Measurement of Differential Gain, Differential Phase, and Chrominance to Luminance Delay in Cable TV

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Abstract

Beginning in mid-1995 cable TV operators must measure the quality of the color signals they are delivering to subscribers. The measurements chosen to judge color quality are differential gain, differential phase, and chrominance-to-luminance delay.

Local insertion of full-field signals allow the operator to test the performance of the system but requires program interruption. Local vertical interval test signal (VITS) insertion allows in-service testing without program interruption or picture impairment.

Another in-service approach utilizes programmer supplied VITS. In addition to lower cost, this is an end-to-end test which more closely links the test result to the actual subscriber picture quality. This approach, however, risks the signal not being present when needed or that the signal, if present, is already impaired enough to call its value into question.

INTRODUCTION

A great deal has been written on the 3 "color" tests selected by the FCC to be performed by cable TV operators[1,2,3,4,5,6]. Rather than repeat work already accomplished in describing how to do the measurements, this paper will look at some of the issues surrounding getting set up to make these measurements. Minimizing disruption of service will be a high priority.

The author is a relative neophyte in making these measurements so the approach of this paper will be to review what has been written and apply that knowledge to getting started doing it the first time. The intended audience are other people in the cable TV community who are also neophytes in these matters. Also, with the concept in mind that you can't know where you're going if you don't know where you've been, we'll take a look at some of the history involved.

Legal Requirements

As of June 30, 1995, the color rules will apply. Chroma delay shall be within 170 nanoseconds, differential gain shall not exceed +/-20%, and differential phase shall not exceed +/-10 degrees. Generally, the number of channels that must be tested are 4 plus 1 for every 100 MHz of spectrum use. (See the rules for the specific requirements[7].) However, since a consultant or FCC auditor can check any channel, and since all channels must comply, few operators will feel comfortable unless all channels are tested. Thereafter, these tests must be done once every 3 years.

The FCC requires these tests of the headend related signal processing equipment only. Since the trunk and distribution system components are all broadband, their contribution to color signal impairment is minimal. Not having to test outdoors in the system should be good news especially during bad weather.

A LOOK AT THE TEST SIGNALS

The differential gain and differential phase measurements are done using a modulated stairstep signal (Figure 1). The modulation on each step is the color frequency at an amplitude of

+/-20 IRE on each step. What is being measured are changes in amplitude and phase of that color signal as the luminance signal is stepped through its range of operation. Ideally there would be no changes at all in the chroma amplitude and phase as the luminance staircase goes from black to white.

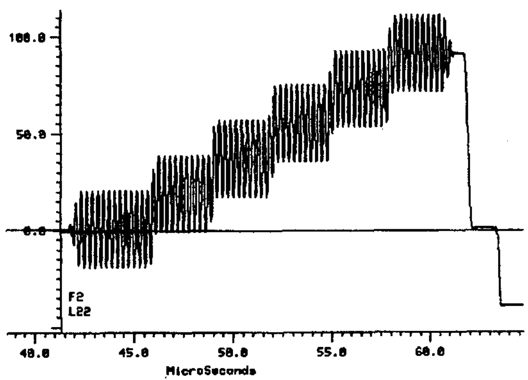

Figure 1. Modulated Stairstep Signal (NTC)

The third test, chrominance-luminance delay inequality (CLDI, also called relative chroma time or RCT) uses a different test signal called variously the modulated 12.5T sin^2 pulse, or chrominance pulse. This cleverly designed signal consists of both luminance (Fig. 2) and chrominance (Fig. 3) components which occur simultaneously. Figure 4 illustrates the 12.5T pulse as it appears after the low and high frequency components are added together. As the two components which are at different frequencies travel with the TV signal, any speed differences encountered because of being at different frequencies become readily visible through predictable distortions of the 12.5T sin^2 pulse. Generally, the higher chroma frequency will encounter more delay than the luminance signal so the test is probably named for this. However, negative delay, where the chroma component arrives first is not uncommon.

These test waveforms, the modulated stairstep, and the 12.5T sin^2 pulse, have both been incorporated into 2 common test signals called the FCC Composite (Fig. 5) and the NTC-7 (Fig. 6, hereafter just NTC) Composite signals*. The 12.5T sin^2 pulse is identical in both signals, but the modulated stairstep is slightly different. In the FCC Composite signal the 5th stairstep has a DC level such that the color signal at peak excursion is exactly 100 IRE. However, in the NTC version the DC level of the 5th step is already at 90 IRE so the color signal's peaks extend to 110 IRE. This has implications for the cable TV operator that will be explored later. Compare Figures 5 and 6. Figure 1 is the NTC modulated stairstep in more detail.

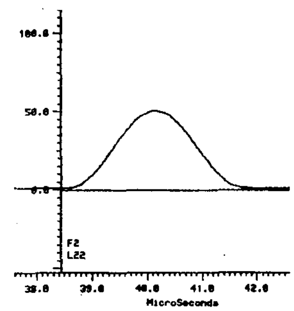

Fig 2. Low Freq Portion

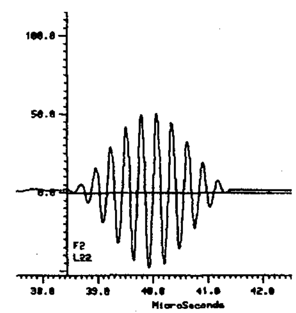

Fig 3. Hi Freq Portion

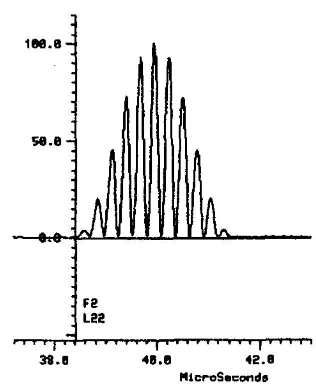

Figure 4. 12.5T Chrominance Pulse

The reason there are two such similar test signals seems related to differences in their application. The NTC is intended for network video transmission to affiliate broadcasters and the FCC is for the terrestrial broadcast environment. The NTC Composite signal is explicitly intended for

* Note that it is easy to confuse the name "Composite" signal with that of the NTC-7 "Combination" signal which is quite different. Fortunately, there is no "FCC Combination" signal.

testing "video facilities leased by the major television networks from the Bell System[8]." For this purpose, Johnston[9] writes that the NTC members preferred having the line bar occur first because it gave a more valid reading on line-time distortion. In addition, the author suspects the excursion of the 5th stairstep's modulation in the NTC Composite signal to 110 IRE is good for testing marginal network capability but would put broadcast transmitters under unduly harsh treatment.

The FCC Composite signal, on the other hand, seems intended for terrestrial broadcast. Indeed, it's called the "Composite Radiated Signal" in the NAB Engineering Handbook[10].

Other differences between the FCC and NTC Composite signals are the order of occurrence of the test signal elements. In the FCC Composite signal the modulated stairstep comes first, while in the NTC Composite signal it comes last. The 12.5T $\sin^2$ pulse occurs in the middle of the signal for both, but the timing of the center of the pulse after the leading edge of the sync pulse is 39.2 uS for the FCC Composite and 37 uS for NTC Composite signal. In general, these timing differences should not matter to the cable TV operator. However, the amplitude differences of the 5th modulated stairstep does matter. This issue will be covered in a later section.

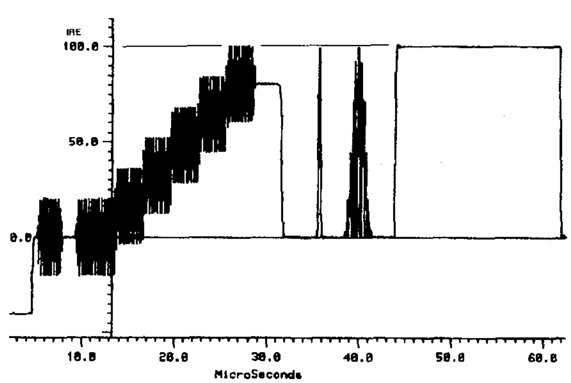

Figure 5. FCC Composite Signal

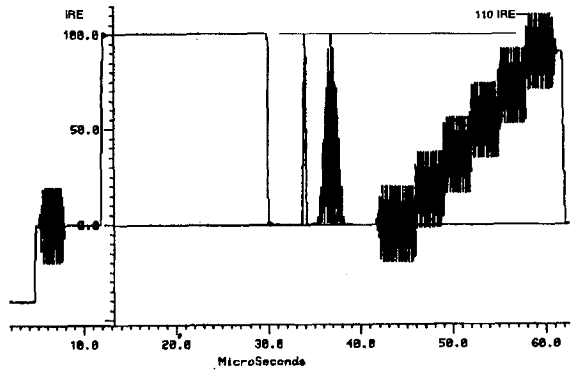

Figure 6. NTC-7 Composite Signal

Both Composite test signals also include two other features called the bar and the 2T pulse. The 2T pulse is the short pulse occurring just before the 12.5T $\sin^2$ pulse. It is used for measuring short-time waveform distortion. The bar is a relatively long period of time with the signal at the white level. Both of these features are used in other video tests not specifically called for by the FCC, however the bar is useful in cable TV for measuring depth of modulation.

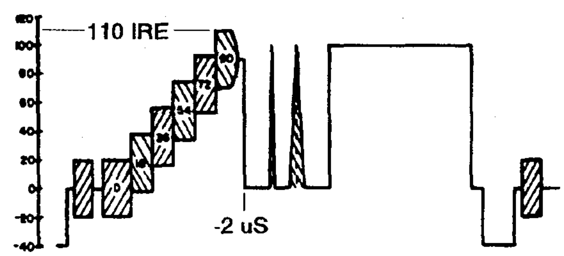

Figure 7. STOC Composite Signal

Figure 7 illustrates a now rare but not completely absent test signal developed by the Satellite Technical Operational Committee and reported on in the early 1970's[11]. This reference says its purpose was to "test microwave radio relay systems". Another reference[12] says it was for "testing satellite NTSC transmission". It is strikingly similar to the FCC Composite signal and can be easily mistaken for it. The differences, however, between the STOC and FCC Composite signals are the chroma peak amplitude in the 5th stairstep, and a 2 uS shift forward in time of the rest of the signal components after the 5th stairstep.

The main reasons to bring this up here are that the chroma level on the 5th stairstep, like the NTC Composite, reaches 110 IRE. The other reason is that the author recently saw this signal, or something very similar to it, on an off-air signal in Arkansas. As will be discussed below, chroma at 110 IRE can lead to overmodulation and clipping, thus compromising the differential gain and phase tests. And the fact it has been seen means it's lurking out there threatening to confuse the situation.

A Bit of Test Signal History

Taylor[13] writes that in the 1950's and 1960's TV network video feeds carried by the Bell System to TV broadcasters sometimes became impaired. Attempts to locate the source of the impairment could lead to finger-pointing between Bell System and TV broadcaster personnel. To help resolve this problem the National Transmission Committee (NTC) was formed. This committee consisted of engineers from ABC, CBS, NBC, the Public Broadcasting Service, and AT&T and produced the well known NTC-7 Engineering Report[14].

Jenkins[15] wrote that in 1966 the NTC was considering using both fields of lines 18 and 19 for Vertical-Interval Test Signals (VITS). Field 1 of line 19 was to carry a "sine-squared signal" defined as a 2T pulse and bar (no 12.5T pulse yet). Field 2 was to carry a modulated stairstep. These two signals were later combined with the 12.5T pulse onto a single line.

Rhodes[16] wrote that in 1965 P. Wolf introduced the 20T modulated $\sin^2$ pulse in Munich, Germany. Rhodes then proposed that a 12.5T pulse was more appropriate for NTSC. He also developed a number of nomographs for determining CLDI from the amplitudes of the distortion of the pulse baseline.

USING THE COMPOSITE TEST SIGNAL

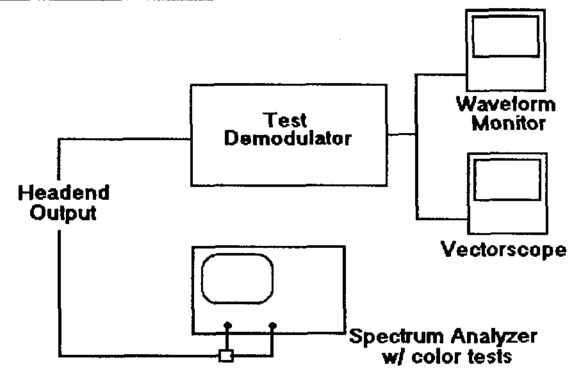

Fig. 8 Measurement Setups

The 3 color tests can be measured at the output of the final headend combiner using a directional coupler. They can also be obtained from the input test point of the first trunk amp.

The traditional equipment needed is a precision demodulator, waveform monitor or TV triggered oscilloscope for the differential tests, and a vector scope for the CLDI test. The above pieces of test equipment are available in a wide range of performance and costs. Alternatively, a new spectrum analyzer has recently come to market which combines these 3 color tests with the traditional cable TV test capabilities in one portable unit.

VITS Testing

VITS, as opposed to full field, testing allows measurements to be made on the equipment in service. This minimizes service disruption and when programmer supplied VITS are used, the result is an indication of the actual signal quality delivered to the subscriber.

Substitution Full Field Testing

Another option for doing the color tests is to substitute temporary headend signal processing equipment into the signal path of the channel to be tested. The equipment substituted for would include channel filters, processors, modulators, and any other components in the signal path that would have narrowband enough amplitude and/or phase characteristics to affect the color measurements. As with trunk and distribution equipment, headend switching and combining equipment should not affect the color tests.

This method would limit service interruption to the time to change cable connections. This would allow bench testing using a full-field test signal. Other advantages of this method are not needing a VITS inserter in order to maintain service, and because of full-field testing, having the ability to test over the full range of average picture level (APL) as recommended in the NAB Engineering Handbook.

The actual processes for making these measurements has been well explained by other authors. The purpose of this paper is to explore the in-service options available to the cable operator for obtaining the Composite test signal and analyze the merits of each option.

Satellite & Local Origination Channels

The first point at which the cable TV operator has any control over a satellite or local origination signal is as it is delivered as baseband either from a satellite receiver or from another source such as a VTR or text generator. If a Composite signal is present in the signal it may or may not be usable. If not, a VITS inserter can be placed in the baseband video path at this point.

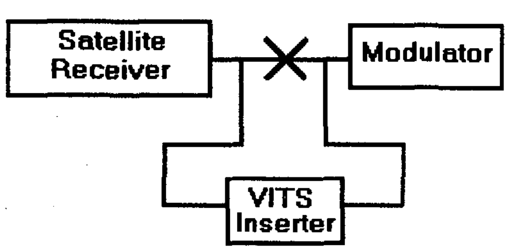

Fig. 9 Satellite Channel VITS Insertion

Recently a VITS survey was done for the NCTA of 118 satellite services by Reed-Nickerson[17]. He found that 33% had the FCC Composite signal, 33% carried the NTC-7 Composite signal, and 40% had no Composite signal at all. (There were some which carried both Composite signals.)

It is attractive to use the satellite programmer supplied test signal because it is convenient and does a complete end-to-end test. If the result is within test limits, not only are the FCC requirements met, but the cable operator can have greater confidence in the final quality of the product at the subscriber terminal (ignoring the effects of a converter). A potential inconvenience, though, is that the test signal can be interrupted or changed because of programmer or local signal switching. Local ad insertion is a prime example.

Since initial indications are that satellite programmer provided Composite VITS can be a usable, if not always continuous, signal source for the cable color tests, one hopes the 40% not carrying the Composite VITS will diminish.

Off-Air Channels

Channels using processors present a bit more of a challenge. While broadcasters are more likely than other sources to have a Composite signal, VITS derived from off-air channels tend to be more impaired than when delivered by satellite. The author speculates this mostly results from impairments in broadcast transmitters, multiplexers, and/or effects of multi-path. This increases the likelihood that VITS will have to be inserted. But the Composite VITS will have to be inserted at RF at the input to the processor in order to do the test properly. This requires the use of a test modulator in addition to the VITS signal generator. See Figure 10.

To insert VITS into an RF signal it must first be demodulated, VITS inserted, then the signal is re-modulated to RF and connected to the processor input. For this case the demodulator does not need to be precision. It merely needs to supply a good enough signal to carry the inserted VITS and keep the channel in service during the period of the test. An agile demodulator is the best choice because the audio path is most easily managed. In a pinch, a VCR or TV with a baseband video output could be used. However, the audio would most likely be available as left and right and not a composite audio signal at 600 ohms.

Modulators

To the author's knowledge, one cannot buy a "precision" video modulator specifically designed for test. Precision demodulators for test are available, but not their reverse function. Therefore the operator must make do with buying the one with the best specifications then verifying its performance with a precision demodulator.

However, at least a couple of cautions must be observed. Bowick[18] reports that many modulators in cable TV use may not have CLDI precorrection circuitry. If the measurement assumes precorrection is present, the results can be off by 170 nS. Since the FCC requires this precorrection of broadcasters, it almost certainly is assuming that precorrection will be present in the signal delivered to cable subscribers. It may be hard to justify use of modulators without it.

What we are considering here is defining a modulator to be used for test. But what about headends now populated with modulators without precorrection? This issue and how it relates to the concept that the cable TV operator is not to change CLDI by more than 170 nS, nor is the operator charged with fixing a bad signal, is beyond the scope of this paper.

Another modulator issue is peak clipping. Some modulators used in cable TV limit modulation to 90 - 95% to avoid overmodulation. Recall that the NTC and STOC 5th stairsteps have chroma amplitudes at 110 IRE. Even when depth of modulation is correctly set to 87.5%, this 5th stairstep could cause the modulator with modulation limiting to reduce the chroma amplitude. This will significantly affect the differential gain measurement. The Recommended Practices document of the NCTA[19] addresses this by stating "if the modulator under test contains a clipping circuit (90% modulation) ignore the fifth step in a 5 step signal". Using the FCC Composite test signal and making sure depth of modulation is properly set minimizes the effect of this problem.

A last caution is that if using a precision test demodulator, the test modulator must have a stable enough carrier for the precision demodulator to be able to phase lock to it. It has been seen that at least one state-of-the-art agile modulator is not stable enough for a top-of-the-line precision demodulator to phase lock to it. As noted below, phase lock is needed for synchronous detection which is required for some tests. At this time, this author has no data on the potential extent or seriousness of this issue.

In summary, when choosing a modulator to be used as a reference test modulator, chroma-luminance precorrection must be present, white clipping would ideally not be functioning, and it would have a stable carrier output.

Demodulators

Synchronous versus envelope detection is an issue that deserves attention. Rhodes[20] writes that synchronous detection can be used for all video measurements as long as ICPM and static phase error are known to be negligible on the signal to be tested. Excessive incidental carrier phase modulation (ICPM) can make differential phase measurements read artificially high with true synchronous detection. In this case envelope detection may help. Static phase error can affect

CLDI, however, it still must be measured using synchronous detection.

Rhodes goes on to say that depth of modulation when measured at baseband with synchronous detection can be strongly affected by ICPM. He suggests envelope detection here but cautions that envelope detectors are usually quite non-linear at low (white) carrier levels. This author suggests that since depth of modulation is such an important setup parameter for the color tests, that it be measured at RF using a spectrum analyzer. This relatively narrow band technique uses envelope detection and a calibrated linear scale to avoid problems with ICPM and linearity.

In summary, when making color measurements with a test demodulator, it must be capable of synchronous detection which must be used for all tests except for differential phase and depth of modulation which may use envelope detection if the signal under test is impaired by ICPM. Additionally, the test demodulator must be capable of phase locking to the test visual carrier signal.

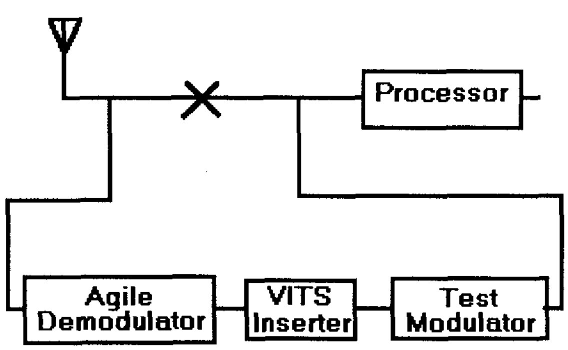

Fig. 10 Off-Air VITS Insertion

CONCLUSIONS

The intent of this paper was to identify the assumed few subtle issues that might arise when doing the color tests in the cable TV environment. Unfortunately, a search of the available literature uncovered more subtleties than anticipated. It is hoped that most if not all of the issues raised here will prove to be minor in practice. Until experience proves otherwise, though, here is a summary of some of the things to watch out for in no particular order.

1. Depth of modulation has to be set to 87.5%. Broadcasters shoot for 85-90%. The NCTA Recommended Practices suggests 80-84% to ensure against overmodulation. This lower modulation will also guard against white clipping due to high chroma levels in the 5th stairstep of some Composite test signals.

2. Differences in average picture level can affect test results. The NAB Engineering Handbook recommends measuring at 10, 50, & 90% APL. The effects of different APL's on test results, however, may be more of an issue for broadcast transmitters than for cable TV modulators.

3. Some cable TV modulators may not have chroma-luma delay precorrection.

4. Johnston[21] warns that "many signal generators actually produce triangular or ramp shapes for signals which should have sine squared shapes". This he says could compromise measurement accuracy. This author has never seen a 12.5T chroma pulse that has straight sides, but it's worth being on the lookout for.

5. The chroma level must be sufficient for a reliable differential gain and phase result. Chroma levels in off-air programmer VITS appears particularly problematic.

6. The test demodulator must use synchronous detection and be capable of phase locking to the test signal.

7. If using programmer supplied Composite VITS, programmer and/or local signal switching, such as ad inserts, can change or eliminate the test signal at inconvenient times.

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