Ingress Margin Improvement
in
Sub-Low Return HFC Plant

Paul D. Brooks – Staff Engineer

Engineering and Technology – Plant Engineering Department

TIMEWARNER CABLE

Englewood, Colorado

ABSTRACT

Many engineers regard the task of overcoming ingress as the most difficult in reliable operation of return plant. Because ingress levels are dependent only on source characteristics and physical coupling "receiving antenna" mechanisms, every dB of operating level is one additional dB of ingress immunity. Since the physical coupling mechanisms have historically been difficult to control, it is essential to operate signal sources at the highest possible levels in order to "buy margin" over ingress sources.

This paper will introduce three techniques of ingress margin improvement:

1. *Leveling of tap port sensitivity through purposeful introduction of loss in the sub-low band.*

2. *Leveling of tap port sensitivity by a new approach to selection of return amplifier input levels.*

3. *A brief examination of the upper limits of existing terminal device output levels and power densities, and the implication of these limits on the selection of the operating points of return amplifiers as these operating points pertain to ingress margin.*

INTRODUCTION

Ingress is only harmful when it becomes high enough in power to affect the transmission of information. This can occur in two ways:

1. High levels of ingress can cause clipping or intermod products in an active device.

2. When located within its passband, the ingress can overcome the wanted signal such that there is no longer sufficient margin to reliably transmit the desired information.

Since ingress power and coupling efficiency typically cannot be controlled, the margin can only be increased by raising the power of the desired signal, while decreasing the sensitivity of the network such that the power received at the return laser transmitter remains constant.

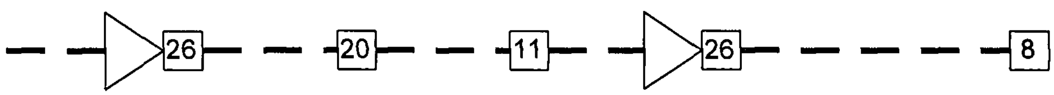
The sensitivity of the sub-low return plant is not equal at all potential ingress input sites. Instead, this sensitivity varies based on the location-dependent loss between a given tap spigot and its respective amplifier return input. Sensitivity also varies based on the operating point selected for each amplifier return input and its relationship to the forward output level upon which tap value selection rules are based.

It is well established that in a properly maintained plant, most ingress enters the sub-low return spectrum in the house drop, and specifically in the subscriber premises portion of that drop.

For the purpose of simplification, this paper will assume that all ingress fields are uniform throughout the service area, and that each tap has a total ingress sensitivity independent of the number of tap spigots and the nature of the drop plant. In practice, certain ingress fields have a strong local component, and tap sensitivity is dependent on the number of connected drops at a given tap location, and the summed coupling effectiveness of these drops. Ingress sensitivity is examined at 40 MHz in the return spectrum. While it can be shown that a greater disparity in sensitivity exists at 5 MHz, the value of these techniques is evident even at the higher cable loss frequency of 40 MHz.

Location Dependent Tap Spigot Sensitivity

In light of the above assertions, it is entirely possible that a large portion of the return plant ingress "gets in" at low value taps which are deployed downstream of longer cable segments. This assertion leads to one potential means of significantly reducing total ingress power. Additional loss could be purposely introduced in the sub-low band to force remotely located return signal sources to operate at levels comparable to devices proximate to amplifier outputs. This technique would also reduce the need for wide output attenuation ranges, which require complex circuitry and can consume power, particularly in NIUs with relatively wide, spectrally dense outputs.



Losses in dB	Tap	Cable	Tap	Cable	Tap	Gain	Tap	Cable
750 MHz	.8	10.85	1.1	8.68	4.8	29.48	.8	26.04
50 MHz	.3	2.70	.7	2.16	3.4	10.07	.3	6.48
40 Mhz	.3	2.45	.7	1.96	3.4	9.55	.3	5.88
5 MHz	.3	.80	.8	.64	3.5	6.28	.3	1.92

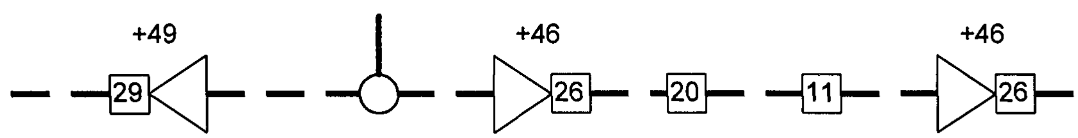
Levels in dBmV	Amp Port	26-4 Tap Spigot	20-4 Tap Spigot	11-4 Tap Spigot	Amp Port	Amp Port	26-4 Tap Spigot	8-4 Tap Spigot
750 MHz	46	20	14.35	13.57	16.52	46	20	13.33
50 MHz	35	9	12.0	18.14	24.93	35	9	20.76
40 Mhz	17	**43**	**39.75**	**33.41**	26.55	17	**43**	**30.69**
5 MHz	17	**43**	**38.10**	**30.54**	23.28	17	**43**	**27.06**

Figure 1.

Figure 1. shows the losses and levels in an example coax feeder. The required tap spigot return inputs are shown in bold. This example is included to illustrate the reason for the variation in tap port sensitivity. In this case, the 8dB 4 port end of line tap is over 12 dB more sensitive to ingress than the 26 dB taps at 40 MHz.

The Practice of Forward Output Derating

Amplifier return inputs in today's HFC networks are normally set to a uniform level at all actives in the feeder portion of the plant, with no regard to the typically non-uniform forward output levels. This practice causes taps downstream of lower output feeder actives to have greater ingress sensitivity than taps fed by higher output feeder actives. The return input level of any active which directly feeds taps should be scaled in inverse proportion to its forward high channel output level. For instance, if a given line extender has a forward high channel output of +49 dBmV and a return input of a flat +17 dBmV, then a "derated" line extender with a forward high channel output of +46 dBmV (3 dB lower) should be set to a return input of +20 dBmV (3 dB higher). This technique will reduce sensitivity to ingress on taps fed by derated line extenders.



Levels in dBmV	29-4 Tap Spigot	Amp Port	Amp Port	26-4 Tap Spigot
750 MHz	20	49	46	20
50 MHz	9	38	35	9
40 Mhz	**46**	17	17	**43**
5 MHz	**46**	17	17	**43**

Figure 2.

In Figure 2. the coax feeder of figure 1. is joined by a non-derated feeder fed from the same bridger output. The required tap spigot return inputs are shown in bold. Note that taps in the derated feeder are 3 dB more sensitive to ingress. This example is included to illustrate how tap port sensitivity is affected when forward levels are derated and return levels are left alone. If return amplifier inputs are increased in proportion to the decrease in forward outputs, the disparity in tap sensitivity is eliminated.

Plant Design Analysis

Example Plant Characteristics

An existing 350 mile cable system was analyzed to examine the value of these techniques. This typical, midwestern, mostly aerial plant was comprised of 38 service area nodes passing about 23,000 homes. Density ranged from 10 to 190 homes per mile. The RF cascade limit was two trunks, one terminating bridger, and three line extenders. Minimum tap port levels were 11 dBmV to 13 dBmV at 750 MHz depending on drop length class. Tilts were a uniform 11 dB, with bridger ports at +48, single line extenders at +49, and both two and three extender cascades derated to +46 dBmV. In should be noted that if a third deration step of 5 dB down were to be used for the three extender cascades, a greater improvement to ingress margin would be attainable than in this design, where LE levels were chosen at a uniform +46dBmV.

Software and Methods

The design software tool employed here provides a "test window" function. This optional function reports instances where the difference between the specified maximum tap spigot return input and the calculated spigot input requirement exceeds a user defined threshold.

If this threshold is set to .001 dB, then the network location and magnitude of each calculated spigot return input level variance is reported for every tap. These differences, reported in dB, indicate differences in tap port sensitivity.

The software provides automation capability which allowed rapid evaluation of these large plant sections. While separate "test window" thresholds are available at 5 MHz and 40 MHz, only the 40 MHz test was performed. As stated earlier, the 5 MHz test produces more dramatic results, but the 40 MHz test results represent the minimums which hold throughout the entire sub-low spectrum.

Results of Plant Analysis

A baseline was established to represent the sensitivity of this plant to a power summation of all signals present at the tap spigots, and therefore to global ingress sources. With this baseline normalized to zero dB, the table (Figure 3.) represents the results of various ingress margin improvement techniques.

While all numbers in the table are based on analysis of actual design, the "theoretical" equalizer step size improvements are extrapolated based on the assumption that with a lossless device, the "not to exceed" step size will produce a sensitivity reduction such that the summed power of all tap ports will average one half of the step size. Also, the "theoretical" numbers assume equalization of tap ports independent of the through path.

Ingress Margin Improvement Results

Item	Description	dB
1.	Theoretical port eqs, continuous	7.19
2.	Theoretical port eqs in 1 dB steps	6.69
3.	Theoretical port eqs in 3 dB steps	5.69
4.	Theoretical port eqs in 6 dB steps	4.19
5.	Theoretical port eqs in 9 dB steps	2.69
6.	Increased levels at derated LEs	1.53
7.	6 dB feederline eqs to 5 MHz	3.22
8.	Items 6. & 7. combined	5.10

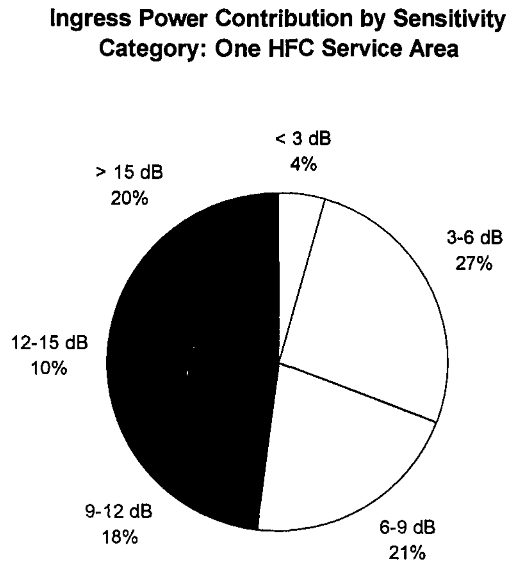
Figure 3.

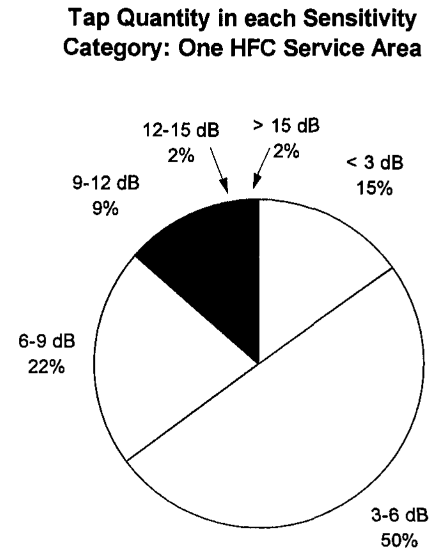
Design Runs

Items 6, 7, and 8 represent individual design runs where all 350 plant miles were redesigned each time. Item 8 produced results better than 6 and 7 summed; this is due to the fact that with higher return outputs, feederline equalizers could more often be placed between the bridger port and the first extender. The margin improvement of 3.22 dB shown in item 7 shows generally good agreement between implementation and the 4.19 dB theoretical limit of item 4.

Feederline Equalizers to 5 MHz

In item 7, a fictitious but reasonable feederline eq was specified to have 1 dB of insertion loss, and a characteristic equal to the inverse of 6 dB of cable at 750 MHz. Where this device differs from today's line eq is that no diplex filters are used; the response is well behaved down to 5 MHz. The elimination of diplex filters should allow for the low insertion loss (1 dB) and should also provide lower cost of manufacture. In item 7, only tap plates were allowed to be changed. All cables and amplifier locations were retained, and no new amplifiers or cables were added. Line equalizers were only placed where the existing plant had sufficient gain to allow re-balancing to correct forward and return levels. A total of 274 equalizers were used, about 0.78 per mile.





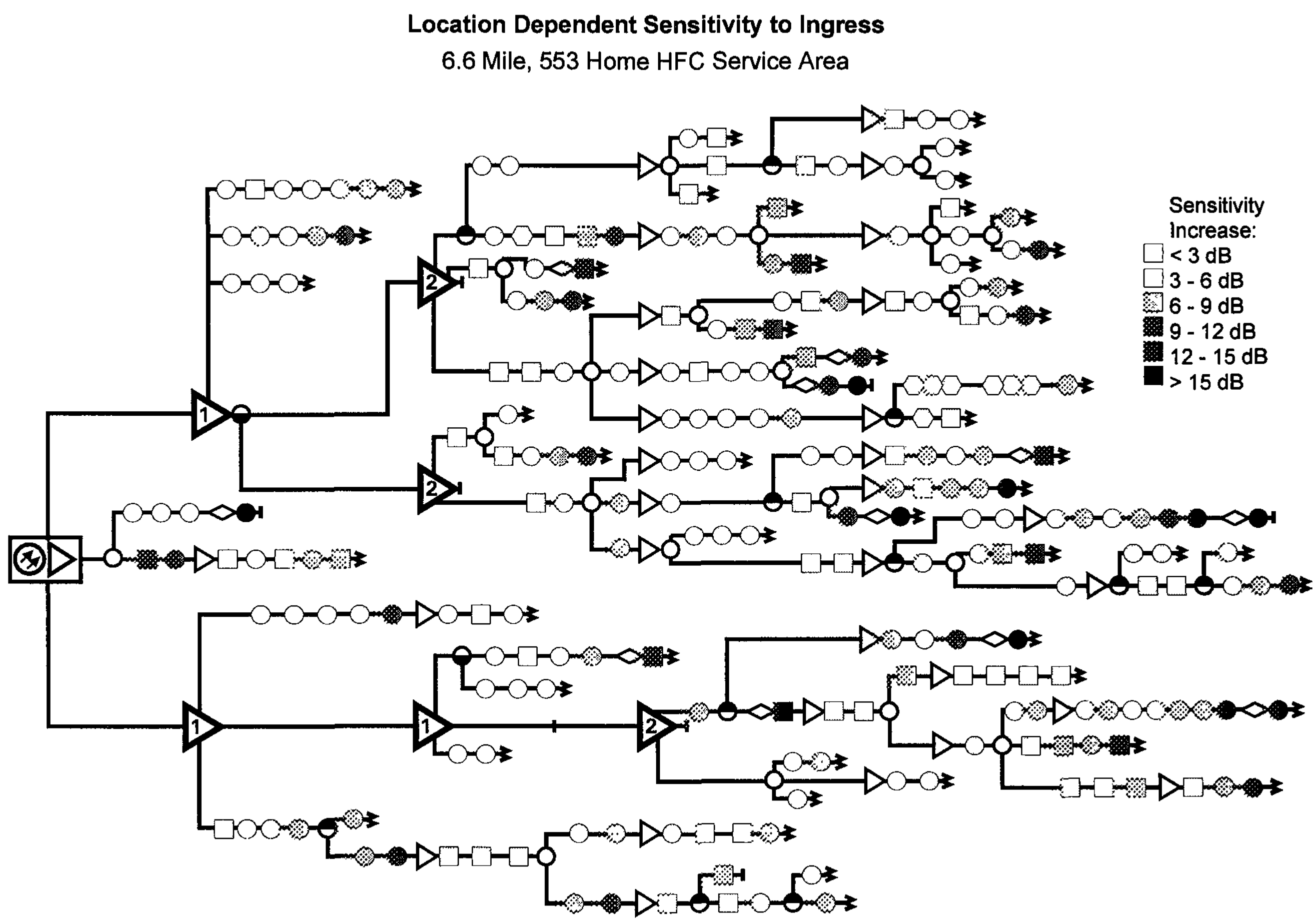


Figure 4.
A Typical Service Area Node

A Typical Service Area Node

Figure 4 provides insight into how location dependent ingress sensitivity operates in a typical node. The pie charts and node diagram were developed from one existing node designed without use of margin improvement techniques. The sensitivity variance is a combined result of tap location and the derating effect. The pie charts, taken together, contrast the ingress power contribution vs. the quantity of taps in each sensitivity range. The diagram shows where these taps are located in a real design.

Optimizing Return Operating Points

Return Plant Alignment Theory

Return operating levels are shown in figures 1 and 2 of this paper for the purpose of clarity. In practice, levels in the return plant are arbitrary and meaningless without a reference to the bandwidth of the signals being carried.

For the purpose of the following discussion, the terms "upstream" and "downstream" refer to the cable and equipment between the amplifier under test and the headend, and further from the headend, respectively.

When return plant is aligned, the gain of each amplifier is adjusted to exactly compensate for the cable and passive losses of the upstream "span" or "spacing." As long as the alignment signal is locally injected at the amplifier, it makes no difference what levels are used, provided no interference is caused, and the levels are within the useful dynamic range of the amplifier under test. These test signals are measured at the local amplifier return output, at the input to the upstream amplifier, or at the headend with certain automated test equipment. Return pads and equalizers are then selected based on these measurements, thus establishing a "unity gain" system.

Modern terminal devices provide remote output level adjustment capabilities which are typically controlled from the headend. As such, final operating level adjustment is normally performed "after the fact" of plant alignment.

The Alignment Reference

The Fabry-Perot return laser transmitter, collocated in the field with the optical receiver, typically determines both the upper and lower limits of the dynamic range of HFC sub-low return plant. Therefore, the input power levels supplied to this transmitter establish the system operating point, based on a tradeoff between noise floor margin and overload margin. Once this operating point is determined, the amplifier gains can be specified to best utilize all of the available terminal device return output power. The methods of establishing this operating point are beyond the scope of this paper.

If the optical receiver/transmitter supplies signals directly to tapped feeders, it will likely be necessary to select appropriate pads to balance these return inputs against other ports which feed only amplifiers. These pads provide for the use of high terminal device outputs by preventing the laser transmitter overload point from imposing a false limit on the maximum useable terminal device output levels.

Ingress Margin Improvement

Every dB of usable terminal device output level improves ingress margin by one dB. The degree of improvement possible is limited only by the compression point performance of the amplifier return modules.

Amplifiers used in HFC plant should have their return operating points selected based on knowledge of compression points of the return gain blocks. The chosen operating points are located below compression by reasonable safety factors. Terminal devices such as converters and telephony NIUs need adequate return output capabilities to attain the desired return amplifier output power.

5 to 40 MHz Operating Levels: Power outputs in dBmV, gains and losses in dB						
Power bandwidth, MHz	**35.0**	**6.0**	**2.0**	**1.0**	**0.1**	**0.05**
Amplifier return output compression point	71.4	63.7	59.0	56.0	46.0	43.0
Compression safety factor	-6.0	-6.0	-6.0	-6.0	-6.0	-6.0
Amplifier return output operating point	65.4	57.7	53.0	50.0	40.0	37.0
Amplifier return gain	18.0	18.0	18.0	18.0	18.0	18.0
Amplifier return input operating point	47.4	39.7	35.0	32.0	22.0	19.0
Spigot loss, tap on amplifier forward output	-29.0	-29.0	-29.0	-29.0	-29.0	-29.0
Spigot return input, tap on amplifier forward output	76.4	68.7	64.0	61.0	51.0	48.0
Exterior drop loss, 150' of series 6, 1.0 dB per 100'	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5
Return output of NIU at house bonding block	77.9	70.2	65.5	62.5	52.5	49.5
Four way drop splitter loss	-7.0	-7.0	-7.0	-7.0	-7.0	-7.0
Interior drop loss, 50' of series 6, 1.0 dB per 100'	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Return output of set top or computer modem	85.4	77.7	73.0	70.0	60.0	57.0

Figure 5.

Figure 5 illustrates the effect of bandwidth on operating level, with the spectral power density held constant. A typical amplifier compression point of 71.4 dBmV in 35 MHz was selected as a convenient reference.

Spectral Power Density

The lack of sufficient power density (output level per Hertz) in terminal devices can limit the chosen return amplifier outputs for these specific services to levels significantly below the compression points of the gain blocks in place. While there is generally more than adequate noise margin available in the coax portion of the plant, ingress margin is sacrificed due to this power deficit.

Today's RF Converter

For the first example, examine the 0.1 MHz column in Figure 5. This bandwidth represents a typical RF return converter. The bottom row in the table shows a level of 60 dBmV, a typical maximum converter output. Thus, today's converters can be operated to effectively utilize an amplifier compression point performance of about 72 dB over 35 MHz.

If RF converter return levels were used in the design software as a reference, then the maximum tap port return input levels would be set to +51 dBmV for this service (assuming that the drop described in Figure 5 is the worst case), and the return amplifier input level would be established as +22 dBmV (assuming that the 29 dB tap is the highest loss path between any tap spigot and its upstream amp input). Basically, an output level of +60 dBmV works pretty well for a 100 kHz wide service.

The Telephony NIU

For the second example, examine the 2.0 MHz column, which is representative of a typical time division multiple access telephony network interface unit. The NIU has an advantage in that it is located at the bonding block, and thus does not need to drive through the lossy drop splitters found in the house. However, use of the wide bandwidth required by TDMA imposes a strict requirement on output level. In order to operate at the optimum ingress margin point, the NIU must have an output power capability of +65.5 dBmV in the 2.0 MHz of occupied spectrum.

Today's NIUs can commonly attain power levels of only +50 dBmV. The result is a failure to realize 15 dB of potential ingress margin improvement that is incremental to the techniques discussed earlier in this paper.

The Computer Modem

For the third example, examine the 6.0 MHz column in Figure 5. To make a long story short, the computer modem must produce an output of +77.7 dBmV to best utilize the ingress margin available to it. A +50 dBmV capable modem experiences a penalty of 27 dB of wasted potential ingress margin improvement.

Margin Against Wideband Interference

As a service requires simultaneous use (TDMA, for instance) of a large chunk of contiguous bandwidth, the sensitivity to wideband interference increases in direct proportion to the bandwidth occupied. Localized electrical interference generated by small appliances is an example of such wideband interference. The power of such an interference source is often relatively flat with respect to frequency, and therefore total power increases with increasing bandwidth.

An Additional Safety Factor

Because few amplifiers will ever see anywhere near full spectrum loading, a built-in power loading safety factor exists. This safety factor is due to the fact that only one path can use a given portion of the spectrum at a given instant in time. The number of unique paths through the network is nearly as great as the number of inputs, by virtue of the tree and branch topology of HFC networks. Therefore, power loading is statistical in nature, and as a device is located further out in the forward network, the probability of high return spectrum power loading is vastly reduced.

ACKNOWLEDGMENT

I wish to acknowledge the contributions of Trygve Lode, president of Lode Data Corporation. The current release of the Design Assistant® network design software was enhanced to allow faster completion of research work necessary for this paper.