSonics), Recommended Practices Subcommittee Chairman; Hugo Vifian (Harmonic Lightwaves), Working Group #1 Leader; Tom Hill (Tektronix), Working Group #2 Leader; Bob Dickinson (Dovetail Surveys), Working Group #3 [absorbed Working Group #4] Leader; Dean Stoneback (NextLevel Systems, formerly General Instrument), Working Group #5 Leader; Gregg Rodgers (Trilithic), Working Group #6 Leader; Rex Bullinger (Hewlett-Packard); Dan Pike (Prime Cable); Syd Fluck (Hewlett-Packard); John Kenny (ANTEC); Dave Large (Media Connections); Bill Morgan (Hewlett-Packard) and Oleh Sniezko (TCI).

Introduction

Upstream cable television transportation certainly is not a new topic. It's been talked about for years. In the late 60's and early 70's, a number of public policy issues were examined which culminated in FCC Rules that, among other issues, required a 5 MHz to 30 MHz reverse path capability in equipment used in the industry. Various uses have been made of the medium since then, with the concomitant issues of noise funneling and ingress noted in the literature. As time moved forward into the late 1970's, major franchising issues placed a great deal of pressure on the practitioners of the day to create applications for this available path. But, none of the proposed services were universally successful in the marketplace and attention waned from the upstream path.

Today's renewed interest in bi-directional communication on the band for mostly high speed digital data signals is coincident with many important industry trends. While the recent Hybrid Fiber Coaxial (HFC) architecture reduces the vulnerability to relevant negative attributes found in all-coaxial systems, the advantage is somewhat offset by public policy trends that leave the consumer in greater control of the drop wiring and its use. There are also some new considerations.

This results in the need to add upstream practices to the Recommended Practices for Measurements on Cable Television Systems. *Upstream Transportation Issues* is devoted to making the upstream plant a useful operational entity by expressing the best considered information to date. Throughout the many months of hard work by a group of very dedicated individuals, the following guideline prevails:

> *The charter of this group focuses on identifying relevant* ***upstream*** *issues and elements. The ultimate goal* ***creates field technician friendly*** *RECOMMENDED PRACTICES, including testing procedures and suggested target values (if appropriate) as they apply to upstream operation for inclusion into the "NCTA RECOMMENDED PRACTICES FOR MEASUREMENTS ON CABLE TELEVISION SYSTEMS".*

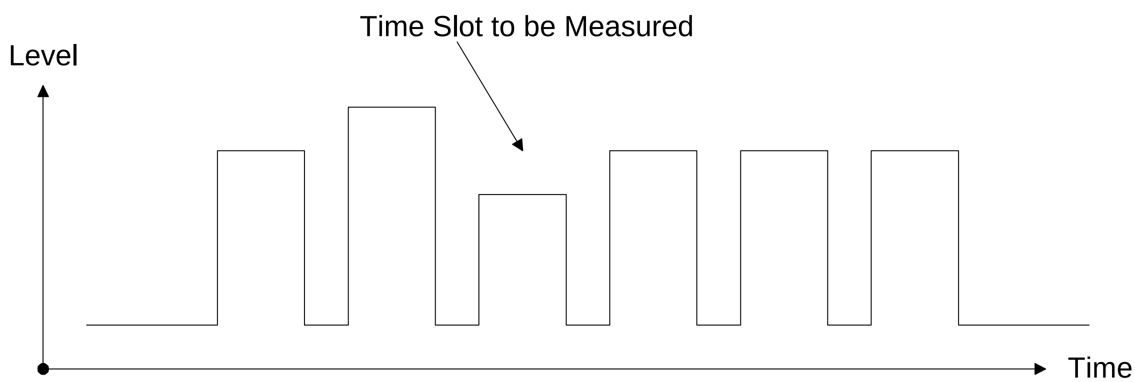
Chapter Three satisfies the Charter. However, because of the relative import, the Subcommittee wishes to enhance the original assignment by including upstream setup suggestions. As we prepare this document, pioneers in the substantial use of the upstream path willingly share their experiences, and, as they are relevant, are included in the document for reference. Other chapters address the complex issues of accurately measuring digital signals, assessing the dynamic range of reverse laser transmitters, the impact of impulse noise and introduce some methods to describe channel availability.

Chapter 1: Definitions

1.1 Signal Level

Definition: The definition of the level of a digital signal shall be the power level as measured by a power meter which uses a thermocouple as a transducer. That is, the measurement shall be the average power in the signal, integrated over the actual occupied bandwidth of that signal. The signal level should be presented in decibels with respect to one millivolt RMS in a 75 ohm system. Thus, the measurement reported is the RMS value of the sinusoidal that would produce the same heating in a 75 ohm resistor as does the actual signal.

In the case of an intermittent signal, such as a signal that occupies one assigned time slot in a time division multiple access (TDMA) sequence of time slots, the level reported shall be the equivalent level as if the signal being measured (any one of the multiple signals included in the total sequence) was on continuously.



Discussion: It shall be the responsibility of each manufacturer of a signal measuring device, to publish a valid procedure that allows a user to translate the level reported by the device, to the level according to the above definition. This procedure should include correction factors if required, to allow the user to measure signals in less than their full occupied bandwidths, and to correct for the occupied bandwidth. The manufacturer should provide information to allow a user to measure the level of one signal element in a sequence of signal elements in a TDMA signal, regardless of the presence or absence of other elements of the signal sequence.

It shall be the responsibility of the supplier of a system which employs any type of digital modulation, to publish the peak-to-average power ratio of that signal in a 75 ohm environment. The supplier should make the average power measurement using a meter which responds as stated above.

To aid in measuring levels of TDMA signals, the manufacturer of a TDMA system should provide at the TDMA receiver, a signal which may be used to synchronize a measuring instrument to any one element of the returning signal sequence. This may be done on a frame basis such that the measuring instrument will setup a delay to the desired signal element. Alternatively, it may be done such that the synchronizing signal appears just prior to the receipt of the signal element to be measured.

More investigation may be required to define the proper measurement conditions of more advanced modulation methods such as those involving spectrum spreading. For example, the peak-to-average ratio may be dependent on the number of signals present simultaneously in the occupied bandwidth. The manufacturer should define the peak-to-average ratio for any number of simultaneous signals (1, 2, etc.) up to the maximum allowed number of simultaneous signals.

In addition, it is necessary to further define the "peak" value of a signal. Generally the peak value reported should be that value at which the signal dwells for a long enough time that the transmission of a single symbol of any other digital signal may be affected (by clipping in any portion of the transmission system). For discussion purposes it is suggested to consider any peak that occurs for a time longer than 20% of a single symbol time for any digital signal which could be clipped.

Each of the modulation types may have different symbol rates for a given channel bandwidth. (For example, QAM and QPSK have a symbol rate approximately equal to the channel bandwidth, and VSB has a symbol rate approximately twice the channel bandwidth.)

One may find it useful to specify the percentage of time the signal remains above certain "peak" values to allow for statistical studies of clipping.

1.2 Noise Level

Definition: The definition of noise level shall be the power level of the noise as measured by a power meter which uses a thermocouple as a transducer. That is, the measurement shall be the average power in the noise, integrated over the actual bandwidth of the measurement. The noise level should be presented in decibels with respect to one millivolt RMS in a 75 ohm system (along with the measurement bandwidth). Thus, the level reported is the RMS value of a sinusoidal voltage that would produce the same heating in a 75 ohm resistor as would the actual noise level in the measurement bandwidth. (Reported noise level is often normalized to a 1 Hz bandwidth.)

1.3 Peak-to-Average Ratio

Discussion: The peak-to-average ratio of digitally modulated signals is important to the overall headroom needed to transmit these through the distribution system. The average power needs to be set high enough to provide sufficient Signal to Noise. The peaks of the signal can, if it is set too high, clip the laser or other devices (amplifiers) in the system.

When multiple signals are combined in a single system the peak voltage of the combination is not simply the addition of the peaks of the separate signals. Furthermore the total average power obtained by adding the separate average powers is not an indicator of the composite peak. See Section 1.4: “Peak Voltage Addition Tutorial” for an explanation.

The measurement of this ratio requires specialized equipment. However this parameter is not in itself adjustable in a digital modulator.

This therefore is not a parameter that needs to be measured in an operating system, but rather can be calculated.

The peak-to-average ratio should be specified by the manufacturer of the digital modulator in use. This parameter is a function of the modulation method used, and the filtering applied within the modulator.

If the peak-to-average ratio is incorrect, it is an indication of a much more serious distortion, such as a modulator problem, severe clipping or severe channel amplitude flatness distortion.

It is sufficient verification of the peak-to-average ratio to simply check the bit error rate of the channel, or the constellation measurements (such as Modulation Error Ratio, Error Vector Magnitude, Cluster Variance, or similar measurements).

These measures will be quite sensitive to any distortions that can produce an incorrect peak-to-average power ratio.

1.4 Peak Voltage Addition Tutorial

A sinusoidal (CW) carrier has a definite and well known peak-to-average ratio of 20*log{√2} or 3 dB. A composite signal made up of N equal-value, randomly phased, CW carriers will have a total average power which is 10*log{N} dB greater than the average power of a single carrier. The peaks of that composite signal add on a voltage basis and so the peak power will be 10*log{2*N^2} dB greater than the average power of a single carrier.

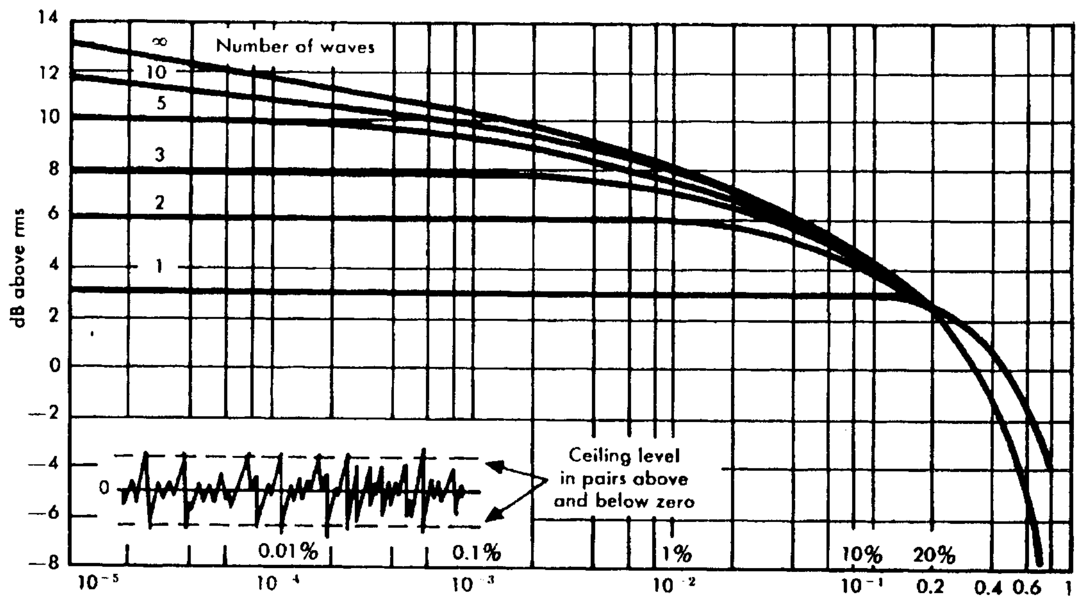
In contrast to CW carriers, typical reverse path signals, QPSK, QPR, OFDM and QAM, have significantly higher peak-to-average ratios and most have broad spectra, filling most of their allotted channel. The reverse path carries (or will carry when the reverse path spectrum becomes fully utilized) a multiplicity of such signals. Allocating individual signal levels proportional to channel width results in a composite signal with a nearly flat power spectral density and a high (about 14 to 15 dB) peak-to-average ratio similar to that of gaussian noise.

A noise-like signal has a well defined and measurable average power, but it doesn't have a distinct peak value. There can be rare, but very high, signal excursions which stress the linearity capability of amplifiers and optical components. It is necessary to define a peak value for a noise-like signal in terms of a signal level exceeded with a certain probability (or fraction of the time). The probability or the fraction of the time should be based on the tolerance of the services to transmission impairments, for example BER.

To associate some numbers with the above concepts, first consider a composite signal composed of 4 randomly phased CW carriers, each with average power, P_{av}. The average power of the composite signal is P_{av} + 6 dB. The peak power of the composite signal is P_{av} + 15 dB, and the peak-to-average ratio is 9 dB. Figure 1 illustrates how the peaks are related to the rms value of a sum of randomly phased CW carriers in terms of the probability that peaks exceed a given value. The infinite number of CW carriers case corresponds to the probability distribution for gaussian noise.

One can see in Figure 1 that a sum of even a moderate number of sinusoids approaches the gaussian noise probability distribution. The sum of digitally modulated carriers will more rapidly approach the gaussian noise probability distribution as the number of such carriers increases. A gaussian noise exceeds its average by 15 dB with a probability of 10^{-8}. In this case we would say that the peak-to-average ratio for this gaussian noise is 15 dB with the understanding that this ratio is exceeded very rarely, i.e. 10^{-8} of the time.

From the above example it can be concluded that 4 CW carrier characterization does not adequately exercise the peak signal capacity of amplifiers or optical components which are intended to carry a composite power noise-like signal. This is due to the fact that, for the same total power, the noise-like signal has peak signal excursions about 6 dB higher than those of 4 CW carriers. In addition, one should not take a 1, 2, or 4 channel video specification and assume that the power sum of the specified video levels is a proper operating point for a composite noise-like signal. The best characterization method for composite noise-like signal loading is the Noise Power Ratio (NPR) test described in Section 3.4.2.



Distribution of instantaneous amplitudes of randomly phased sine waves.

Figure 1

Notes and Hints

A reverse path composite signal comprised of several QPSK carriers will have a peak-to-average ratio less than that of gaussian noise, or less than 15 dB at a probability of 10^{-8}. For field testing purposes, a test signal comprised of 10 independent, equal level, CW carriers has a peak-to-average ratio of 13 dB. Such a test signal would stress the peak signal handling capability of reverse path active transmission components to within 2 dB of actual operating conditions.

Chapter 2: Configuration and Setup

The goal for this chapter is to provide a **setup and alignment procedure** as well as the measurement and characterization methodology to verify the proper operation of the plant.

2.1 Return Plant Setup and Operational Practices

Introduction

Although the recommended practices included in this document only refer to measurements, a prerequisite to meaningful measurements is a properly aligned plant. Therefore, the following setup and operational procedures are included as guidelines for operators. No specific operating parameters are suggested, but rather an organized process for setting those parameters.

The upstream plant differs in several critical ways from the downstream situation, even though they share the same physical distribution network. In the downstream direction, for instance, signals are usually present continuously and at well-defined power levels. The channelization scheme, bandwidth and modulation are also well-defined. Finally, each amplifier has but a single input.

In the reverse direction, by contrast, signals may be of a wide variety of bandwidths and modulation types and may be carried only intermittently and at varying power levels. Operating frequencies may vary from time to time, also. Finally, due to network splitting, each amplifier may receive signals from several inputs. All of these variable factors require that the procedures used to operate the upstream plant differ from those used in the downstream direction.

Another difference is that, while amplifiers in the downstream direction are aligned by adjusting their <u>output</u> signals to predetermined levels, in the upstream direction the plant is adjusted so that <u>input</u> signals are equal. The operator must decide whether to use the actual upstream amplifier module inputs or the external amplifier ports as the **Reference Points** for upstream alignment and setting operating levels. Figure 1 is a diagram of a typical trunk/bridger station showing the logical locations of each of the possible Reference Point choices. Each has its advantages and limitations:

<u>Amplifier Upstream Module Input Reference Point</u>

Many amplifier manufacturers use the same internal amplifier modules for all amplifier stations, regardless of the number of downstream output ports. Thus, all modules have similar noise figures, gains and signal handling capability. It can be shown that, when such stations are cascaded as they are in bridging node configurations, setting amplifier module input levels equal results in the minimum noise addition and distortion buildup.

Using this procedure, however, requires that different test signal insertion levels be used for different amplifier configurations, depending on how the upstream signals are combined internally. Also, in cases where, for instance, trunk bridger ports have a high internal combining loss in the upstream direction, higher upstream transmitter power levels will be required to adequately drive return amplifier modules. This may make drop configurations in some homes (especially those fed from high value taps near the amplifier output) more difficult, as the upstream losses must be minimized.

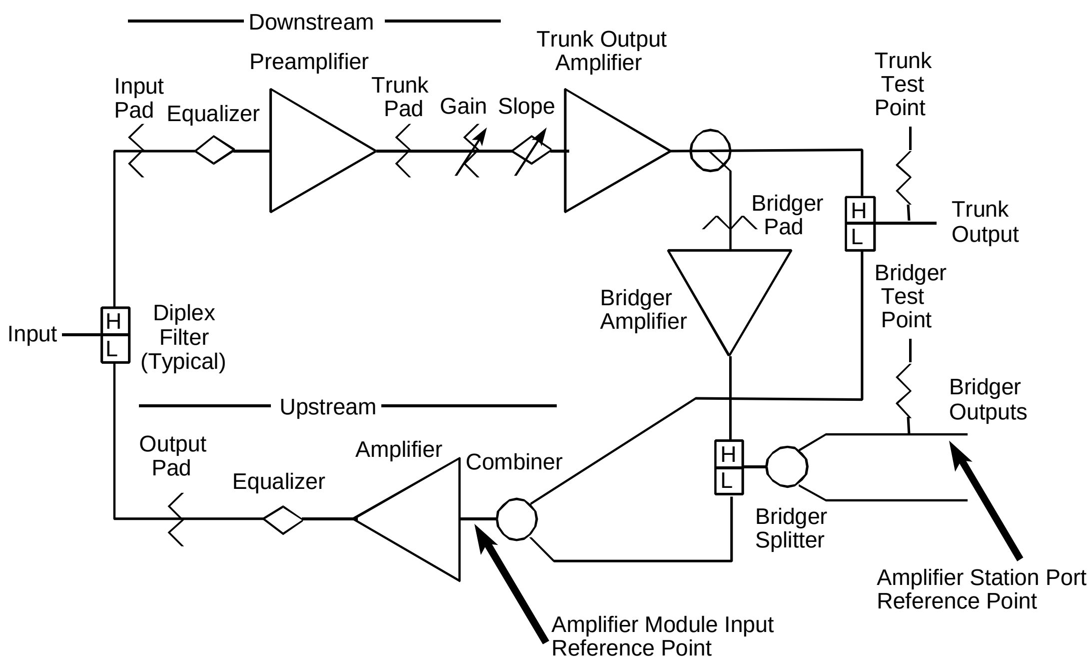


Figure 1: Typical Amplifier Station Showing Reference Point Choices

<u>Amplifier Station Port Reference Point</u>

Using one of the external amplifier output (upstream input) ports as the Reference Point has the advantage of simplicity in that test insertion levels are the same throughout the plant (assuming identical test port attenuation values), and also the advantage that upstream transmitter levels will not have to be higher in tap strings which are fed by multi-output amplifiers.

A major disadvantage to this scheme is that some upstream modules will have levels which are lower than others. For instance, a four-output system amplifier will generally have about 7 dB of additional combining loss between external ports and the upstream amplifier module. Thus, the noise contribution of this station will be five times as high as it would be if it were being driven at the "full" input level. The impact of this additional noise is, of course, dependent on the percentage of amplifiers which have multiple downstream outputs and the amount of excess loss in each amplifier.

Operators choosing to use an amplifier station port as the Reference Point should be aware of the fact that levels from all upstream input ports must be matched after internal combining in an amplifier station. This will result in external port levels which will differ by the difference in upstream combining losses.

Whichever method is chosen, operators should understand the compromises involved.

STEPS TO PROPERLY SETUP AND ADJUST THE UPSTREAM PLANT

None of the steps in properly aligning an upstream plant is unnecessarily complex, but all are essential:

1) First, each type of line equipment, including coaxial amplifiers and the fiber node equipment, must be characterized. Most critically, it is necessary to know the signal loss from the test point that will be used to inject upstream test signals to the Reference Point chosen in the last section - either input of the reverse amplifying module or the external amplifier port chosen as the reference. In the case of a simple line extender, this may be approximately equal to the test point loss (typically 20 or 30 dB) in either case, but a trunk amplifier or distribution amplifier will have additional losses to the module input due to combining of signals from several coaxial legs. Also amplifiers differ in test point losses, whether they are directional or non-directional, and the placement of test points in the circuit. Some provide separate upstream test points while others provide common test points.

   For operators choosing external port Reference Points, the input port with the highest upstream combining loss (say the bridger port or ports in a trunk/bridger station) is usually chosen as the Reference Point as this minimizes upstream transmitter level variation. In that case, the levels at ports with less combining loss (say the trunk port) will have to be reduced by the difference in combining loss. The result of this difference is that the levels of upstream signals in the trunk line will be lower than those in the distribution line. When the upstream alignment is performed at this station, either the normal test signal must be inserted at the bridger test port, or a level which is reduced by the difference in combining losses must be inserted into the trunk line test port to get the proper alignment levels in the plant.

2) Second, the operator must determine how much total input power will be allowed for all intentional signals in the return band. **This may be different for the upstream optical transmitter than for the upstream coaxial amplifiers**. Consult the manufacturers' data for this information.

   Some amplifier and optical transmitter manufacturers may specify a total power handling capability. In some cases, however, peak composite signal voltage, rather than total average power may limit levels. Refer to Section 1.4: "Peak Voltage Addition Tutorial" for a detailed discussion on choosing maximum total power levels based on maximum signal voltages.

   However it is determined, for future reference call this total amplifier input power handling capability P_1. Note that P_1 may need to be adjusted as a function of the depth of the cascade.

See Table 1 and Figure 2 for a summary of the power relationships and references used in this section.

System Location	Total Power Handling Capability	System Test Signal Level	Specific Upstream Service Signal level
Amplifier Input Reference Point	P_1	P_3	P_5
Upstream Optical Transmitter Input	P_2	$P_4 = P_3 - (P_1 - P_2)$	
Headend Optical Receiver Output	P_8	$P_9 = P_8 - (P_2 - P_4)$	$P_6 + A$
Headend Optical Receiver Test Point		P_0	$P_6 = P_0 - (P_3 - P_5)$
Specific Service Data Receiver Input			P_7
Headend Optical Receiver Test Point Attenuation: $A = P_9 - P_0$			
Required Gain from Headend Optical Receiver to Specific Service Data Receiver Input: $B = P_7 - (P_6 + A)$			

Table 1: Level References and their Relationship

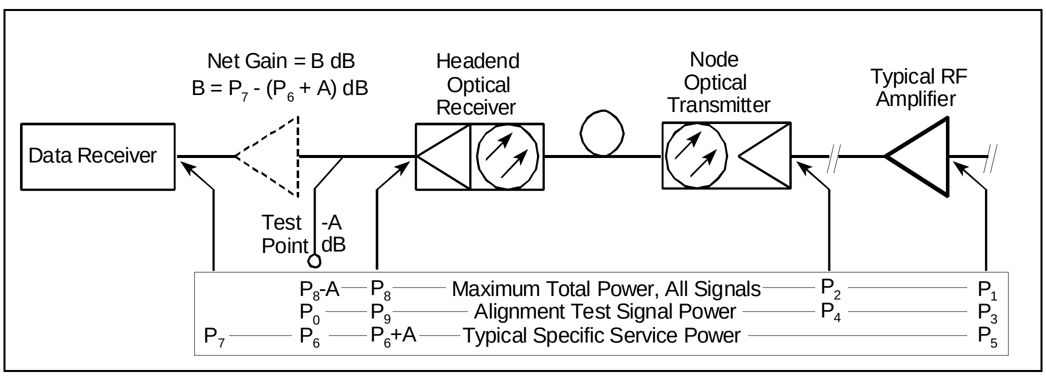


Figure 2: Symbolic Diagram of Upstream Showing Level Reference Points

Upstream laser transmitters vary more than coaxial amplifiers in their recommended input power, with some rated for a single carrier and others for four or more. This is due partially to the different transmitter technologies used: Fabry-Perot (FP) vs Distributed Feedback (DFB) lasers, cooled vs uncooled and optically isolated vs non-isolated. Call the total input power handling capability of the laser transmitter P_2 in dBmV. **P_2 may or may not be equal to P_1.**

Finally, headend optical receivers may have post amplifiers with limited power handling capability. Since optical losses of links will vary, setting optical transmitter input levels may not be sufficient to guarantee that the headend optical receiver output level will be non-distorted. Therefore, the total output power handling capability of the headend receiver must also be determined based on the manufacturer's ratings. This tutorial will refer to receiver total output power capability as P_8.

The consequences of designing for too much total input (and therefore output) power is that distortions will be excessive, including both intermodulation distortion and laser clipping. Additionally, non-intentional signals such as ingressing carriers and electrical transients will be more likely to drive the system into saturation. If the total power is set too low, then individual signals will be received at the headend with unnecessarily degraded carrier-to-noise ratios.

Note also that one reason that the total power level must be set well below the limiting level for a single carrier is that the peak voltage levels with multiple signals will be higher than that from a single signal, and the peak-to-average ratio will increase with the number of signals and will be higher for some types of modulation than for others. Thus, operators may wish to set the total power limit based on a probability density analysis related to clipping-level voltage rather than simply total average power. Note that P_1 may need to be adjusted as a function of the depth of the cascade. Alternatively, the total power level can be selected based on the results of a Noise Power Ratio test (see Section 3.4.2). For more information on peak-to-average ratios, see sections 1.3 and 1.4.

3) Pick standard reference levels at the upstream Reference Points and upstream laser transmitter input which will be used for system alignment.

   A common industry practice is to use +20 dBmV at amplifier Reference Points (external ports or module inputs), but operators may choose to use some other value. Whatever level is chosen, the total test signal power should be at or below the total input power loading value, P_1, chosen above and sufficiently above the system noise so that accurate results can be obtained. This section will refer to this test level as P_3 in dBmV

   The reference input level for the laser transmitter should differ from the amplifier level by the difference in the total input power levels chosen in step 2. For example, if the total input power for the amplifier modules is to be +26 dBmV and the total input power for the upstream transmitter is to be limited to +16 dBmV, the difference in reference test power levels must be 10 dB. Thus, if +20 dBmV is chosen as the reference level for alignment of the coaxial amplifiers, then the reference level at the return laser input must be +10 dBmV. This tutorial will refer to the laser test reference input level as P_4 in dBmV. Mathematically,

$$P_4 = P_3 - (P_1 - P_2).$$

4) The first step in system alignment is to insert a signal within the node so that the return laser is driven at the P_4 level. This signal may consist of a single carrier,

several carriers, or a sweep signal. As with downstream testing, sweep signals will allow more accurate alignment and reveal problems that may not be apparent if testing is done at only a few frequencies, while use of multiple, unmodulated carriers will allow direct observation of distortion products.

Depending on the design of the node, it may be possible to inject the test signal directly into the upstream optical transmitter, possibly by removing a jumper cable. In other cases, it may be necessary to use the node forward path output test point. In the latter case, if this is the initial alignment of a new upstream system, all other inputs to the laser transmitter should be disconnected. The best method of doing this is to insert high values of output pads in all the return amplifiers directly driving the node. This preserves the impedance matches on all the lines. Isolating the node allows the performance of the upstream optical link to be evaluated independently from the coaxial distribution system.

5) Evaluate the signal at the headend upstream monitoring point for the node being tested. If the node has been isolated, as described above, the fiber optic link can be tested for its noise contribution, amplitude flatness and other parameters in this step. Note that if the C/N is to evaluated relative to manufacturer's specified performance, it will be necessary to correct for any level difference between the test signal and the specified operating conditions and also to measure noise in the specified bandwidth.

6) Measure the upstream receiver output level. If the optical receiver/post amplifier provides the means for adjusting internal gain, either through adjustments or plug-in pads, set the receiver output level, P_9, so that it will be operating optimally under conditions of full signal loading. This level can be determining as follows:

$$P_9 = P_8 - (P_2 - P_4)$$

This adjustment compensates for the variation in upstream link losses.

If the optical receiver output is not adjustable, then measure the upstream output level P_9 and calculate what the output level P_8 would be if an upstream amplifier were driven with a single carrier whose level was equal to the full input power handling capability of the amplifier, $P_{1:}$

$$P_8 = P_9 + (P_2 - P_4)$$

7) Carefully measure and record the level of the signal(s) or sweep trace at the headend monitoring point. This reference level, which will be lower than P_9 by the attenuation of the test coupler, A dB, will be used for all subsequent node alignment. Call this level P_0.

8) Restore the node to normal operating conditions.

9) Align the coaxial distribution plant, working <u>from the node outwards</u> (beginning with the node itself, unless the node output test point was used to insert the test signals in step 4), using the following procedure at each amplifier station:

- First, insert a test signal into the reverse insertion point determined in step 1) above. The inserted signal should have a level such that the power at that amplifier's Reference Point will be P_3. For example, if a given line extender has an actual loss of 31 dB from the common output test point to the Reference Point and the P_3 level is chosen to be +20 dBmV, then the inserted test signal(s) should be at a level of +51 dBmV.

- Now adjust the upstream output pad and equalizer for the station being tested so that the headend monitoring point signal is just equal to P_0. This is most conveniently done if the field technician can directly observe the signal at the headend. Special purpose upstream sweep equipment provides this visibility by transmitting that information back to a combination test signal generator/display that the technician uses. Lacking that, some spectrum analyzers provide an NTSC video output representation of their screen display which can be connected to a modulator on a spare downstream channel. Then the field technician can use a portable television set to observe the headend signal.

- Continue to the next downstream amplifier in cascade. Where the network splits, amplifiers can be done in any order, so long as all amplifiers in the direct path between the amplifier being aligned and the node are done first.

If this procedure is followed correctly, the result will be that the signal level at the chosen input Reference Point of every amplifier between any insertion point and the node will be identical, and that the upstream optical transmitter levels (assuming an HFC plant) will differ from the Reference Point levels by exactly the difference in total allowable input power. If the chosen Reference Point is the upstream amplifier module inputs, it also results in each amplifier contributing equally to the total thermal noise in the system.

CHOOSING OPERATING LEVELS FOR SPECIFIC SERVICES

The next step is choosing the operating level for the various services which will share the upstream transmission path. This is simple if just one service is contemplated, as signals can be run anywhere between where C/N is adequate and where the signals are unacceptably compressed. In the more general case, however, the operator may want to retain future flexibility by assigning power levels to each service in such a way that the total power is below the power handling capability of the amplifiers and upstream optical transmitter unless the entire usable bandwidth is occupied.

While there is no general industry agreement on how much power to allocate to each service, one popular method is to assign power on the basis of occupied bandwidth, sometimes called "Constant Power per Hz." Since the thermal noise power in a given channel is also proportional to bandwidth, this results in all services experiencing the same C/N ratio, provided that:

- The noise power is flat across the return spectrum, and
- The noise susceptibility bandwidth of each service is the same as its occupied bandwidth.

Performance with respect to discrete interfering carriers is more difficult to predict. To the extent that ingressing carriers are randomly distributed with respect to both frequency and level, the probability of an ingressing carrier falling within the susceptibility bandwidth of a service occupying a narrow bandwidth will be lower, however any ingressing carrier will be larger relative to the desired signal, due to the lower assigned signal level. Thus the overall probability of interference will be dependent on the statistical distribution of interfering signals and may be better or worse for narrow-band, lower-level signals.

As an example, if the total amplifier input power, P_1, is equal to +26 dBmV and the usable return system bandwidth is 35 MHz, then the allowable power density is

$$+26 - 10 \log (35 \times 10^6) = -49.4 \text{ dBmV/Hz.}$$

A upstream signal occupying a 2 MHz band would then be run at a level of

$$-49.4 + 10 \log (2 \times 10^6) = +13.6 \text{ dBmV.}$$

While this seems an inherently “fair” method of power allocation among services, it has its limitations:

- As discussed previously, and in more detail in Section 1.4, upstream signal levels are primarily limited by peak voltage excursions, rather than total input power. Thus, a single unmodulated carrier may have the same average power as ten modulated carriers carried at 10 dB lower level, but will generally have a much lower peak voltage. In recognition of this, the maximum total power used in the above calculation must include a defined “headroom” for peak-to-average voltage ratio, or the maximum total power should be determined with a signal that has a high peak-to-average voltage, such as band-limited noise.

- While the thermal noise floor may be nominally independent of frequency, the sum of noise, distortion products and ingress is certainly not, with the result that some frequencies are more degraded than others.

- Not all services may use the same modulation scheme, and thus may require different C/N ratios. A simple frequency shift keyed (FSK) modulated carrier, for instance, is more robust than a 16 level quadrature amplitude modulated (16 QAM) signal. Logically, therefore, we should operate the latter signal at a higher level to get comparable performance.

- Not all services will tolerate the same error rate. Voice telephony signals, for instance, typically offer no opportunities to recover from lost data, while Internet data packets can be re-transmitted if damaged. Similarly, some protocols may include forward error correction (FEC) which is able to correct some errors.

- Services utilizing frequency agile upstream transmitters (as a means of moving away from potentially interfering ingress signals), may be assigned exclusive use of a portion of the upstream spectrum which is much greater than the channel bandwidth. The difference between channel bandwidth and service bandwidth will not be used for services and, thus, carrier levels could be higher.

Whatever method is used, the signal of each service should be assigned a power level at the amplifier input Reference Point. Call this level for a given service P_5.

DETERMINING UPSTREAM TRANSMITTER DYNAMIC RANGE

Once an operating level is defined for a given service, the upstream transmitters, installation configurations and plant design must be analyzed to make sure that the desired levels are achievable.

In the downstream direction, it is common to set signal levels at all subscriber taps nominally the same (with a tolerance for available increments of tap values and for the unavoidable variations across the spectrum). Part 76.605(a)(3) through 76.605(a)(5) of the FCC's rules set the allowable limits on levels of downstream analog video signal levels and their variations. Part I.C. of this book covers measurement techniques for determining compliance with those rules.

Since the loss of both passive components (usually) and coaxial cable (always) increase with frequency, the upstream loss from subscriber's outlets back to the last amplifier station will be less than the loss for the downstream signals. Not only that, but the loss from subscribers who are more distant from the last amplifier may be much less (as much as 20 dB) than from subscribers fed from the first tap. If upstream amplifier module inputs, rather than external ports, are chosen as the Reference Points for system alignment, then an additional variation will result from the variation in internal amplifier losses in the upstream path.

The total loss from upstream transmitter to amplifier input reference point should be analyzed over the full range of expected configurations to determine the required transmit levels. If these are not within the range of the selected terminal equipment, then either plant, drops, terminal equipment or operating levels must change. Some options for reducing the required upstream transmit range are:

- Selectively replace high value taps with lower values to lower maximum required upstream transmit levels

- Install in-line equalizers to increase the minimum required upstream transmit levels. In new designs, avoid low value taps for the same reason and also to reduce the sensitivity to ingress.

- Where allowed by adequate downstream signal levels, use unequal splitting arrangements in houses to favor the data transmitter and thus lower the maximum required upstream transmit levels.

- Selectively deploy drop amplifiers with two-way gain to lower maximum required upstream transmit levels.

Where it is not practical to reduce upstream losses sufficiently that transmitters will be able to reach amplifier input reference points at the desired level (P_5) under extremes of temperature and operating variations, then either different terminal equipment should be selected or the operator must accept a lower-than-optimum system operating level for the service supplied through the selected equipment. If the level must be lowered, the C/N and carrier-to-ingress ratios will be degraded relative to optimum transmission conditions in the upstream system, though they may be adequate for the service in question. The amount by which the level needs to be lowered will depend, at least in part, on the tolerance of the headend data receivers to varying input levels.

SETTING UPSTREAM RF TRANSMITTER LEVELS

Upstream transmitter levels must vary from transmitter to transmitter if the system operating levels are to be uniform. If transmitted levels are all the same, as is the case with some two-way set-top boxes, then the signal from some homes may cause severe overloading, while others are so low as to be noisy when received at the headend. This was sometimes tolerable when two-way boxes were the only users of the upstream system, used FSK modulation which is unaffected by signal limiting, and were polled to prevent more than one box from transmitting at a time. It is clearly a problem when multiple services will share the spectrum and are required to not interfere with each other.

Many modern upstream transmitters are agile in power level and controlled from the headend so that their levels as received in the headend data receiver are approximately the same. Setting up such a system is discussed in the next section. Where transmitters are fixed in power, they must be adjusted or padded externally so that the levels received at the headend are appropriate for the service. The proper headend test point level, P_6, for a service whose amplifier input operating level is P_5 (see previous section) is

$$P_6 = P_0 - (P_3 - P_5).$$

For example, if the headend test point level was +12 dBmV when the system was aligned with a Reference Point signal of +20 dBmV and the desired operating level for a given service is +5 dBmV at the same point, then the corresponding headend test point level used to set the upstream transmitters should be $P_6 = +12 - (20-5) = -3$ dBmV.

SETTING UP SYSTEMS UTILIZING POWER-AGILE TRANSMITTERS

If upstream transmitters have a transmit level that is controlled by the headend data receiver (resulting in a condition known as a “long loop AGC”), as is common with cable modems and telephony systems, then the headend must be carefully configured if the proper operating levels are to result. In order to do this, the operator must understand all the losses and gain stages between the headend optical receiver output and the headend test point and the data receiver input. In particular, if the loss from the headend optical receiver output to its test point is A dB, then the actual optical receiver output level corresponding to test point level P_6 is P_6 + A dBmV. If the data receiver will control all upstream transmitters so that they hit the receiver at level P_7, then the operator must assure that the net signal gain, B, between each optical receiver output and data receiver input is

$$B = P_7 - (P_6 + A) \text{ dB}$$

(if the result of the calculation is negative, then attenuation must be inserted, rather than gain).

Note that, unless all optical receivers were adjusted to equal test signal outputs in step 6, the net gain between each optical receiver and its corresponding data receiver must be independently adjusted.

If too much gain is inserted between the optical receiver and the data receiver, the result will be lowered signal levels for that service in the plant and degraded C/N. If too little gain is inserted, the result will be that the upstream transmitters will be turned up too high and may overload the plant.

SUMMARY

Although this process may seem complex, the steps are individually quite simple:

- First, determine the power handling capability of the upstream amplifiers, optical transmitter and headend receiver (assuming the system is an HFC network, otherwise only the amplifier capabilities need be considered).

- Second, pick a test level for alignment and set all amplifiers such that the input levels in the aligned plant are equal and the input to the upstream optical transmitter differs from the amplifier levels by the proper amount;

- Third, assign a power level to each carrier that optimally allocates the total system power handling capability among services. Where the selected upstream transmitters are unable to reach the optimal power from all locations, a lower level may be assigned to the service, at the expense of reduced C/N and carrier-to-interference ratios.

- Fourth, for manually adjusted upstream transmitters, adjust transmit levels so that the headend received levels are appropriate for that service;

- Fifth, for headend-controlled upstream transmitter power levels, adjust the net gain or loss between the optical receiver output and data receiver input so that the plant levels will be correct when the upstream transmitters are controlled by the data receiver.

If these procedures are followed, the plant will operate optimally, with the services operating in a mutually non-interfering manner, while obtaining the maximum possible C/N consistent with adequate headroom to accommodate operating variances and ingressing signals.

2.2 Upstream Noise Prediction

Description: The noise power in a 4 MHz bandwidth from a 75 ohm resistor into a 75 ohm load (which has no noise of its own) at 68 °F is -59 dBmV.

Noise Power (dBmV/Hz)

$$= -59 - \left[10 \times \mathrm{Log}(4 \times 10^6)\right] = -125 \text{ dBmV/Hz}$$

Total Noise Power

$$\mathrm{N}_{\mathrm{TH35}} = -125 + \left[10 \times \mathrm{Log}\left(\mathrm{BW_T}\right)\right] = -125 + \left[10 \times \mathrm{Log}\left(35 \times 10^6\right)\right] = -49.6 \text{ dBmV}$$

where:

$\mathrm{BW_T} =$ the total upstream bandwidth (35 MHz in this example)

$\mathrm{N}_{\mathrm{TH35}} =$ the thermal noise in a 35 MHz bandwidth

RF Coaxial Amplifier Noise

If, in the coaxial portion of the network, the return amplifiers have equal noise figures of 10 dB, the equivalent input noise power will be -39.6 dBmV. For a 32 amplifier configuration, the amplified thermal noise power funneled by the coaxial portion can be calculated using the following equation:

$$N_{COAX} = N_{TH35} + NF + \left[10 \times Log(M)\right] = -49.6 + 10 + \left[10 \times Log(32)\right] = -24.6 \text{ dBmV}$$

where:

$\mathrm{N}_{\mathrm{COAX}} =$ the total amplifier noise power at the node station input

$\mathrm{NF} =$ the amplifier noise figure

$\mathrm{M} =$ the total number of amplifiers in the node

This is an increase of 15 dB at the input of the upstream node.

The above example assumes all amplifiers have the same noise figure. In the more general case, several different station configurations, each with a different noise figure, may exist in a node. In addition, the effective noise figure of a station will depend on whether the Amplifier Upstream Module or the Amplifier Station Port was chosen as the alignment reference point (see Section 2.1: “Return Plant Setup and Operational Practices” for more details). Assuming that several station types exist and that all noise figures are calculated relative to the reference point, the total noise contribution can be calculated as follows:

1. Calculate the input noise power of each station type using the following equation:

$$\mathrm{N_X} = -125(\mathrm{dBmV/Hz}) + 10 \times \mathrm{Log}\left(\mathrm{BW_T}\right) + \mathrm{NF_X}$$

where:

$\mathrm{N_X} =$ the input noise power of an upstream amplifier station type

$\mathrm{BW_T} =$ the total upstream bandwidth

$NF_X =$ the noise figure of an upstream amplifier station type (specified or calculated relative to the reference point used for alignment)

2. Calculate the total noise contribution of the coaxial plant using the following equation.

$$N_{COAX} = 10 \times \mathrm{Log}\left[\left(M_1 \times 10^{\frac{N1}{10}}\right) + \left(M_2 \times 10^{\frac{N2}{10}}\right) + \left(M_3 \times 10^{\frac{N3}{10}}\right) + \ldots\right]$$

where:

$N_{COAX} =$ the total amplifier noise power at the node station input

$N_1, N_2, N_3 \ldots =$ the input noise power of each upstream amplifier station type

$M_1, M_2, M_3 \ldots =$ the quantity of each corresponding upstream amplifier station type

Optical Link Noise

The actual noise power at the output of the optical link is the total coaxial noise combined with the upstream optical link noise. The optical link noise is not subject to funneling additions and must be determined independently from measurements or manufacturer's specifications. The combining must also take into consideration the difference in total power between the coaxial portion, and the laser transmitter input.

In order to add the optical link noise to the RF coaxial amplifier noise, the optical link noise will be calculated as if it occurred at the node station input. An estimate of the noise contributed by the optical link can be made using the following equation.

$$N_{OPT} = C_2 - (C/N)_2 + \left[10 \times \mathrm{Log}\left(\frac{BW_T}{BW_2}\right)\right] + (P_1 - P_2)$$

where:

$N_{OPT} =$ the total equivalent input optical noise power (in dBmV) normalized to the node station input.

$C_2 =$ the laser transmitter input signal power (in dBmV) for a specified or measured C/N ratio

$(C/N)_2 =$ the specified or measured C/N ratio for some bandwidth and the C_2 signal power

$BW_T =$ the total upstream bandwidth which is the same as used for the coaxial analysis

$BW_2 =$ the bandwidth under which the reference C/N was measured or specified

$(P_1 - P_2) =$ the difference between the coaxial reference point and laser transmitter inputs, respectively. Note that the terms P_1 and P_2 are fully defined in Section 2.1: "Return Plant Setup and Operational Practices".

The $(P_1 - P_2)$ factor is required to normalize the optical noise power for the difference in operating levels in the coaxial amplifiers versus the laser transmitter.

Combined Noise (Coaxial and Optical)

With the normalized optical noise determined, the total equivalent input noise can be calculated using:

$$N_T = 10 \times \mathrm{Log}\left[10^{\frac{N_{COAX}}{10}} + 10^{\frac{N_{OPT}}{10}}\right]$$

where:

$N_T =$ the total equivalent noise power normalized to the node station input.

$N_{COAX} =$ the total amplifier input noise power at the node station input.

$N_{OPT} =$ the total equivalent optical input noise power as determined above.

Figure 1 is a plot of the total noise power for different quantities of amplifiers and compares the coaxial noise (N_{COAX}) calculated earlier with the combined coaxial and optical noise. This example assumes the optical link performance is approximately equivalent to a 10 amplifier cascade (N_{OPT} is equal to -29 dBmV). An additional trace has been provided with 10 dB of noise in excess of the thermal noise in the coaxial portion of the network.

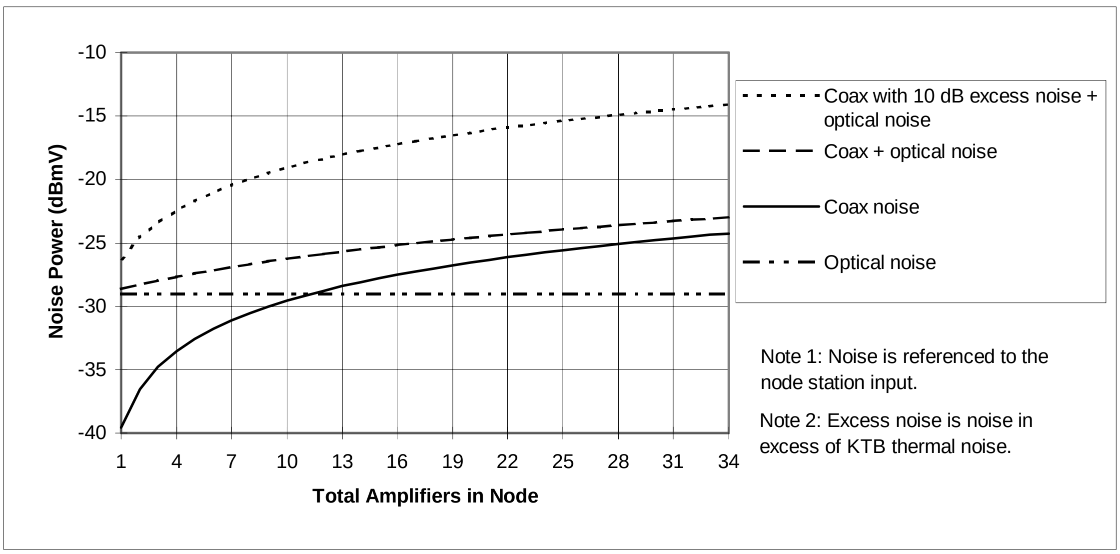


Figure 1 - Return Noise Power Considerations (35 MHz BW)

If channel power is allocated per Hz, then for any given bandwidth channel, the carrier to noise ratio (which can be directly related to the modulation error ratio or BER) is nearly the same as the total power to total noise ratio as long as total noise is at least 10 dB lower than total power. The low power operating limit will be a function of amplifier noise funneling and the upper operating limit will come from laser clipping or amplifier compression. If the total link noise is calculated as above, then C/N of any service can be determined once the network size, characteristics of the amplifiers and optical link, and operating levels are known.

Chapter 3: Measurement Procedures

3.1 Signal Level

3.1.1 Continuous Signals

Definition: See Section 1.1: "Signal Level".

METHOD 1 - Manual Spectrum Analyzer Method (estimation)

Discussion: This procedure applies to digitally modulated signals which are "noise-like".

Required equipment

- Spectrum Analyzer with 75 ohm input.

Test procedure (1)

Set the spectrum analyzer to a resolution bandwidth that is between approximately 1/20 and 1/100 of the expected channel occupied bandwidth. (If the channel is 6 MHz wide, then between 60 and 300 kHz would be useable.)

Set the analyzer to display a frequency span that is a bit wider than the channel width. (For a 6 MHz channel, a span of 10 MHz would be fine.)

Note the actual transmitted noise bandwidth of the digital signal. This is the 3 dB bandwidth of the transmitted signal (See Notes below).

Set the spectrum analyzer for the center frequency of the channel and set it for zero span with sample detection. Now note the signal power as measured by the spectrum analyzer at the middle of the channel.

The power of the digital signal can now be estimated using two calculations.

First the power measured in the middle of the channel must be multiplied by the ratio of the noise bandwidth of the signal divided by the noise bandwidth of the resolution filter in the spectrum analyzer. (Use the information supplied by the spectrum analyzer manufacturer for its filter.)

Second there is a correction to be added to the measured power to correct for the log and detector response of the analyzer. (Again use the information supplied by the manufacturer.)

Notes

This method will produce an erroneous answer if the desired signal power is not flat across the channel bandwidth. The error will depend on the flatness of the channel being measured. If (for example) the signal being measured was 6 dB down at both edges of the modulation sidebands, and had relatively flat slope from the center to these edges, the error would be 3 dB, and if it were 3 dB down at the edges, then the error would be only 1.5 dB. These examples are unlikely to be found in practice but are easy to calculate for an example. If the signal were to be 3 dB high at one edge of the channel, and 3 dB low at the other edge (a simple slope down with increasing frequency for example) the errors cancel themselves and the measurement at the middle of the channel gives the correct answer.

The noise bandwidth of the transmitted signal is the bandwidth which would have been occupied had the signal been filtered by a rectangular filter instead of the smooth filter actually used. Since the filter used is a root-Nyquist filter, the portion of the signal that is removed by the smooth filter skirts inside the 3 dB points is exactly the same amount as the power that passes through the filter skirts beyond the 3 dB points. The equivalent noise bandwidth is therefore the 3 dB bandwidth.

METHOD 2 - Partially Automated Method

Discussion: This procedure applies to digitally modulated signals which are “noise-like”.

Required equipment

- Spectrum Analyzer with 75 ohm input, and a "Noise Measurement" marker.

Test procedure (2)

Set the spectrum analyzer to display the signal to be measured. Place the Noise Marker in the middle of the signal. Enable the noise marker as per the analyzer manufacturer’s instructions.

This Noise Marker will automatically perform the necessary corrections, and will usually provide a "per Hertz" power measurement readout.

Now it is only necessary to multiply the power reading by the channel noise bandwidth (the 3 dB Bandwidth, in Hertz) to find the total desired signal power.

Notes

This method still requires the desired signal to have a flat spectrum to avoid large errors.

The span control of the spectrum analyzer should be set so that the digitally modulated signal occupies most of the screen. On some spectrum analyzers the “noise-measurement” takes data from points around the marker frequency, not just at the marker.

METHOD 3 - Fully Automated Measurement

Discussion: This procedure applies to digitally modulated signals which are "noise-like".

Required equipment

- A Spectrum Analyzer or SLM that has an internally automated measurement that integrates the full power in the channel.

Test procedure (3)

This instrument will make all corrections automatically including any corrections needed for a channel that is not spectrally flat. When using an SLM with a Digital Channel measurement mode, simply measure the channel power in accordance with the instructions provided by the SLM manufacturer.

Follow the manufacturer's recommendations about adjacent channels (if any) while making the measurement.

3.1.2 TDMA Signals

Definition: The level of a TDMA signal is defined in Section 1.1: "Signal Level". For the discussion of the measurement of TDMA signals, the signals will be separated into two basic types.

TDMA (Time Division Multiple Access) - Narrowband Modulation refers to intermittent signals from multiple sources with a modulation bandwidth narrower than the resolution bandwidth of the measuring device. These are typically FSK type set-top signals and may be measured using normal peak hold methods.

TDMA (Time Division Multiple Access) - Wideband Modulation refers to intermittent signals from multiple sources with a modulation bandwidth wider than the resolution bandwidth of the measuring device. Accurate measurement of wideband signals requires the mathematical integration of multiple sample points across the bandwidth of the signal.

Discussion: The procedures presented here will not distinguish between signals from multiple signal sources in a sequence, and will typically measure the level of the highest powered carrier in the sequence. In order to measure the level of a signal from a specific source in a sequence of TDMA signals, a gating trigger is required which is unique to that signal. This gating signal is currently not available from most headend data receivers. Ideally, the specific signal to be measured should be isolated prior to measurement.

Three different methods will be discussed in the following procedures. Methods 1 and 2 use readily available test equipment without IF or video gating capability. The disadvantage of this approach is that the procedure is more difficult to optimize for minimization of measurement errors and will normally produce a less accurate result. The last method discusses spectrum analyzers with various types of triggered gating capability allowing the use of dedicated average power measurement algorithms internal to the analyzers. This last method is the most accurate but also requires referencing the test equipment manufacturer's measurement procedures due to the uniqueness of each approach. This document has attempted to summarize the key steps to the measurement.

This document does not discuss some of the newer test equipment currently available which have specific TDMA measurement algorithms available. It is up to the user to determine the viability and accuracy of these approaches.

Each method discussed below recommends the use of an optional channel selection filter. This filter is used to reduce the total power into the analyzer in order to minimize distortion in the analyzer's front end when measuring low level signals in the presence of higher level signals. This filter is recommended when the upstream path is loaded with many different types of signals at differing levels and the user is attempting to measure one of the lower level signals.

Non-Gated Measurements

Method 1 - TDMA Measurements with a signal level meter: A signal level meter (with a peak hold function) may be used to measure a single point at the center frequency of the TDMA signal and the result adjusted for bandwidth and additional corrections associated with the use of the peak detector in the meter. If the signal is nearly flat across its passband and the proper correction factor is used, this method is capable of providing a result within ±2 dB.

Required equipment

- Signal level meter with a known IF resolution bandwidth

Optional equipment

- Bandpass filter for channel selection

Procedure

1. Set the signal level meter as follows:

• Center Frequency	Channel center frequency
• IF Resolution Bandwidth	Maximum (if adjustable)
• Detector Mode	Peak Hold
• Video Filter	Maximum (if adjustable)

2. Allow enough time for the peak of the signal to be captured.
3. Record this level which is the measured level.
4. Adjust the measured level using the following equation:

$$\text{Channel Power (dBmV)} = \mathrm{dBmV_{Meas}} + \left[10 \times \mathrm{Log}\left(\frac{\mathrm{BW_{CH}}}{\mathrm{BW_{Meas}}}\right)\right] + \mathrm{K}$$

where:

$\mathrm{dBmV_{Meas}} =$ measured level
$\mathrm{BW_{CH}} =$ bandwidth of the TDMA carrier (in Hz)
$\mathrm{BW_{Meas}} =$ IF resolution bandwidth of the signal level meter (in Hz)
$\mathrm{K} =$ correction factor provided by the signal level meter manufacturer (in dB)

Note: This correction factor (K) should compensate for the following discrepancies and will be unique for each type of modulation:
- peak detector used for an average power measurement
- log amplifier response when measuring noise like signals
- IF resolution bandwidth noise equivalent bandwidth
- video filter

This correction factor should be provided by the manufacturer of the test equipment used, or may be generated by the user using the following procedure.

1. Measure a reference continuous digital carrier using the above procedure.
2. Measure the same carrier using a calibrated average reading power meter.
3. The difference between the two measurements is K.

K = reference average power meter result - SLM result

Ideally, this calibration should be done on each meter since the RBW, VBW, and peak detector response will vary from unit to unit.

It should be noted that some signal level meters are currently available with automated TDMA power measurements and provide an accurate integrated measurement on TDMA signals. These meters simplify this procedure and should be used following the manufacturer's recommendations.

Method 2 - TDMA Measurements with a spectrum analyzer: The spectrum analyzer allows the RBW to be set to the optimum bandwidth for the width of the carrier being measured and provides an accurate measurement of the skirts of the carrier. This optimum resolution bandwidth is between 1/20 and 1/100 of the carrier bandwidth. By triggering a zero span spectrum analyzer on the detected signal (in sample detection mode), the power spectral density of the pulse can be measured. Using the normalized 1 Hz power density (using the marker noise function available on many analyzers), and the 3 dB bandwidth of the signal as an approximate noise equivalent bandwidth of the signal, fairly accurate approximations of the channel power can be made.

In order to make this measurement, the user must have an approximate knowledge of the TDMA burst pulse width being measured, and the TDMA burst repetition rate (the number of times the pulse occurs per second). If the burst repetition rate is not known, it can be measured by observing the TDMA signal in zero span on the spectrum analyzer while adjusting the sweep rate until at least two burst pulses are displayed in single sweep. If multiple signal sources are present in the same channel, it may be possible to set the analyzer to trigger on the largest signal. For simplicity, this procedure assumes only one signal source is present. Once at least two burst pulses are displayed on the screen, the spectrum analyzer markers can be used to measure the time between pulses. This is the burst repetition rate.

Required equipment

- Spectrum Analyzer with a variable resolution bandwidth, noise marker functionality, and known frequency response.

Optional equipment

- Bandpass filter for channel selection

Procedure

1. Setup the equipment as shown in Figure 1.

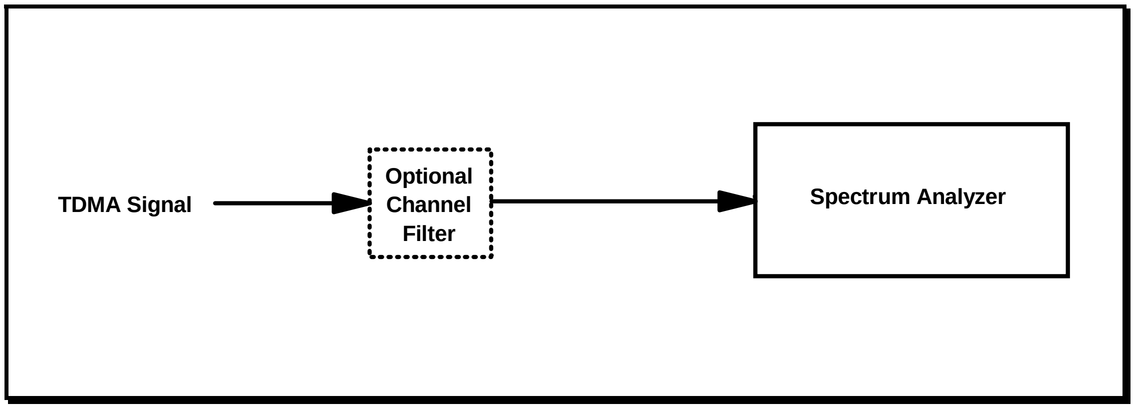


Figure 1. Spectrum Analyzer Measurement Setup

2. Set the analyzer as follows to measure the 1 Hz channel power:
   - Center Frequency   Channel center frequency
   - Scan Width   0 MHz
   - Sweep Time $\approx 2 \times \tau_W$
   - IF Resolution Bandwidth $\approx \dfrac{4}{\tau_W}$
   - IF Video Bandwidth   Maximum
   - Video Detector Mode   Sample
   - Trigger Mode   Video

   where:
   $\tau_W =$ the minimum TDMA burst pulse width

3. Adjust the trigger level until the pulse can be clearly seen, and the screen is continually triggering. The pulse will occupy approximately half of the horizontal display screen when capturing the minimum pulse width. Varying pulse widths will cause the portion of the screen to the right of the minimum pulse to fluctuate more in level as averaging progresses

4. Set the video averages to 500 (or large enough number to get the stability desired) and wait for the averaging to complete.

5. Place a marker on top of the displayed pulse and select the marker noise function. Note that the marker value is in dBmV/Hz. This value should be recorded for use in Step 8.

6. Readjust the analyzer for the following settings to measure the channel bandwidth:
   - Scan Width $\approx 2 \times BW_{CH}$
   - IF Resolution Bandwidth $\approx \dfrac{2}{\tau_W}$ (Round down to the next available value)

- Trigger Mode — Free Run
- Video Averaging — Off
- Sweep Time — $\geq 400 \times \tau_R$
- Video Detector Mode — Peak Detect

where:

$\tau_W =$ TDMA burst pulse width

$\tau_R =$ TDMA burst repetition rate

$BW_{CH} =$ Channel bandwidth

7. Turn the video averaging back on. (Note: some analyzers may need to be reset to peak detect mode).
8. Determine the approximate 3 dB bandwidth of the resultant signal.

The approximate channel power can be calculated from:

$$\text{Channel Power (dBmV)} = dBmV_{Hz} + 10 \times Log(BW3dB_{CH})$$

where:

$dBmV_{Hz} =$ the noise power measured with the marker in step 5.

$BW3dB_{CH} =$ the 3 dB channel bandwidth (in Hz) measured in step 8.

This method can be used for pulse times as short as 4 uSec and is typically accurate to within ±2 dB depending on the spectrum analyzer used.

Gated Measurements

There are several different methods that may be used to measure TDMA carriers if a spectrum analyzer is used with video gating capability. Video gating connects the detected RF to the sampling circuitry in the analyzer for a user controlled period of time (the gate time). The trigger for this gating signal can be generated internally by the analyzer's own video circuitry, or may be generated externally and connected to the analyzer, typically via a rear panel connector. Internal video gating circuitry is relatively new, and therefore the procedure for making a burst measurement with video gating tends to be analyzer specific. It is our recommendation that the user contact the analyzer's manufacturer for their specific TDMA burst carrier measurement procedure. What we will do here is summarize a typical gated procedure to help describe the process.

A narrow video gate can be used to approximate sample detection if the length of the gate (in µSec) is short relative to the occurrence of modulation peaks of the signal. In other words, the gate must be short enough that an amplitude peak of the signal is not captured with each sample. With a noise like signal, a gate length of < 20 µSec will provide results very close to true sample detection. By carefully adjusting the spectrum analyzer sweep time, resolution bandwidth, video bandwidth and video gating parameters, a very narrow video gate can be used to effectively sample detect a bursted RF carrier.

On some analyzers, the video gating will work with the mathematically integrated average power measurement, providing a more accurate result. Currently, video gating is only available on higher performance spectrum analyzers, but signal level meters could evolve to provide this capability in the future. Once again, it is recommended that the user contact the manufacturer of the user's specific analyzer for the manufacturer's recommended procedure.

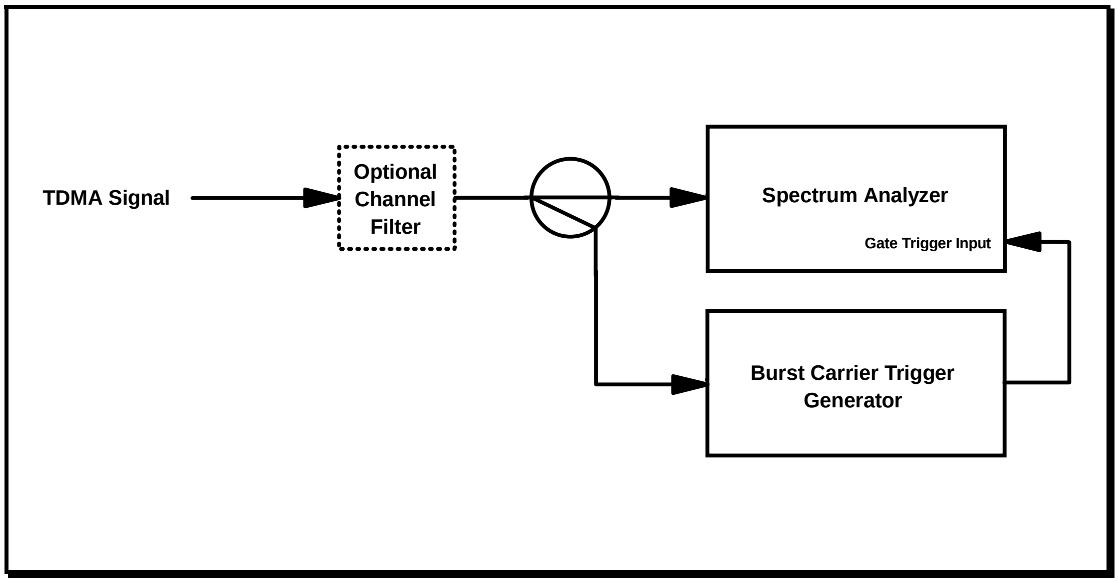


Figure 2. Typical Gated Spectrum Analyzer Measurement Setup

Figure 2 is an example of a typical measurement setup for a TDMA measurement using video gating. In some configurations the burst carrier trigger generator is internal to the analyzer. The burst carrier trigger generator detects the envelope of the signal and provides a TTL compatible signal to the gate trigger input of the analyzer when a user adjustable threshold is exceeded.

The most common TDMA burst procedures use the analyzer's average power measurement and the video gating and/or video sweep triggering to enable the detector sampling of the analyzer during the TDMA pulse on time. Measurement methods which trigger the sweep circuits of the analyzer from the video pulse are more effective when measuring signals with varying pulse repetition rates. Typically, the automated procedures will provide the mathematically integrated average power measurement result directly. The operator's manual of the analyzer should be consulted for specific steps.

3.2 Noise

3.2.1 Thermal Noise

Definition: See Section 1.2: “Noise Level”.

Discussion: Noise, also called thermal noise, is the energy inherent in all matter and varies with the thermal agitation of the material. It is independent of frequency within the band of interest. It is the baseline noise floor resulting from the noise addition of all the active devices in the upstream whose outputs are combined into the upstream path. This is called “noise funneling”. For the purposes of the upstream path, noise is intended to be measured in a narrow bandwidth to avoid upstream impairments such as ingress and electrical transients. It is expressed as an absolute power in dBmV in a 1 Hz bandwidth.

This noise measurement is intended to characterize the upstream path as though it were perfectly clean with no ingressing carriers or impulse type impairments.

Test Procedures: The following procedures are intended to serve as reference methods and be usable with generic measurement instruments. Many test equipment manufacturers provide valid and more convenient alternative methods of measuring noise.

Required equipment

- A spectrum analyzer capable of IF resolution bandwidth of 300 kHz, with 30 kHz and 100 kHz bandwidths also desirable, or a signal level meter (SLM) with known noise correction factors for bandwidth and detector noise response.

Test Procedure Using a Spectrum Analyzer

Prepare the Measurement Setup

1. Connect the spectrum analyzer to the signal to be measured.
2. Adjust the spectrum analyzer as follows:
    - Resolution IF Bandwidth: 30 kHz (wider bandwidths can be used as desired)
    - Video Bandwidth: 100 Hz or less desired; (no greater than 300 Hz)
    - Log Scale: 10 dB/Hz
    - Detector: Sample
    - Frequency Span: 2 to 6 MHz (or less if desired)
    - Sweep Time: Automatic
3. Tune the center frequency of the analyzer to a point near the frequency of interest to find a relatively flat spot in the noise which avoids any contribution from ingressing signals. If it is desired to measure at a frequency where active transmissions are occurring it may be necessary to temporarily disable those upstream transmissions.
4. Record the noise floor level in dBmV.

5. Apply the following correction factors from the number determined in step 4:

Convert 30 kHz to 1 Hz:	-44.8 dB
Log Detect Rayleigh noise:	+2.5 dB
IF noise equivalent BW: (for example: -0.52 dB for 3 dB filters, or +1.1 dB for 6 dB filters)	See manufacturer's specifications
Noise-near-noise:	Disconnect upstream signal & use Fig. I.D.2

Example:

Uncorrected noise level:	-50 dBmV
Noise drop when disconnecting cable from analyzer input:	7 dB (use Fig. I.D.2 to get -1 dB)

Noise level = -50 - 44.8 + 2.5 - 0.5 - 1 = -93.8 dBmV (1 Hz BW)

Video Bandwidth Note: When using the narrow video bandwidths called for in this procedure, make sure the noise response is below the reference level by greater than 10 dB. This assures that the noise amplitude distribution peaks do not overdrive the spectrum analyzer's circuitry in the signal path preceding the video filter. Temporarily widen the video bandwidth to maximum to make sure noise peaks do not go above the reference level.

Test Procedure Using a Signal Level Meter

1. Connect the SLM to the signal to be measured.
2. Tune the SLM for a minimum level near the frequency of interest. For SLM's with a spectrum viewing mode, find a relatively flat spot in the noise near the frequency of interest. This avoids any contribution from ingressing signals.
3. Remove attenuation from the SLM attenuator until the minimum noise level can be read. If it is desired to measure at a frequency where active transmissions are occurring it may be necessary to temporarily disable those upstream transmissions.
4. Note the noise level after applying the manufacturer's recommended compensating factors or switches for measuring noise. Convert this result to a 1 Hz bandwidth using the SLM manufacturer's specification for its IF noise equivalent bandwidth. Record this final result.

Notes

The carrier-to-noise ratio is one of several basic measurements performed on cable television systems downstream paths. It is a useful system maintenance tool and is referenced to a 75 ohm impedance and stated in a 4 MHz bandwidth.

For the upstream path various types of digital signals are carried in addition to analog television signals. These digital signals can occupy varying channel widths up to 6 MHz. Since spectrum allocations for these signals is not as clearly defined as it is for the downstream, it is proposed that signal levels be determined using a power density concept. This procedure is explained elsewhere. This is the reason for stating upstream noise in a 1 Hz bandwidth.

3.2.2 Impulse Noise

Definition: Impulse interference is caused by broadband, fast risetime signals which may or may not be periodic in nature. These may be the result of electrical faults in the cable system, sheath current effects generally related to power company neutral currents flowing on the outer conductor of the coaxial cable, ingress of signals such as ignition noise or other sources generating interference signals which are not confined to narrow ranges of frequency. Such signals are particularly damaging to data transmissions where short bursts of interference can seriously reduce the data throughput. Quantifying and locating the source(s) of these signals is important for out-of-service setup of the upstream system as well as monitoring and controlling these disturbances while in-service.

Procedure: The following are suggested methods of addressing these interferences in the upstream transmission network and ways of analyzing and presenting the results. Since this is a very complex subject and may utilize a variety of existing and future test equipment the approaches outlined here will need refinement for each specific application.

System Parameters: To be meaningful the results of testing for impulse interference must be related to the operating levels of the system. In other words the amplitudes of transients detected need to be quantified in terms of the overall upstream signal power or to the signal levels of the channels in question in order to assess their effects. Refer to Section 3.6: "System Frequency / Time Unavailability" for an applicable reference level procedure.

Required equipment

- For "Method A" below a sampling oscilloscope or other high speed waveform capture device is employed. The data output must be gathered and stored in a computer for analysis.
- For "Methods B & C" below a Spectrum Analyzer or other frequency selective device capable producing the necessary triggers is required in addition to the equipment of "Method A".

Equipment setup

The equipment configuration of Figure 1 is applicable for "Method B" and is applicable to "Method A" with the omission of the Spectrum Analyzer.

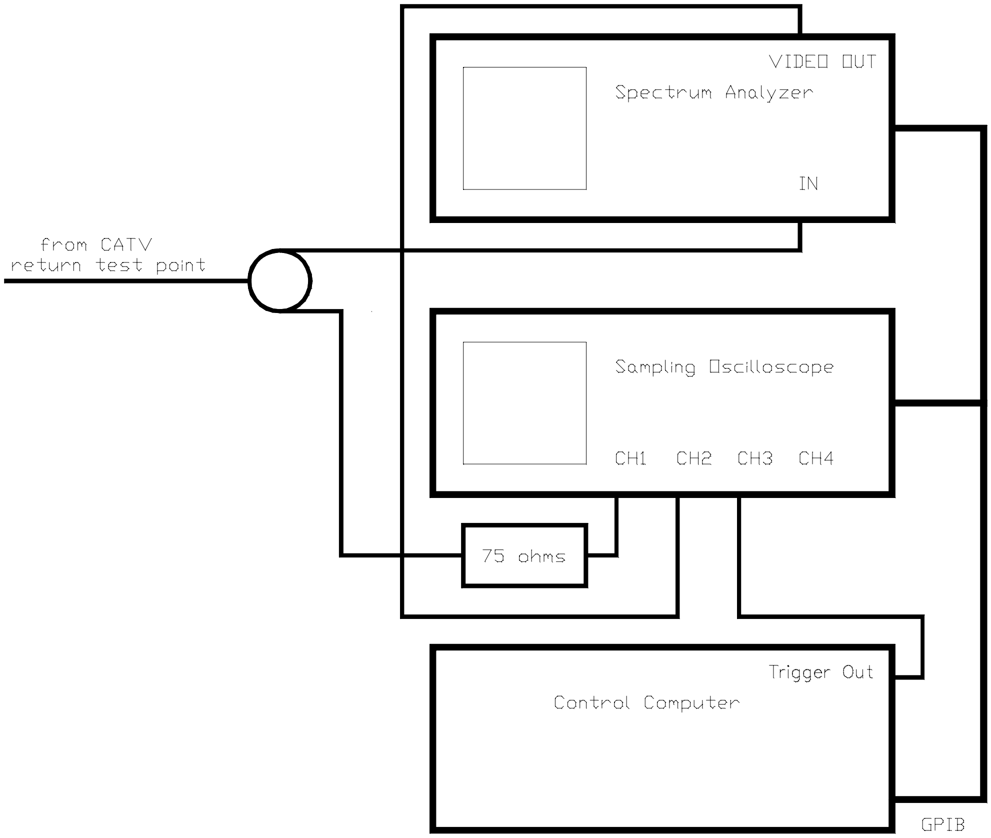


Figure 1: Equipment setup

Data Capture

The function of the sampling oscilloscope is to capture real time transient waveforms and transmit them to the computer for storage and later analysis. There are two general conditions under which these captures may be made. In the condition of the plant not being in service (no information signals present), it is possible to simply monitor the upstream spectrum and trigger the sampling oscilloscope on transient events which exceed the peaks of the noise background (Method A). The spectral components and rate of occurrence of such captures give a good indication of the integrity of the upstream system.

In the situation where traffic is being carried on the upstream system capturing transient events is more difficult since there is continuous signal energy present which will trigger the scope and may obscure the data. In order to avoid these problems it is necessary examine only parts of the spectrum which are not in use. This is accomplished by using the spectrum analyzer to select a “quiet “ portion of the spectrum. In this configuration (Method B) a transient event within the passband of the spectrum analyzer is used to trigger the sampling oscilloscope and the video signal from the spectrum analyzer is captured or an rf capture is initiated (Method C).

Method A

The sampling oscilloscope is set to so that it does not trigger on background noise but will trigger at a slightly higher level. This trigger level is available as part of the setup data and should be recorded on the computer with the captured waveforms. A waveform should be captured at every trigger and recorded in the computer. It should be noted that some time is expended in transferring data to the computer and that there may not be the facility to capture subsequent events until the transfer is complete.

Method B

In this method the analyzer is tuned to the selected quiet area of the spectrum using the maximum possible bandwidth while excluding information signals. The analyzer is then set to “zero span” so that it acts as a tuned radio receiver. The vertical response of the analyzer is set for “linear” in the general case although a logarithmic mode may be selected when the situation warrants. The oscilloscope is fed with spectrum analyzer video output and its trigger is set at a level somewhat above the noise floor as before. Note: Instead of the spectrum analyzer a filter of the desired bandwidth may be substituted and direct rf captures made with the sampling oscilloscope. In either case the transient signals are filtered and therefore only the components of the transient which lie within the preselected band are captured.

Method C

This method is the same as method B except that the sampling oscilloscope takes its input directly from the rf upstream signals and its trigger from the spectrum analyzer. The time waveform of the entire spectrum including the information signals as well as the transients is captured. In order to compensate for the delay of the trigger signal through the spectrum analyzer the sampling oscilloscope must have its buffers configured for continuous sweeping and buffer retention prior to the trigger in order to capture the onset of the transient. The value of this type of capture will become evident in the analysis phase.

Data Acquisition and Storage Requirements

The computer must be programmed to control the instruments as well as retain the captured data. This will require some rather complex software and impose certain limitations on the number and timing of the captures. The same computer may also be employed for data analysis.

Computer Control and Data Analysis

Control

The computer is setup to cause captures either continually upon occurrence or to gather only a preset number of captures in preprogrammed time periods. The buffer size of the captures must be set in the oscilloscope and the computer memory managed accordingly. Commands from the computer to the instruments must be transmitted by some means. The GPIB or IEEE-488 bus is quite convenient and other configurations such as RS-232 may be employed. It is strongly recommended that the same bus be chosen for both instruments to simplify programming.

Data Analysis

There is a great deal of information contained in captures of transient events as described above. Individual captures of transient events reveal the shapes of the impulse and may allow identification leading to discovery of the source of the impulse interference. Application of Fast Fourier Transform processing will separate the spectral components of the impulse and may provide clues to its origin. This FFT data does point out the amount of contamination in each spectral area and hence the information traffic which will be affected by the interference. This processing must be customized to the specific test equipment, system and situation addressed and is beyond the scope of this specification. However, Figure 2 illustrates one possible output and display format which illustrates the employment of these techniques.

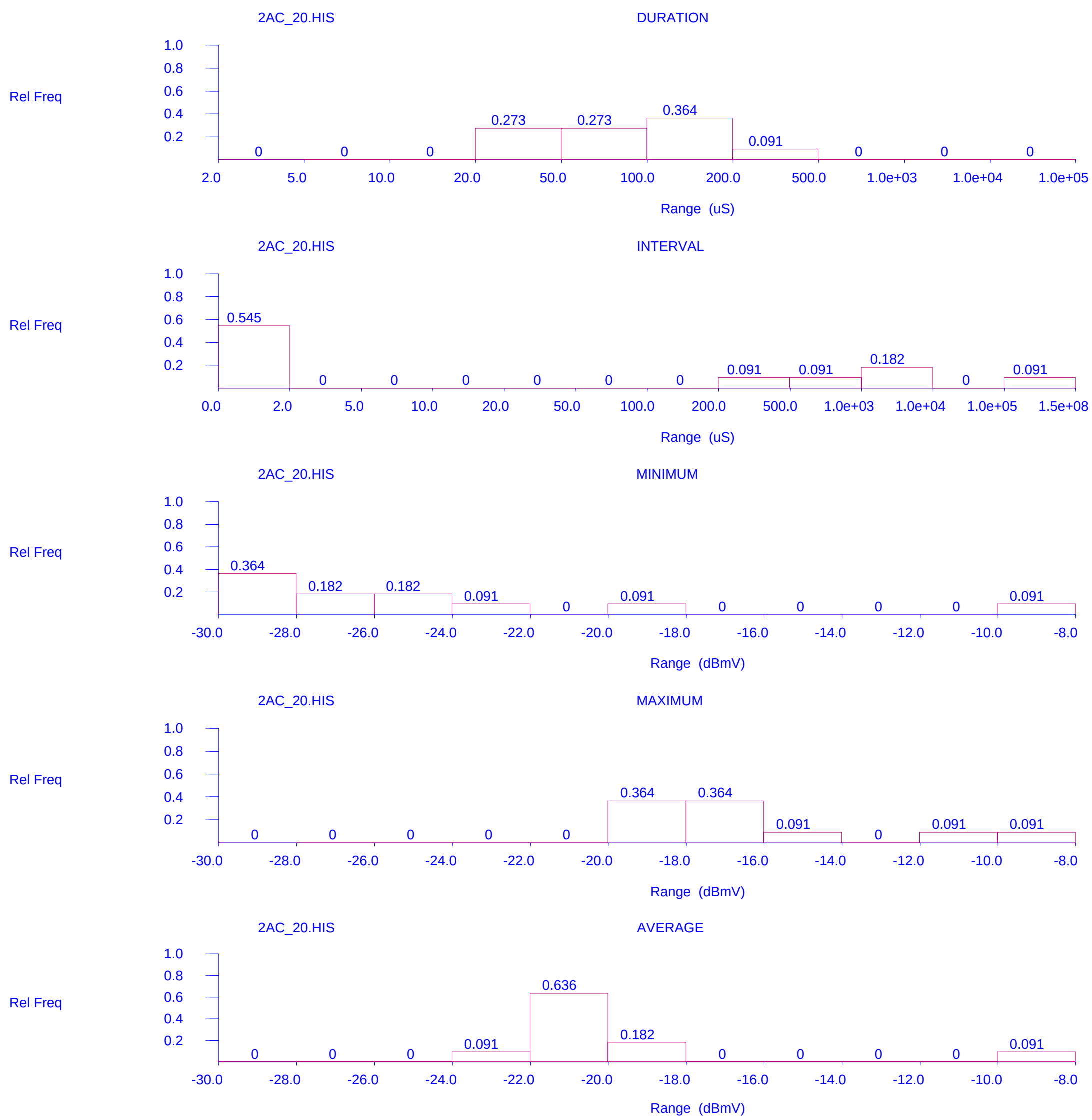


Figure 2: Possible output and display format

When data is taken using Method C it is possible to subtract a normal (non-interfered) FFT spectrum from that developed by analysis of the transient capture to generate a first order approximation of the broadband transient spectral components.

3.2.3 Phase Noise

Definition: Phase Noise is the random changes in an oscillator's phase due to the effects of thermal noise in the oscillator and the noise injected through external power supplies and control circuitry.

Discussion: Phase noise degradation due to the cable TV distribution system is not of significant importance except in band stacking return systems where the conversion oscillators in the up/down band stacking converters contribute to phase noise. When excessive phase noise is added by band stacking, degradation in bit error rate will occur. The amount of phase noise that can be tolerated in a given system depends on the modulation type being employed and the carrier recovery bandwidth of the demodulator. Phase noise which lies outside of the carrier recovery bandwidth is of greatest concern because the demodulator cannot correct for its detrimental effects. Phase noise is typically specified in dBc per Hz (dB relative to carrier peak when measured in a 1 Hz bandwidth) at a specified offset from the carrier. To determine what phase noise versus frequency offset is necessary to insure acceptable BER performance, consult the modem manufacturer.

Procedure

To determine whether phase noise introduced by the return system is within acceptable limits, a signal of known good phase noise characteristics can be placed on the system beyond the last conversion. The phase noise degradation of this test signal can be measured at the headend with a spectrum analyzer. When measuring phase noise in this manner it is a good practice to first determine that the phase noise performance of the test signal and analyzer combination is adequate for the intended system measurement.

Required equipment

- Spectrum Analyzer
- Crystal controlled CW source (one or more return frequencies) or signal generator with good phase noise performance. See test equipment verification.
- Variable attenuator for controlling the CW source level

Test equipment verification

1. Determine the system levels at the point where phase noise is to be measured. This will most likely be the reverse output at the headend. If possible measure directly at the fiber receiver's output or the reverse modem's input to maximize test signal level in an effort to give the largest signal to Analyzer noise floor ratio possible.
2. Determine the phase noise specification to be measured. This will normally be expressed in -dBc/Hz at a specified frequency offset from the carrier.
3. Set the CW source to the expected system return level.
4. Set the Analyzer as follows:
    - Span/div. to approximately the desired measurement offset. (approx. 10 kHz/div)

- Resolution BW to 1/10 or less of the measurement offset (RBW).
- Video BW > resolution BW

5. Connect the CW source to the Analyzer.
6. Tune the Analyzer to center the signal on a reference graticule.
7. Note the carrier peak amplitude (CAR).
8. Note the phase noise amplitude at the desired offset (PN). Using frequency markers is helpful.
9. Correct the phase noise level for the Analyzer's noise BW and log detector error.
10. Corrected Phase Noise (CPN) level = PN + Analyzer correction factor for resolution BW used + log detector Rayleigh noise correction factor (2.5 dB)
11. Compute phase noise performance:

$$\text{Phase Noise (dBc/Hz)} = \text{CPN} + 10 \log (1 \text{ Hz} / \text{RBW (Hz)}) - \text{CAR}$$

This reading should preferably be 10 dB better than the desired system performance level (i.e. if the desired system measurement is -60 dBc/Hz it desirable to have a test set performance of -70 dBc/Hz), however, with suitable correction for noise-near-noise you could make useful readings with a test set that is between 0 and 10 dB better than the intended measurement. See Figure I.D.2 for noise-near-noise correction factors.

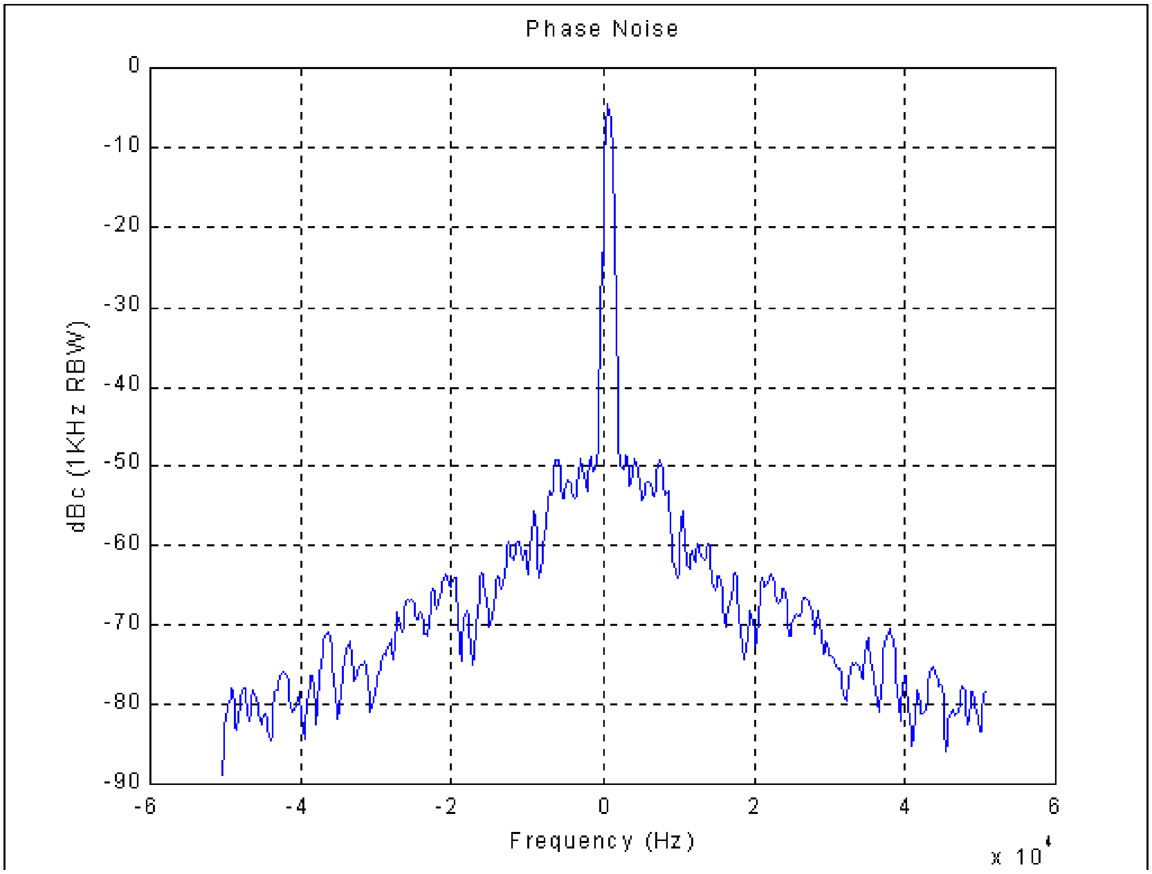


Figure 1. Phase noise of test equipment

Measuring system performance

1. Inject the CW source at the node using the maximum permissible level. Connect the Analyzer to the headend test point.
2. Set the Analyzer as follows:
    - Span/div. to approximately the desired measurement offset.
    - Resolution BW to 1/10 or less of the measurement offset (RBW).
    - Video BW > resolution BW
3. Tune the Analyzer to center the signal on a reference graticule.
4. Note the carrier peak amplitude (CAR).
5. Note the phase noise amplitude at the desired offset (PN). Be sure that the system noise floor (point at which noise amplitude flattens) is at least 10 dB below the PN level.
6. Correct the phase noise level for the Analyzer's noise BW and log detector error.
7. Corrected Phase Noise (CPN) level = PN + Analyzer correction factor for resolution BW used + log detector Rayleigh noise correction factor (2.5 dB)

8. Compute phase noise performance:

$$\text{Phase Noise (dBc/Hz)} = \text{CPN} + 10 \log (1\ \text{Hz/ RBW (Hz)}) - \text{CAR}$$

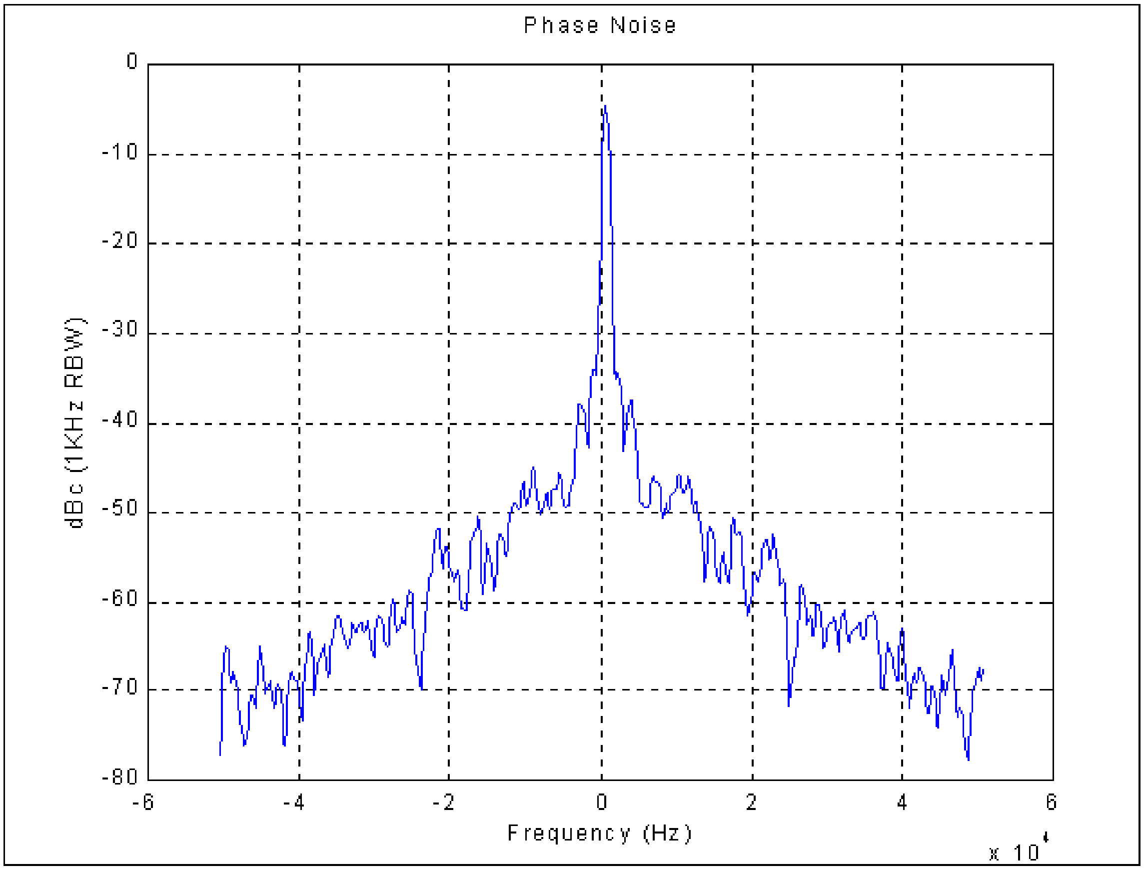


Figure 2. System phase noise

3.3 Flatness

Method 1 - Sweep system (or equivalent):

Definition: The flatness of the reverse path is the relative gain difference at various frequencies throughout the range of the reverse path. For U.S. cable systems this is usually from 5 to 40 MHz. The entire path from a subscriber to the headend can be tested, or any segment can be tested separately. (For example, the fiber portion and the coaxial portion could be tested separately if desired.)

When testing just a portion of the system, the signal source will be connected at the end of the tested segment that is furthest from the headend (or node) and the signal measurement device will be at the end of the tested segment that is closest to the headend. See Section 2.1: "Return Plant Setup and Operational Practices" for a discussion of the appropriate test points.

Flatness is measured when setting up the system or when verifying performance.

Required equipment

- A sweep system capable of reverse path testing.

Test Procedure

Using an automated reverse sweep system inject the signal at the source point to be tested (usually either a subscriber tap or at an amplifier test point).

This system will provide a measurement of the flatness of the reverse channel.

When making this measurement use caution to not allow the test system to inject a test signal that might interfere with existing signals in the transmission system. This includes signals that are not seen at the injection point, but which are being sent to the headend by another portion of the system.

Method 2 - Out of service

Discussion: This method uses generic test equipment, but requires that the system be tested out of service.

Required equipment

- A sweeping or stepping signal generator.
- Spectrum Analyzer.

Test Procedure

Using the signal generator, inject the signal at the source point to be tested (usually either a subscriber tap or at an amplifier test point).

At the upstream point to be tested, use the spectrum analyzer in the max-hold mode to build up a display of the flatness of the reverse path.

Notes

Any unflatness of the signal generator itself must be subtracted from the display to provide the correct answer.

A spectrum analyzer plot should be made at the upstream point to be tested before the signal generator is connected. This will show the ingress and any spurious signals present. These signals should be noted as they are not to be used as a part of the flatness measurement.

Flatness Appendix

When testing by inserting any signal into an operating system, there is the possibility of causing non-linear operation due to compression or laser clipping. This is the result of adding enough power to the total already arriving at the laser such that the maximum allowable (without distortion) is now exceeded.

With some reverse path lasers in particular, there is very little margin to add more power without causing clipping.

Use caution to ensure that when adding a sweep or other testing signal that the system remains linear. Consult the equipment manufacturer if necessary.

3.4 Intermodulation

3.4.1 Single Second Order (SSO) and Single Third Order (STO) Intermodulation Distortion

Definition: Distortion is an undesired change to the signal as it passes through the cable system. This change may be due to many factors including the nonlinear characteristics of amplifiers, lasers, and photodetectors or the addition of unwanted signals to the spectrum such as conducted or radiated ingress. Single Second Order (SSO) distortion is defined as the ratio in decibels of the level of a second order distortion beat to the level of the carrier(s). Single Third Order (STO) distortion is defined as the ratio in decibels of the level of a third order distortion beat to the level of the carrier(s). Both are expressed with the unit dBc which is decibels relative to carrier.

Other contributors to distortion such as noise, ingress, and hum modulation are discussed in other sections.

Note: This procedure is only recommended for out-of-service measurements. These measurements require free spectrum space and can cause disruption to any traffic which might exist on the plant during the tests. Before performing this test, the plant must be properly setup and aligned. For more information refer to Section 2.1: "Return Plant Setup and Operational Practices".

Discussion: The test is performed by inserting two carriers into the plant (normally at the end of line), and measuring the resulting distortion at the headend. When these two carriers go though non-linearities (such as amplifiers, lasers, and photodetectors), second and third order distortion products are produced. Assuming that the frequencies of the two carriers are A and B (B>A), this procedure tests the A+B and B-A second order products and the (2*A)-B and (2*B)-A third order products. A, B, and all measured products must fall within the passband of the system.

Required equipment

- Two signal generators or one multicarrier generator
- Spectrum Analyzer
- Optional notch filter

Procedure

1. Connect the injection equipment in the plant as shown in Figure 1.

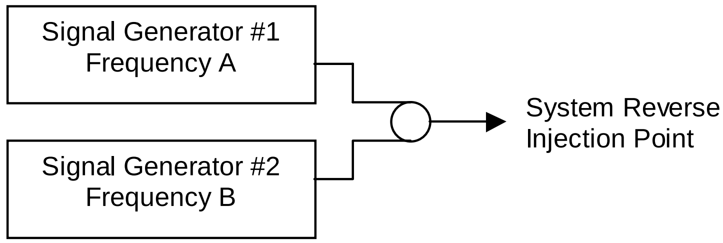


Figure 1: Equipment Connection

2. Turn on the signal generators at the desired frequencies and power level. In general, the proper power setting for the signal generators will be the level which hits the amplifiers (and the laser) at the proper total power. Record the lower frequency as "A" and the higher frequency as "B".
3. Connect the spectrum analyzer to the signal to be measured.
4. Set the spectrum analyzer as follows:
   - Center Frequency "A" MHz
   - Span Approx. 1 MHz
   - Vertical Scale 10 dB/div
   - Resolution BW Approx. 30 kHz
   - Video BW As required
   - Sweep Time Automatic for calibrated measurement
   - Input Attn As required (see text)
5. Adjust the analyzer reference level so that the carrier is close to the top of the screen.
6. Put the marker on the carrier. Record the carrier level.
7. Tune the spectrum analyzer to frequency "B". Put the marker on the carrier and record the carrier level.
8. Compare the two carrier levels and verify that the difference between the two is within the required plant flatness.
9. Calculate the average carrier level as follows:

$$\text{Average Carrier Level} = 10 * \log\left[\frac{10^{\frac{\text{Carrier A Level}}{10}} + 10^{\frac{\text{Carrier B Level}}{10}}}{2}\right]$$

   Or, use power addition tables to add the powers of the two carriers and then subtract 3 dB.

10. Tune the spectrum analyzer to the A+B beat frequency.
11. Put the marker on the top of the beat. Verify that the spectrum analyzer is not contributing to the distortion reading by varying the spectrum analyzer's input

attenuator. Choose the setting which gives the lowest beat level (assure that changing the attenuator by an additional step does not lower the beat further). Calculate the SSO as follows:

SSO = Average Carrier Level - Beat Level

12. Tune the spectrum analyzer to the A-B beat frequency and measure the SSO as in the previous step.
13. Tune the spectrum analyzer to the (2*A)-B beat frequency.
14. Put the marker on the top of the beat. Verify that the spectrum analyzer is not contributing to the distortion reading by varying the spectrum analyzer's input attenuator. Choose the setting which gives the lowest beat level (assure that changing the attenuator by an additional step does not lower the beat further). Calculate the STO as follows:

    STO = Average Carrier Level - Beat Level

15. Tune the spectrum analyzer to the (2*B)-A beat frequency and measure the STO as in the previous step.

Notes and Hints

If spectrum analyzer distortion cannot be avoided, a filter must be used in front of the analyzer. A channel bandpass filter or a notch filter (to remove one of the two carriers) could be used. If a bandpass filter is used, several could be required depending on the location of the carriers and beat frequencies. If a notch filter is used it should have at least 20 to 30 dB of rejection at one of the carrier frequencies and have a constant loss (flat response) at all the measurement frequencies, including the other carrier frequency. When this filter is used, all readings must be referenced to the carrier that is not attenuated.

As an alternative to the above procedure, all beat measurements can be compared to a carrier at that same frequency. To do this, one of the signal generator frequencies needs to be moved from its normal frequency (A or B) to the beat frequency being measured in order to obtain the carrier level reading. Then the signal generator frequency must be moved back to its original frequency (A or B) before the distortion is measured.

Be aware that the distortion products being measured might not be SSO or STO products. For instance, common path distortion could exist at the same frequency. To check for undesired signals, remove the A and B frequencies and make certain that all SSO and STO beats disappear.

A two carrier test does not fully stress the capabilities of the return system. In particular, the peak-to-average ratio of two carriers is not as high as the peak-to-average ratio of a fully loaded system. For a further discussion of this issue see Section 1.4: "Peak Voltage Addition Tutorial".

3.4.2 Noise Power Ratio (NPR)

Definition: Noise Power Ratio (NPR) is a test method that examines the amount of noise and intermodulation distortion in a channel. The test signal is comprised of flat gaussian noise bandlimited to the frequency range of the reverse path (about 5 to 40 MHz) with a narrow band (channel) of the noise deleted by a notch filter. NPR is defined as the level of the signal relative to the level of the combined noise and intermodulation distortion in the channel. Essentially, NPR is the depth of notch.

Note: This procedure is only recommended for out-of-service measurements. These measurements will use the entire return spectrum and will cause disruption to any traffic which might exist on the plant during the tests. Before performing this test, the plant must be properly setup and aligned. For more information refer to Section 2.1: “Return Plant Setup and Operational Practices”.

Discussion: The test is performed by injecting a block of noise into the plant (normally at the end of line), and measuring the resulting distortion at the headend. So that the level of the distortion can be measured, the injected noise has a notch in the spectrum, usually close to the middle. The injected noise is referred to as the “signal” (see Figure 1).

The notch (channel) will contain many types of noise. When the signal goes though nonlinearities (such as amplifiers, lasers, and photodetectors), distortion and clipping will result, which cause the signal to beat with itself. The result is a wide spectrum of noise that will build up under the signal (see Figure 1) and will be visible in the notch. This resulting noise (caused by distortion and clipping) is sometimes referred to as Composite Intermodulation Noise (CIN) or as Intermodulation Noise (IMN). This intermodulation noise will increase as the signal level is increased. Some of the noise under the signal, such as thermal noise, laser RIN, and shot noise, will not change with signal level.

When the signal level is high enough to cause significant distortion, intermodulation noise will dominate the noise level in the notch. When the signal level is low, thermal noise (along with other constant noises such as laser RIN and shot noise) will dominate. This procedure cannot differentiate between the two, since both appear as noise. Therefore, the resulting Noise Power Ratio will always contain the sum of both effects.

Noise is used as the signal because, unlike analog AM video signals, which have a lot of energy in the carrier, complex digital modulations have a noise like spectrum. A full loading of these signals will closely resemble a block of noise, just as a forward spectrum fully loaded with AM video resembles a comb of CW carriers. For more information on the use of noise as a measurement signal, refer to Section 1.3: “Peak-to-Average Ratio” and Section 1.4: “Peak Voltage Addition Tutorial”.

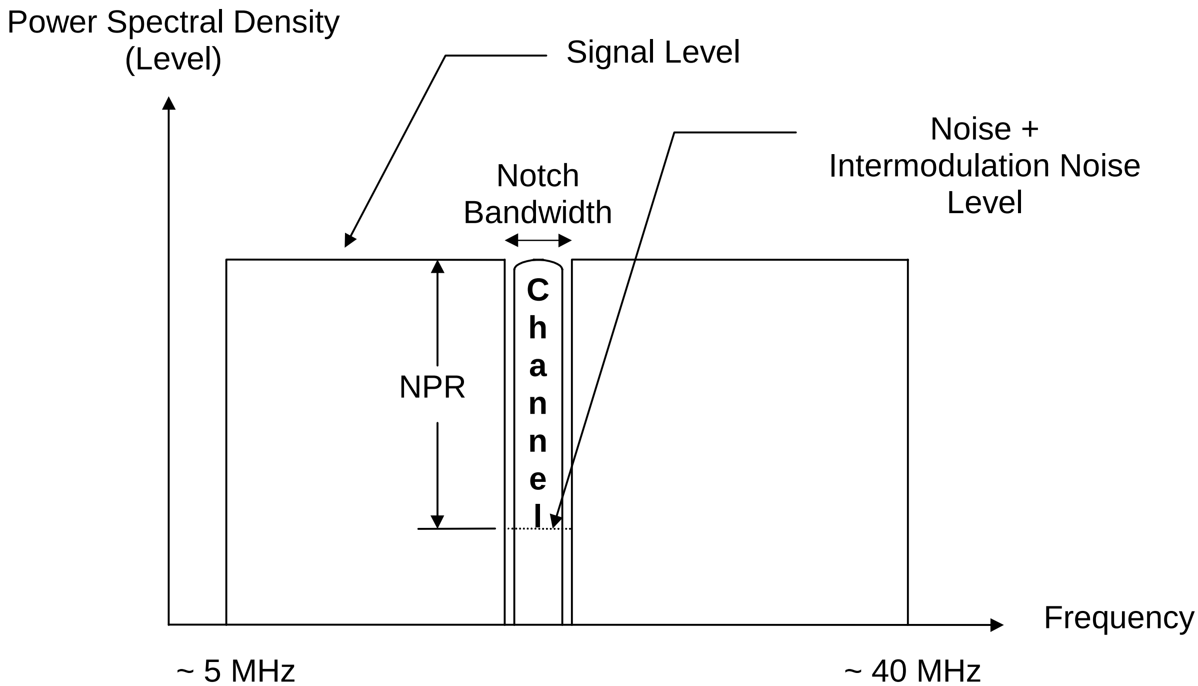


Figure 1: Spectrum of Measurement Signal

Required equipment

- Noise source with a bandwidth at least as wide as the return spectrum
- RF filters to shape the noise
- Spectrum Analyzer

General Procedure

1. Connect the injection equipment in the plant as shown in Figure 2. The setup illustrates a 5-40 MHz return plant. If the return plant has a different bandpass, then different filter frequencies should be used. The three filters shown in Figure 2 can be combined into one box, if desired.

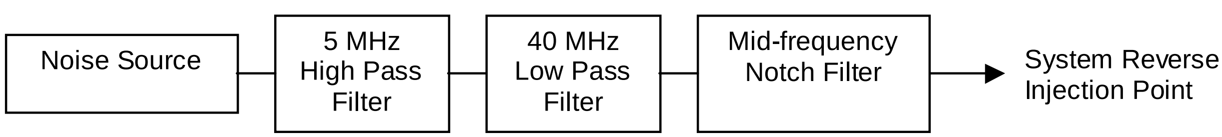


Figure 2: Equipment Connection

2. Turn on the noise source and adjust to the proper power level (see "Notes and Hints" at the end of this section for more information). In general, the proper power setting for the noise source will be the level that hits the amplifiers (and the laser) at the proper total power.
3. Connect the spectrum analyzer to the signal to be measured.

4. Set the spectrum analyzer as follows:
   - Center Frequency — Center of Notch
   - Span — Approx. 10 MHz (see text)
   - Vertical Scale — 10 dB/div
   - Resolution BW — Approx. 100 kHz (see Notes and Hints)
   - Sweep Time — Automatic for calibrated measurement
   - Input Attn — As required (see text)

The remaining steps in the procedure vary depending on the capability of the spectrum analyzer. Two methods are discussed below.

Procedure 1: Noise Marker (Best Method)

1. This procedure requires a spectrum analyzer with a noise measurement mode (sometimes referred to as a noise marker or a noise normalization).
2. Turn on the noise measurement marker.
3. Put the analyzer into the “sample” detection mode. (Note: On many analyzers, activating the noise measurement mode will automatically put the analyzer into the “sample” detection mode.
4. Set the video filter to automatic (or off) and adjust the reference level so that the peaks of the noise never exceed the top of the display. The input attenuator should be in the automatic mode during this adjustment.
5. The input attenuator must be adjusted high enough so that the analyzer does not cause additional intermodulation noise and low enough so that the analyzer does not cause additional thermal noise. To adjust the input attenuator, measure the noise level in the bottom of the notch (using the noise marker). Increase the input attenuator until the noise level in the notch does not get any lower. If the noise level never goes down, return to the original attenuator setting.
6. Measure the signal level by placing the noise marker on the signal. If the marker reading is not stable, turn on video averaging or use a lower video bandwidth.
7. Measure the noise level by placing the marker in the center of the notch. (Note: On some spectrum analyzers, the noise marker reads all frequencies within about ±½ graticule of the marker location. Therefore, if the notch is not at least one graticule wide, readjust the span setting.)
8. Verify that the analyzer noise floor is sufficiently below the noise notch level by either externally attenuating the signal (at the analyzer input) by at least 30 dB or by disconnecting the signal and terminating the analyzer input. If the drop is not at least 10 dB, correct the noise level recorded in step 7 by using the noise-near-noise correction table given in Figure I.D.2.
9. Calculate the NPR by subtracting the corrected noise level (step 8) from the signal level (step 6).

$$\text{NPR} = \text{Signal Level} - \text{Noise Level}$$

Procedure 2: Normal Marker

1. Put the analyzer into the “sample” detection mode.
2. Set the video filter to automatic (or off) and adjust the reference level so that the peaks of the noise never exceed the top of the display. The input attenuator should be in the automatic mode during this adjustment.
3. The input attenuator must be adjusted high enough so that the analyzer does not cause additional intermodulation noise and low enough so that the analyzer does not cause additional thermal noise. To adjust the input attenuator, measure the noise level in the bottom of the notch. It will probably be necessary to turn on video averaging to obtain a stable measurement. Increase the input attenuator until the noise level in the notch does not get any lower (remember to restart video averaging for each measurement). If the noise level never goes down, return to the original attenuator setting.
4. Measure the signal level by placing the marker on the signal. If the marker reading is not stable, turn on video averaging or use a lower video bandwidth. If video averaging was already on, restart it.
5. Measure the noise level by placing the marker in the center of the notch.
6. Verify that the analyzer noise floor is sufficiently below the noise notch level by either externally attenuating the signal (at the analyzer input) by at least 30 dB or by disconnecting the signal and terminating the analyzer input (remember to restart video averaging if it is on). If the drop is not at least 10 dB, correct the noise level recorded in step 5 by using the noise-near-noise correction table given in Figure I.D.2.
7. Calculate the NPR by subtracting the corrected noise level (step 6) from the signal level (step 4).

$$\text{NPR} = \text{Signal Level} - \text{Noise Level}$$

Note: When measuring noise with a spectrum analyzer, correction factors are usually required to correct for noise bandwidth and log detection errors. However, since this measurement is a relative measurement of one noise level vs. another noise level, corrections are not required.

Notes and Hints

The notch in the signal from the setup in Figure 2 should be as deep as possible. The dynamic range of this measurement is limited by the depth of the notch. The maximum NPR measured will never be greater than the notch depth. In general, the notch should be at least 10 dB deeper than the desired measurement.

The width of the notch must be at least as wide as the resolution BW setting on the analyzer. For instance, to use the recommended RBW of 100 kHz, the notch should be at least 100 kHz wide at the depth of interest. Narrower notches will require lower RBW settings which will, in turn, require longer sweep times.

No amplifiers should be used after the filters in Figure 2. If an amplifier is required to obtain sufficient signal level, the amplifier should be placed before the filters. If an amplifier follows the filters, it could reduce the peak-to-average ratio of the injected noise, which could produce unrealistically “good” results. Furthermore, if an amplifier follows the notch filter, its distortion will contribute to the plant distortion.

The injected noise (signal) should be flat. A level variation less than 1 to 2 dB across the band is recommended.

The dynamic range of the plant can be determined by measuring the NPR over a wide range of powers. The range of input powers which yields an NPR greater than a predetermined value is the dynamic range of the plant for that level of performance.

This procedure will not indicate whether noise or distortion is limiting the dynamic range of the system. For instance, a plant which is not correctly aligned for unity gain could simultaneously suffer from thermal noise in some spans and from CIN in other spans. In order to determine where the problems are occurring, the system must be divided into smaller pieces.

Other contributors to distortion such as ingress and hum modulation might exist in the system and are discussed in other sections. If such impairments exist, they will add to the level in the notch and will lower the NPR result.

The bandwidth of the noise marker is not important because NPR is a relative measurement.

If the above procedure does not provide adequate dynamic range for measurements of high NPR, a bandpass filter may be added in front of the spectrum analyzer. Such a filter should pass enough of the signal and the entire notch so that both the signal level and the notch level can be measured .

3.4.3 Common-Path Intermodulation Distortion

Discussion: Common-Path Intermodulation Distortion appears as spurious signals in the upstream path and is composed of distortion products of the downstream signals. These products are caused by plant non-linearities in a portion of the plant where downstream signals are present. Tap plate and seizure connections and end of line terminators are often the locations of the non-linear elements. These non-linear elements are minute diode-like structures at connection points due to dissimilar metal contacts and corrosion activity. The resulting distortion products observed are usually second and third order products of the combination of downstream video carriers (other products exist but are generally of minor importance). Second order products fall at multiples of 6 MHz in all systems (with 6 MHz channel spacing) while third order products appear at 1.25 MHz above and below these frequencies in standard and IRC systems and on-frequency in HRC systems. The contributions of offset channels such as standard channels 5 & 6 are usually not discernible. Common-path products are elusive, often appearing and disappearing over time. At times only one variety is observed (2^{nd} or 3^{rd} order) and sometimes both are seen simultaneously. Amplitudes also vary with conditions. Common-path products are capable of interfering with services just as ingress and other spurious signals. As upstream systems proliferate and loadings increase it is possible that the upstream signals (which often operate at relatively high levels) may also intermod in this manner, therefore, the offending equipment must be located and corrected.

3.5 Delay Inequalities

Definition: Group Delay is the rate of change of phase with respect to frequency and is a measure of the time delay experienced by each frequency component of a signal as it passes through a circuit. Delay inequalities are the result of variations in group delay which occur over the occupied bandwidth of the signal.

Discussion: In well matched or non reactive circuits, phase will vary very linearly with frequency resulting in nearly constant group delay and therefore little delay inequality. If delay inequality is very small (<< symbol length of a digitally modulated signal) over the frequency range spanned by a channel, then all frequency components of the signal will arrive at the same time and the time domain signal will experience little distortion. However if reactive mismatches occur, such as near the cutoff of a diplex filter or due to the mismatch of a defective component, significant delay inequalities can occur causing some frequency elements of the signal to be delayed relative to others resulting in signal distortion.

Procedure I: (Out of service) Delay inequalities can be approximated using one of the multipulse 12.5T pulses. The 12.5T pulse that falls closest to the digital signal frequency should be selected. The bandwidth of the 12.5 T pulse is approximately 320 kHz. For channel bandwidths greater than 320 kHz it will be necessary to step the modulator frequency over the bandwidth of interest or make estimates from the observations of more than one of the 12.5T pulse frequencies.

Required equipment

- NTSC multipulse video signal generator
- Reverse modulator
- Reverse demodulator
- Waveform monitor

1. Connect the equipment as shown in Figure 1.
2. Set the modulator's output to the closest T channel for the frequency band of interest.
3. Set the demodulator to the selected channel.
4. Observe the 12.5T pulse on the waveform monitor.
5. Consult section I.H for measurement procedures

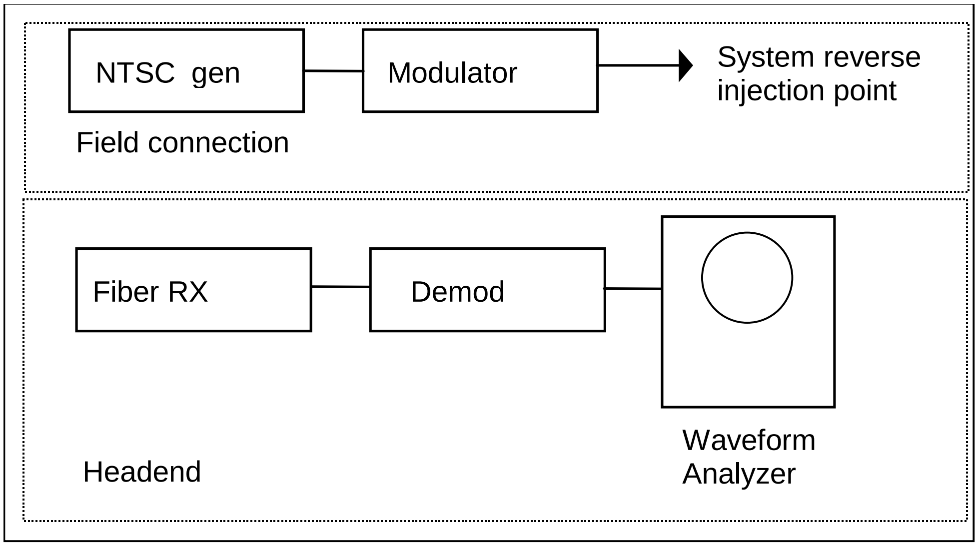


Figure 1. Equipment Connection

3.6 Discrete Interfering Signal Probability

Definition: Discrete Interfering Signal Probability (DISP) is a measure of the percentage of the time that undesired discrete signals which appear at the upstream headend output port exceed certain thresholds which are defined relative to the total signal handling capability of the system. Using the data obtained, it is possible to evaluate the overall interfering signal performance of a system independently of intended signal carriage and also to predict levels of destructive interference to specific signal types as a function of frequency, operating levels and time.

Discrete signals are defined as those signals whose energy is primarily concentrated within a relatively narrow bandwidth (approximately 100 kHz) and which are present for time periods of at least several milliseconds (see discussion at end of procedure). Sources of interfering signals include ingress from over-air signals, antenna-conducted egress from subscribers' directly-attached receivers, spurious and harmonic signals from operator-attached terminal equipment and common-path intermodulation distortion.

The procedure is specifically intended to exclude ingress effects from electrical transients (impulse noise), which affect much wider frequency ranges for shorter time periods.

PROCEDURE

- **Determine System Parameters**

Reference Level

Since measurements are to be made relative to the total power handling limit of the network and will, presumably, be made at a headend test point, the first step is to determine the reference level at that test point. Referring to "Return Plant Setup and Operational Practices," section 2.1, the Reference Level for this procedure is the level appearing at the headend upstream test point when an upstream amplifier Reference Point is driven with a signal whose level is equal to the total power handling capability of the system (P_1 in section 2.1). That level will be equal to (P_8 - A) if the same test point is used for this measurement as was used for system alignment.

Threshold Levels

The procedure will determine how often ingressing signals exceed defined thresholds relative to the Reference Level. In order to characterize the general performance of the system, a sufficient number of thresholds should be defined to allow reasonable extrapolation to intermediate levels. If specific signal types and operating levels have been determined, it may be useful to set one or more thresholds that are meaningful to those signals.

For example, if the headend test point level resulting from driving the system at its maximum recommended input level is +10 dBmV and the upstream level of a particular QPSK signal is 13 dB below the total power capability, then the level of the QPSK signal at the headend test point will be -3 dBmV. Since QPSK signals have a discrete signal interference tolerance of approximately -15 dBc, then a logical threshold for testing would be -18 dBmV which is -28 dB relative to the Reference Level.

Limited testing has shown that the probability of discrete interfering signals exceeding a given threshold may vary about 5:1 for a 5 dB change in threshold. Thus, it is suggested that threshold level increments not exceed that value.

- **Equipment Setup**

The basic data is taken using a spectrum analyzer connected to the headend upstream test point determined above with the data downloaded to a connected personal computer (PC) for analysis.

The spectrum analyzer must, at a minimum, be capable of being programmed to take repeated level measurements over a defined frequency range and must be capable of downloading those measurements to the attached PC.

- **Data Gathering and First Level Analysis**

Method A: External Data Reduction

Program the analyzer to make repeated measurements of peak power level over the entire upstream band. The number of measurement points must be such that the frequency increment between points does not exceed 100 kHz. Set the resolution bandwidth to 100 kHz and the video bandwidth to 300 Hz. If the sweep rate does not automatically set itself to compensate for the bandwidth, manually set it so that the dwell time at each frequency is at least 2 ms.

Set the analyzer to take data over a window of no more than one hour (shorter time periods will give greater time resolution to the results, but will multiply the total database size by the same ratio). The data from each sweep during the measurement window must be downloaded to the PC for analysis. If the data from all sweeps during each time window can be stored within the analyzer, then downloaded at the end of the window, the results will be better than if the data from each sweep must be downloaded before another sweep can begin, however, the memory requirement may exceed that available in the analyzer. For instance, with 401 measurement points and 2 ms time per point, the sweep time will be about 3 seconds and therefore 1200 sweeps will be completed in one hour. If the data is stored within the analyzer and each data point requires 2 bytes of storage, then about 1 MB of storage will be required.

The PC should have two 3-dimensional matrices defined to hold the data. One axis of each matrix should be measurement frequencies, the second should correspond to the defined threshold levels, while the third corresponds to the successive time windows. The first matrix will contain “raw data” counters, while the other is the

“DISP” matrix. In addition to the matrices, a sweep counter variable needs to be defined for each time window to hold the number of analyzer sweeps during that window.

Initialize the counter variables and the raw data matrix values (all integers) to zero. Non-integer values in each cell in the DISP matrix should be equal to the value in the corresponding cell in the raw data matrix divided by the value in the sweep counter variable for the corresponding time window.

The downloaded data from each sweep will typically appear as a serial listing of peak levels at successive frequencies. The peak level information for <u>each frequency</u> should be used to modify the values in one column of the raw data matrix as follows:

1. Compare the received level at the first frequency with the lowest defined threshold. If it is greater, then increment by one the value in the raw data matrix corresponding to that threshold, frequency and time window.
2. Move to the adjacent cell in the raw data matrix that corresponds to the next higher threshold (at the same frequency and time window) and repeat step 1.

When the processing of data from the lowest frequency is complete, then increment the frequency and repeat.

When all the data from one sweep is processed, the sweep counter variable for that time window should be incremented by one.

When the time window has expired, repeat for additional measurement windows. Data should be taken over at least 24 hours and additional sets of 24 hour data should be taken to determine the consistency of the results.

The result of this process will be a raw data matrix with cells representing specific frequencies, threshold levels and time windows. The integer values in those cells will be the number of sweeps during the time measurement window for which the measured levels exceeded the defined threshold.

The DISP matrix will also have dimensions representing frequencies, time windows and threshold levels, as shown in Figure 1, but the each value, U1, will represent the probability that a signal is present at frequency F1 and in time window T1 whose level exceeds threshold level L1.

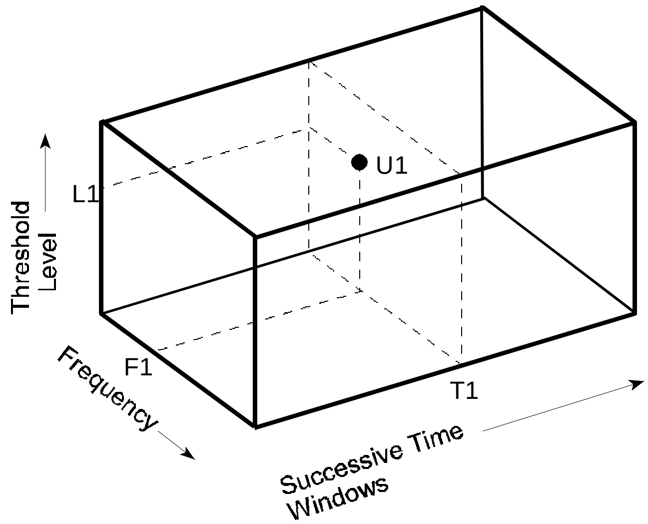


Figure 1: Discrete Interfering Signal Probability (DISP) Data Base

Method B: Internal Data Reduction

Some spectrum analyzers include the capability to create the two-dimensional raw data matrices corresponding to each time window internally using a “PDF” function, whereby the various threshold levels are downloaded to the analyzer and “virtual traces” are defined, each of which contains counters, as a function of frequency, of the number of sweeps for which the level exceeded one threshold level. A master sweep counter is also included.

Using the internal PDF function, the data for all the sweeps in a time window are summarized into one set of values for each defined threshold and can be directly downloaded into probability matrices in the PC at the end of each time measurement window.

- **Data Post Analysis**

The data from the DISP matrices can be analyzed in various ways to quantify the discrete interfering signal performance of the system. In the case of cable systems which are already transporting upstream signals, a preliminary step to data analysis is to exclude measurements of already-occupied frequencies. The following are illustrative of useful interpretations of the remaining unavailability data.

Average Discrete Interfering Signal Probability (ADISP) vs Threshold Level

First, for each threshold level, average the DISP numbers across frequency and time (see Figure 2). This value is the Average Discrete Interfering Signal Probability (ADISP) for a given threshold value. Plot this against threshold level (relative to the Reference Level). The result is a service-independent plot of ADISP vs relative threshold level. This is the most fundamental measure of system performance and the primary result of this procedure.

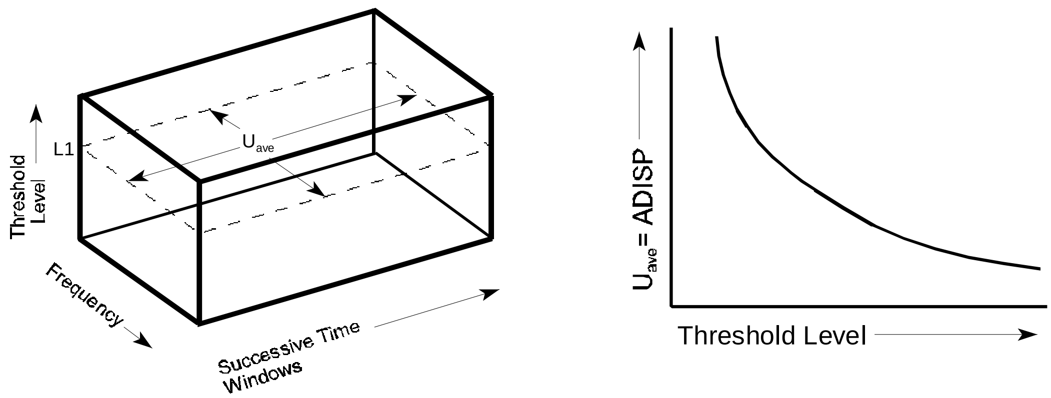


Figure 2: Average Discrete Interfering Signal Probability vs Threshold Level

DISP vs Frequency and Threshold Level

First, at a given threshold level, plot the time average of each frequency's DISP vs frequency (see Figure 3). Then, using a multi-line chart, add lines for all the threshold values of interest. This chart allows prediction of performance vs frequency and operating level.

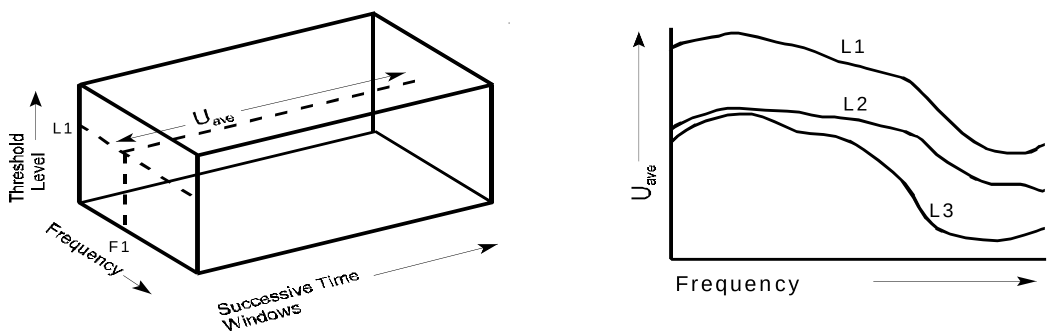


Figure 3: DISP vs Frequency and Threshold Level

Specific Frequency DISP vs Time and Threshold Level

Plot the DISP of a specific frequency at a threshold of interest vs time (see Figure 4). Repeat, if desired, for different thresholds. This allows an analysis of the time variance of the DISP at a specific frequency and how it varies with operating level.

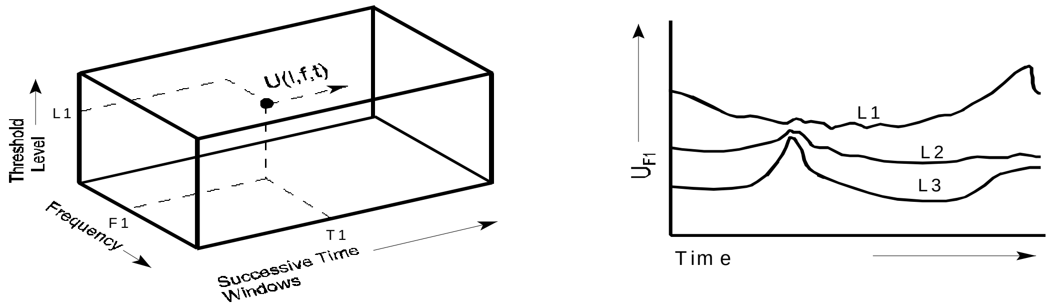


Figure 4: Specific Frequency DISP vs Time and Threshold Level

Specific Channel Unavailability (SCU)

Where specific services have channel bandwidths that exceed the frequency resolution of the raw data and operate at specified signal levels, channel unavailability can be determined similarly to Specific Frequency DISP vs time, except that instead of plotting the DISP of a particular frequency and defining the thresholds relative to the total power handling capability of the network, it is necessary define the levels relative to the onset of destructive interference for the service in question and to plot the highest DISP of all the frequencies within F1±BW/2, where F1 is the channel center frequency and BW is the susceptibility bandwidth of the service (see Figure 5). Note that this is an approximate process, as two simultaneously occurring interfering signals within the susceptibility bandwidth could individually be less than the threshold, but their instantaneous voltage sum could cause interference.

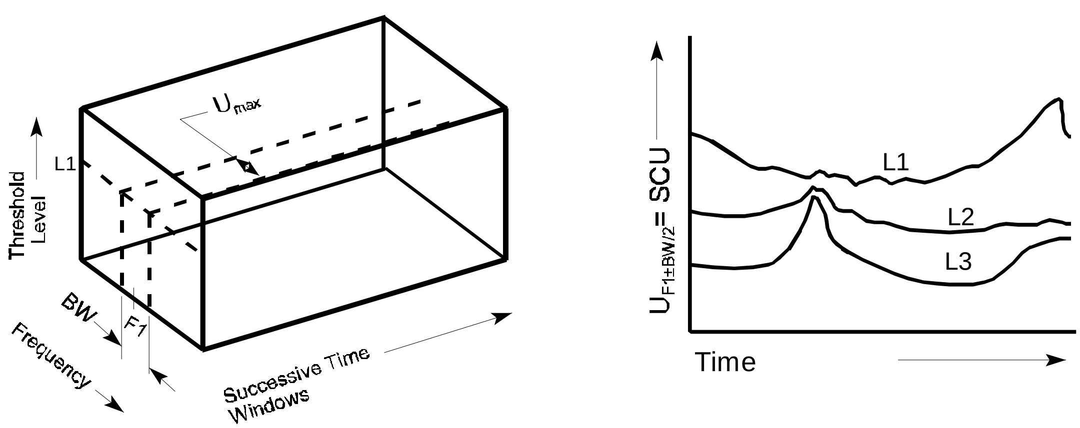


Figure 5: Specific Channel Unavailability (SCU) vs Operating Level

DISCUSSION

The measurement of ingressing signals of all types (plus common path intermodulation products) is, necessarily, a statistical process. Unlike downstream measurements, the signals measured are generally not under the control of the operator and occur semi-randomly in level, frequency, time and location. This procedure is a method whereby a system can be evaluated with respect to the average presence of upstream potentially-interfering carriers. Since absolute levels are difficult to analyze and summarize in a meaningful way and are of secondary interest relative to their effects on communications, the procedure simply determines the percentage of time they exceed one of several defined thresholds. Since the thresholds are defined only relative to the total signal handling capability of the network, the DISP is totally independent of specific system operating parameters or operating signal levels.

Where systems being evaluated are partially loaded with existing intentional carriers, the frequencies occupied by those carriers should be excluded from the analysis. It is understood that analysis of systems with a significant percentage of frequencies occupied will be less accurate than systems with no upstream traffic.

The measurements taken using this procedure will be no better than the raw data. For instance, if analyzers are used which must download the data from each sweep before the next sweep is started, then the majority of time may be taken up with data transfer and many interfering signals may not be detected. Similarly, if only a single day's data is taken and interfering signal levels vary widely from day to day, the data may be statistically meaningless. The statistical accuracy of the measurement process in either case can be improved by taking data over longer periods of time and averaging the results in each time/frequency/threshold cell of the probability matrix.

The choice of analyzer bandwidths is a compromise. 100 kHz was chosen as it was wide enough to contain all common-path intermodulation components in any one group and also wide enough to contain all the sideband energy from expected ingressing signals, yet narrow enough to be useful in identifying usable frequency ranges for upstream signals without being so narrow that the quantity of data to be gathered becomes unwieldy. A wider resolution bandwidth would also reduce the sensitivity because the effect of integrated wideband noise.

300 Hz was chosen as the video bandwidth in order to exclude electrical transients: the rise time at that bandwidth is about 1.1 ms, while most transients are no more than a few µs long. Making the bandwidth even smaller would have unnecessarily lengthened the required dwell time at each frequency, while making it longer would admit some transient energy.

3.7 Modulation Distortion at Power Frequencies

Definition: Modulation distortion at power frequencies ("Hum") is the amplitude distortion of the desired signals caused by the modulation of these signals with components of the power source. For video signals, it is the percentage of the level of the peak-to-peak interference compared to the rms value of the visual signal sync peak level of the RF signal. An equivalent measurement for digital signals is the percentage of the peak-to-peak variation of the signal amplitude compared to the average signal amplitude for a signal which has been averaged over a time period which is very much greater than a symbol time but less than 1 millisecond.

Discussion: It is important to recognize that Hum modulation has no meaning for TDMA digital signals with time periods much less than 16.7 milliseconds. It should be noted that the definition of Hum modulation given here is similar (but not identical) to the traditional definition of percentage of modulation, which is the ratio of percentage of the peak level of the desired signal to the peak level of the unmodulated carrier.

It should be noted that test equipment may exist which can make Hum measurements automatically. The "Discussion" in Section I.A: “Modulation Distortion at Power Frequencies” treats some of the possible variation that may occur among test instruments.

Procedure

The general procedures for low frequency disturbances (Hum) are detailed in Section I.A: “Modulation Distortion at Power Frequencies”. When using the Spectrum Analyzer method use the following settings:

- Resolution bandwidth 10 kHz to 30 kHz
- Video filter 1 kHz.

3.8 Reflections

Definition: Reflections are the result of impedance mismatches between elements in the cable plant such as amplifiers, couplers, splitters and the coax that connects them. When an upstream signal encounters a mismatch, a portion of the signal is reflected back towards the signal's source. The magnitude of the reflected signal depends on the degree of mismatch. This reflected signal is then re-reflected by the mismatch at the source. The re-reflected signal is then traveling upstream where it arrives at the headend as a reduced version of the desired signal which has been delayed in time. Depending on the size of a reflection, it can be a significant source of interference resulting in a reduction in the bit error rate performance of the system.

Modems with adaptive equalizers can cope with substantially greater reflections with short delay times (usually several symbol times) than they can with delays beyond the equalizers limits. Because of this time sensitivity, there is value in knowing reflections in both amplitude and delay time. Modems with adaptive equalizers that can be interrogated as to the equalizer setting can be valuable indicators of reflection problems.

Procedure I: (Out of Service) The 2T pulse in the NTSC multipulse test signal may be used to look at reflections with time delays in the range of about .125 to 1.0 microseconds. The actual maximum delay that can be observed is limited by the time spacing of the multipulses. Some NTSC waveform generators can be set to have only the 2T pulse which extends the maximum time delay which can be observed to as much as 30 uSec .

The method described in this procedure uses simple amplitude detection producing results which are a function of the test frequency and the reflection delay. In order to determine the maximum value of a reflection, the test frequency must be varied until the maximum reflection is observed.

Required equipment

- NTSC multipurpose video signal generator
- Reverse modulator with 250 kHz or less frequency steps
- Reverse demodulator with 250 kHz or less frequency steps
- Waveform monitor

1. Connect the equipment as shown in Figure 1.
2. Set the modulator's output to the closest T channel for the frequency band of interest.
3. Set the demodulator to the selected channel.
4. Observe the 2T pulse on the waveform monitor. See Figure 2.
5. Set the 2T pulse to 100 IRE.
6. Observe and note the amplitude of the reflections.
7. Change the modulator and demodulator’s frequency by 250 kHz. Note: Finer steps may be used to improve accuracy.

8. Observe and note the amplitude of the reflections
9. Repeat steps 7 and 8 until the maximum reflection is noted. The frequency of the test signal may need to be moved over several MHz depending on the length of coax involved in the reflection.
10. Note the maximum reflection

Reflections = 20 log (refl (IRE)/100 IRE)

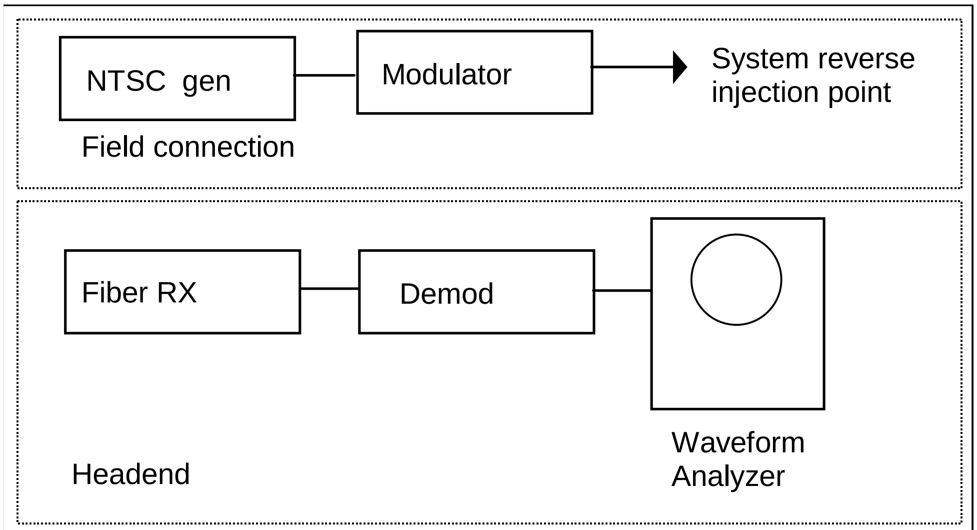


Figure 1. Equipment connection

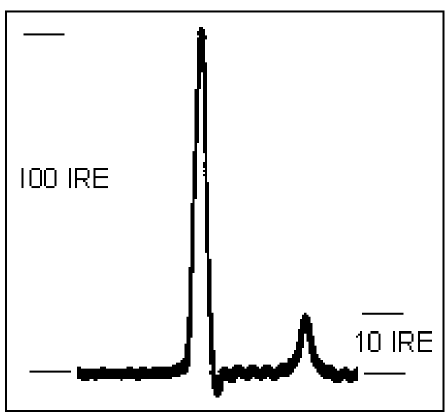


Figure 2. 2T pulse with - 20 dB reflection

Procedure II: (Out of service) A signal generator with pulse or square wave modulation capability is injected into the system at the desired point. The pulse is then displayed on a Digital Storage Oscilloscope located at the headend.

The resolution of this test is limited by the fall time of the Signal Generator pulse. A fall time on the order of 75 nSec will resolve reflections involving approximately 25 feet of coax. Longer fall times will result in proportionally less resolution (limited to reflections involving longer runs of coax). In any case, it is desirable to have the fall time less than 1 symbol time for the highest speed data to be carried.

Required equipment

- RF signal generator with pulse modulation capability having an ON/OFF ratio at least 10 dB greater than the reflection to be measured
- Pulse generator or function generator
- MHz digital oscilloscope

1. Connect the equipment as shown in Figure 3.
2. Set the signal generator's output for the center of the channel of interest.
3. Set the pulse/function generator to produce a 100 kHz square wave.
4. Observe the pulse on the digital oscilloscope.
5. Set the leading edge of the pulse to full scale. Note that reflections delayed by less than the pulse width will cause distortions in the pulse amplitude. It is important to establish the reference amplitude very near to the leading edge of the pulse and observe the variations from this reference. Also note that pulse distortions may be an indication of group delay problems.
6. Use single trigger to capture the leading edge of a pulse near the left edge of the display and adjust the sweep time to place the reflections near the right edge. See Figure 4.
7. Observe and note the amplitude of the reflections with respect to the full scale amplitude of the pulse.

Reflections = 20 log (refl (div)/leading edge div)

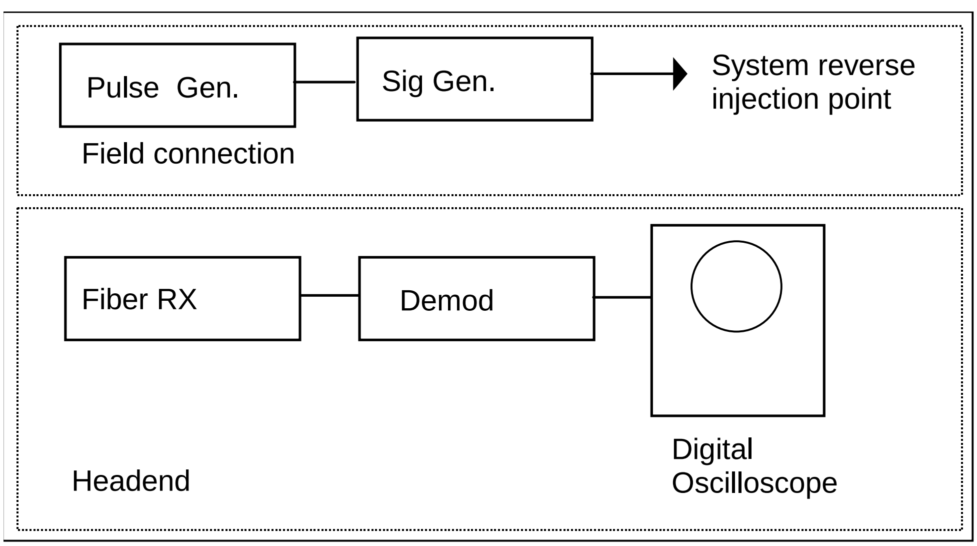


Figure 3. Equipment connection

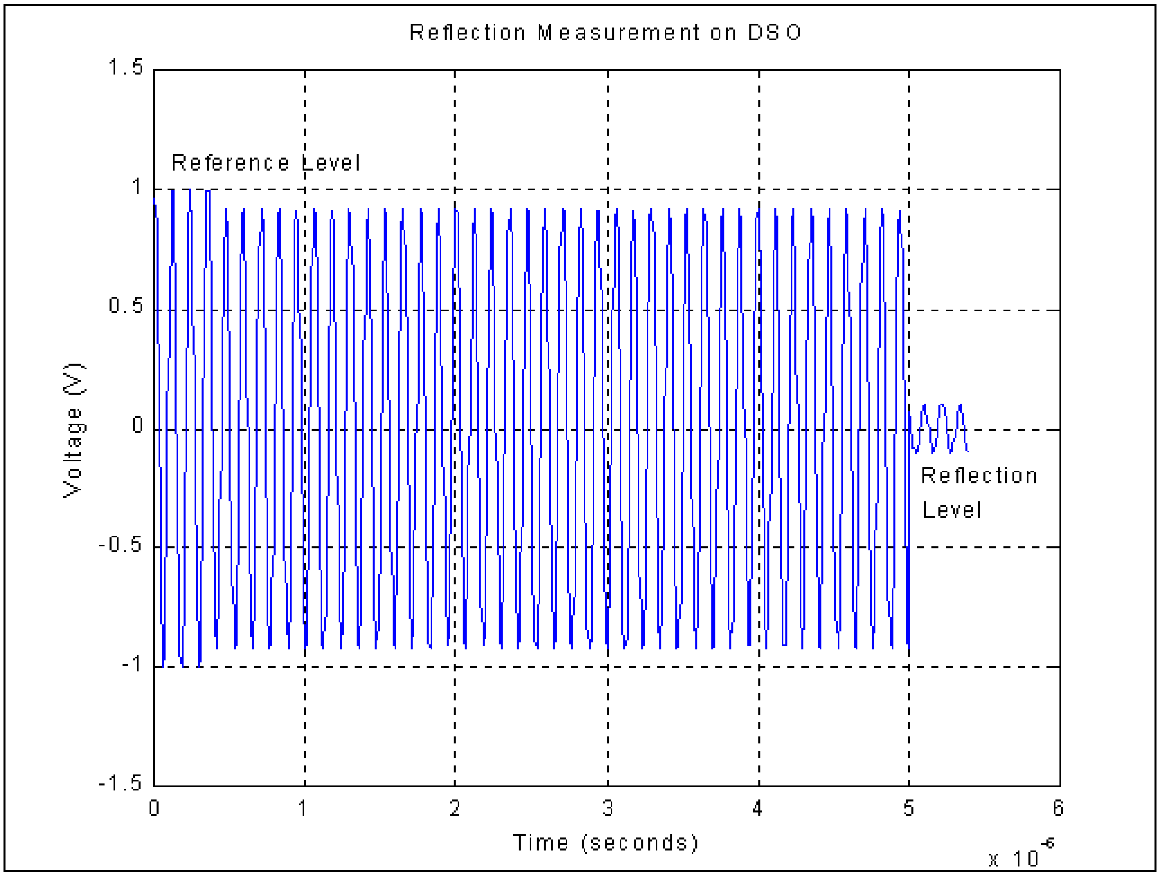


Figure 4. Example of -18 dB reflection

Chapter 4: Troubleshooting

4.1 Diagnostic and Troubleshooting

The goal for this chapter is to provide a **Diagnostic and Troubleshooting** process that allows proper repair and re-commissioning of the plant.

Diagnostic and Troubleshooting

The main objective of a diagnostic and troubleshooting process is to narrow the type and possible source of impairments as early as possible. The diagnostic should establish the type of the impairment and the troubleshooting should indicate the source of the impairment.

Diagnostic

The impairments can be generally categorized as additive and multiplicative. The additive impairments add to the desired signal power. Hence, they are present and can be monitored even without the desired signal being present. The multiplicative impairments are induced on the desired signal. Hence they can be discovered only with the desired signal being present. In extreme cases, the level of additive impairments can cause multiplicative impairments when the desired signal is added (laser clipping, reverse amplifier saturation, etc.).

The additive impairments can be further classified as intrinsic and extrinsic:
<u>Intrinsic additive impairments:</u>

- thermal noise (controlled by the design and alignment accuracy)
- common path distortions
- arcing impulse noise (in connectors and seizing mechanisms)
- oscillations

<u>Extrinsic:</u>

- impulse noise ingress,
- discrete (coherent) signal ingress,
- conducted interference.

The multiplicative impairments can be classified as:
<u>Level dependent:</u>

- distortion caused by substandard elements,
- distortion caused by level misalignment, or

<u>Channel characteristics:</u>

- frequency response inequality
- group delay inequality
- intermittent connections,
- hum,
- sheath currents, transients, and spikes
- loss of continuity and gain

A totally independent set of problems is bad design where the levels from different customer terminals arrive at the headend terminal at different levels due to the miscalculation of the loss between the terminal unit and the first active or excessive loss in the reverse splitting/combining network in the headend.

Although the above classification is very helpful in understanding the effect of impairments, it has little use in fully operational reverse systems. In less loaded systems with some un-occupied bandwidth, some additive impairment levels can be continuously monitored (thermal noise, impulse noise, common path distortion falling into the monitored bandwidth, and discrete interference falling into the monitored bandwidth).

Some of the multiplicative impairments can also be continuously monitored by monitoring the spectrum and level of the desired signals (frequency response inequality, intermittent connections, hum, loss of continuity and gain). If more sophisticated test equipment is available, more impairments can be continuously monitored (for example by the analysis of the eye pattern and constellation, many impairments can be monitored and classified). A bit-error-rate (BER) test can also help.

Additionally, the communication equipment itself can provide some performance statistics to indicate transport system degradation.

Troubleshooting

Three major plant components can be generally singled out as sources of the impairments. These components are:
1. reverse optical link,
2. coaxial main line (trunk and distribution),
3. installation (outside and inside).

In many cases, the spectrum of the impairments in connection with their type will unequivocally indicate their source. For example, thermal noise with spectrum limited to the diplex filter bandwidth with noise filters installed will indicate that the main line actives are the source of the noise. If the high thermal noise extends above the upper limit of the reverse bandwidth, the optical link is the source. Common path distortions expanding within the entire reverse bandwidth in plant with no AC power in drops or with noise filters installed at the tap spigots would indicate that the main line connectors and interfaces are the source. This analysis can be applied to many additive impairments and some multiplicative impairments. The higher level of experience of the field personnel, the easier the troubleshooting based on the monitoring results.

After the main components of the network are identified, further troubleshooting effort should use the following practical guidelines:

The escalation steps in systematic troubleshooting for optical links are:
1. measuring received optical power at the test point and comparing with the records,
2. disconnecting and cleaning connectors at the hub,

3. replacing receiver module,
4. cleaning connectors at the node,
5. replacing reverse laser,
6. OTDR test (bi-directional) and optical link loss test.

Most of these steps result in service disruption. Therefore, they should be used only as allowed by the local outage management policy (demand maintenance caused by emergency or preventive maintenance within the maintenance window). The process should be stopped as soon as the problem is corrected.

If the RF section is the contributor, the following procedure should be used:

1. monitoring at the inputs to the next reverse cumulating point (line passive or minibridger),
2. if none of the legs at this point shows the problem, troubleshoot upstream,
3. if any leg shows the problem, troubleshoot the leg(s),
4. after completion of the leg(s), re-test the reverse at the hub,
5. if problem persists, troubleshoot upstream of the first cumulating point,
6. re-test the reverse at the hub to confirm successful completion.

A flowchart in Figure 1 depicts the logical flow of the diagnostic and troubleshooting process.

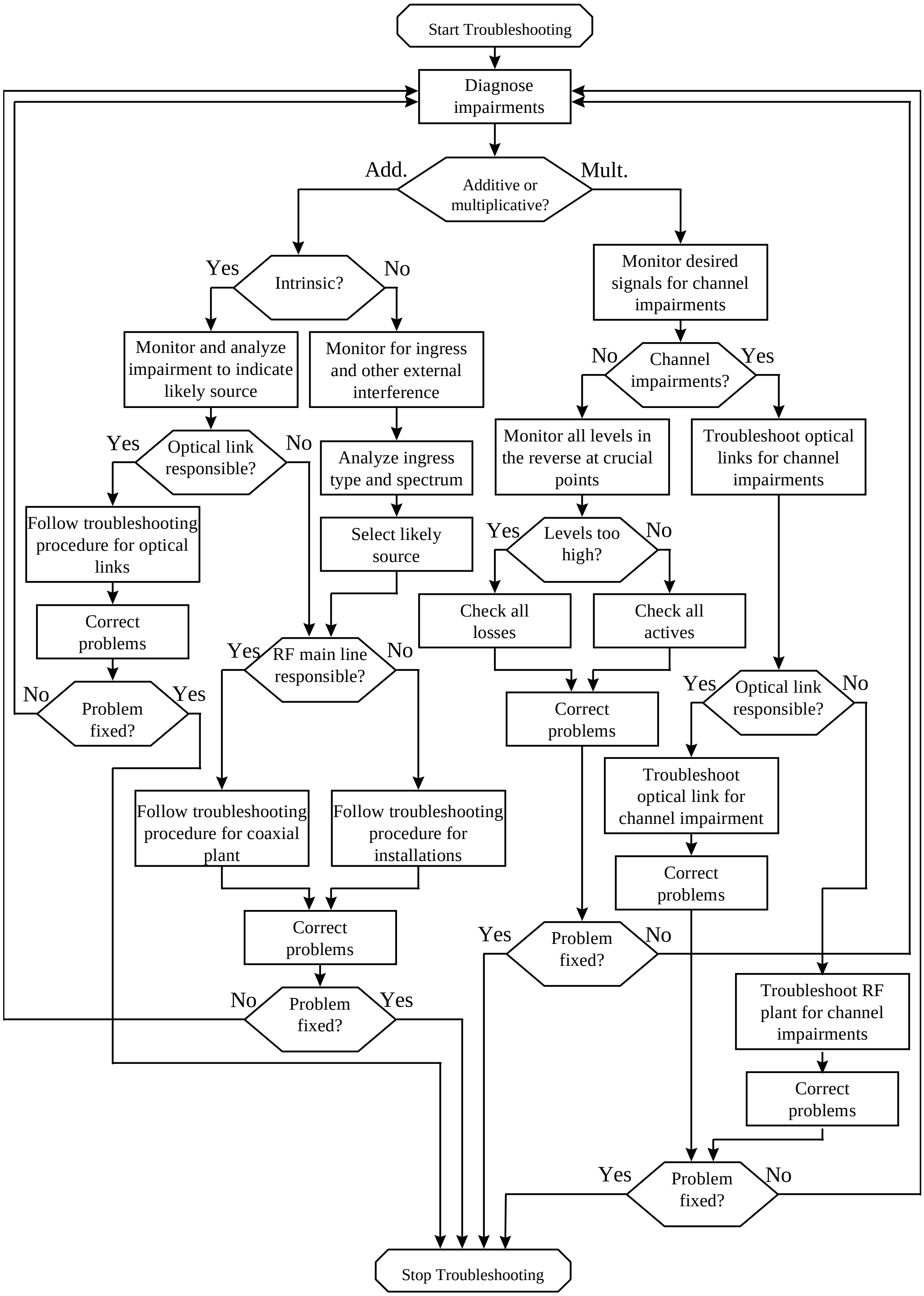


Figure 1: Diagnostic and Troubleshooting Flow Chart

Chapter 5: Possible Future Enhancements

5.1 Multicarrier Testing

Out-of-service:
An alternative approach to both the two carrier and the noise notch testing is to use two groupings of many carriers. If properly generated, these groups of carriers will have a high peak-to-average ratio (similar to a fully loaded return or a noise loading test), but will cause localized clusters of beats (CSO and CTB). The distortion effects are easily separable from the noise effects. It could be a “best of both worlds” measurement, but requires specialized equipment and calculation of correction factors.

5.2 Second Order Effect Observations

In-service:
A method to warn of imminent laser clipping could be to look at the 40 to 80 MHz spectrum. The only signals present in this band will be due to distortion and clipping. Specialized equipment and calculation of correction factors are required.

5.3 Enhanced Modem Features (To Improve In-Service Monitoring)

There are a variety of test methods used on high speed data circuits that can simplify the diagnostic efforts of modem and plant performance, although the techniques haven’t been commonly used in the cable industry.

Constellation diagrams and/or eye diagrams are sensitive to, and can be used to differentiate the effects of impulse, ingress or thermal noise, low frequency disturbances, phase linearity and noise, and intermodulation.

For example, when all the available time slots are filled in by the modem for the “test status” of a TDMA link, many useful measurements can be made at any point of demodulation, to include noise data, bit error statistics, and eye diagram statistics. If a known word is “repeated” continuously by the modem in a test condition, bit error statistics can be derived at any point of demodulation.

Furthermore, modem and digital settop manufacturers can make available the contents of their Simple Network Management Protocol Management Information Base (SNMP MIB) table entries. This information could be very helpful for system monitoring, diagnosing and troubleshooting.

Signal processing can further reveal deterministic traits such as CW interference, laser clipping onset or headroom, and phase linearity and noise issues.

These methods and others are accommodated in the various standards body activities, but incorporation will vary by OEM. They may also be resident in various status monitor and control systems.