CATV Channel Characterization for Digital Data Transmission Applications

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ABSTRACT

To transmit digitally compressed video with co-existing analog video over cable television (CATV) systems, the entire CATV bandwidth is frequency-division-multiplexed (FDM) into 6 MHz wide channels. For reliable data transmission, it is necessary to design an adaptive digital equalizer to compensate for the linear distortion effects, for example, the microreflections, introduced in such a 6 MHz CATV channel. This paper describes the characterization of the linear distortion effects as viewed by a digital adaptive equalizer in a 6 MHz CATV channel by developing measurement techniques using existing equipment. In contrast to other proposed techniques, this method has the added advantage of *non-intrusive* characterization of the channel, i.e., it is not necessary to interrupt existing cable service to characterize the channel. The advent of a new type of spectrum analyzer has greatly facilitated our work. Laboratory tests are performed to validate the measurement techniques. Finally, channel measurements are obtained for an in-house cable system.

INTRODUCTION

A typical cable system has a tree-type network structure, originating from the headend, then going through the trunk cable, distribution (or feeder) cable and the drop cable to the in-house wiring, and finally terminating at some consumer electronics equipment [1]. Numerous amplifiers are required to maintain the signal at specified levels. These amplifiers are generally operated in the linear region. The nonlinear effects, for example, the composite-triple-beats (CTB) and the composite-second-order (CSO) products are at least 53 dB below the main signal which is small compared to the NTSC peak carrier-to-noise ratio (CNR) of 43-46 dB. Hence, for testing the performance of digitally modulated signals, it is sufficient to assume that the CATV channel is a time-invariant linear channel with noise, which could be impulsive in nature.

The received signal at a specific consumer site can be represented simply by a sum of variously attenuated multiple reflections of the same signal caused because of improper termination of the numerous taps in the system. Since the channel is assumed to be linear, the effect of these 'microreflections' can be characterized completely by the frequency-response of the CATV channel. In older analog systems, precise channel characterization was not necessary. Crude methods were sufficient to "measure" amplitude response and group delay, such as observing the envelope of a frequency sweep or the base-line of a two-tone burst on an oscilloscope display. These methods are clearly inadequate as digitally modulated signals are added to these older systems.

A conventional network analyzer is capable of measuring the characteristics of a communication channel if both ends are in the same location. However, in a typical cable television (CATV) system, the receiving location may be twenty miles or more from the cable head-end. With the exception of only a few systems, this spatial restriction limits the use of a network analyzer to laboratory simulations.

In formulating the channel characterization technique described in this paper we made certain assumptions about the channel data required to characterize performance of digital modulation techniques over CATV channels. By the time-frequency duality, a channel characterization of X MHz should be able to resolve all microreflections of 1/X μsec or greater. This implies that the general problem of characterizing *all* the linear-distortion effects of the CATV channel is extremely complex, since this implies that the entire channel frequency-response be known. However, for a digitally modulated signal with a specific center frequency, only a 6 MHz section need be known to evaluate the performance of the digital modulation strategy. This channel characterization technique then concentrates only on the characterization of 6 MHz wide channels and, in this respect, is different from other approaches as described in [2], [3].

The other constraint that is assumed is the fact that such 6 MHz channels in most cable channels are already occupied with analog NTSC. It is possible to remove channels from service temporarily, but that may not always be commercially acceptable. Simulated cable plants at any lab fail to generate 'typical' channel characteristics and tests on actual user-sites are required. The technique presented in this paper can be used for *both* the cases when analog NTSC is present or when empty channel space is available, using the same equipment for either case and thus is different from the technique proposed in [3]. One way to characterize a channel even when an analog NTSC channel is being used, is to make use of the recently adopted Ghost Cancellation Reference (GCR) signal used for echo cancellation. This reference signal is sent during the vertical blanking interval (VBI) of analog NTSC. The received signal is then a convolution of the transmitted GCR reference and the channel impulse response. Thus, the channel characteristics are obtained quite simply by dividing the received frequency response by the frequency response of the known reference. It should be emphasized that both the magnitude and the phase-response of the channel is of interest for determining the performance of the adaptive equalizer.

The above 'one-shot' technique of determining the channel frequency response usually has some noise added to it. Using averaging techniques, implemented efficiently using the new HP 89440A vector signal analyzer, it is possible to eliminate this noise, by assuming that the channel frequency response is time-invariant, at least during the total time required for averaging. One problem associated with averaging is the possibility of having a random initial phase-offset for each measurement because of sampling time jitter. This uncertainty causes the amplitude-response to be attenuated at high frequencies. Using the NTSC sync pulse, a stable reference can be generated which has provided sufficiently accurate channel measurements and is limited only by the timing-jitter present in the sync-regenerator circuits of an NTSC receiver. A similar sync pulse can be provided for the case when empty channel space is available.

An inherent problem associated with channel measurements obtained using the existing analog NTSC channels is that the bandwidth of channel measurement is limited to at most 4 MHz because the picture carrier is placed 1.25 MHz away from the band-edge and also because of the presence of the sound-carrier at 5.75 MHz. In fact, the GCR signal, introduced in the VBI of analog NTSC, has a 3 dB bandwidth equal to 4.15 MHz. To determine the frequency response over a 6 MHz bandwidth, an interpolation technique can be used, which is not included here and will be described in [4]. Thus, the output of the channel measurement scheme will be a frequency-response measurement of at least 6 MHz bandwidth obtained either by using empty-channel locations or using the GCR signal in existing analog NTSC channels.

In the next section, the measurement philosophy and setup are described in more detail. Following that, validation experiments performed in a laboratory are described using a simple single-echo channel simulator. Finally, measurements are provided for an in-house cable system.

MEASUREMENT SETUP

As discussed in the previous section, the GCR signal is used as a reference signal to characterize the linear CATV channel. Fig. 1 describes the measurement setup used for laboratory validation tests. For the purposes of the validation tests, the GCR pulse along with the synchronization pedestal was sent repetitively. An HP 89410 spectrum analyzer was used extensively, a description of which follows.

The HP 89410A (dc-10 MHz) vector signal analyzer (VSA) represents a new class of measurement instrument. These analyzers calculate both frequency and modulation domain characteristics from a time-record. The time-record of the desired frequency span is produced by accurately digitizing the input waveform, mixing with a digital quadrature local oscillator and band-limiting with digital filters. Selectable trigger delay and time-record length control the portion of the time-domain waveform that is captured. In addition, time-gating allows a subset of the time-record to be selected for subsequent calculations. The HP 89410A also has an arbitrary source generator.

For the laboratory setup shown in Fig. 1, the HP 89410A arbitrary source generator is configured to send the test signal repetitively. Fig. 2 shows the signal sent by the HP89410A source which consists of a GCR signal on an NTSC sync waveform. This signal is then modulated by the HP 8780A vector modulator, thus resulting in a double-sideband (DSB) modulated signal with the synchronization pulse providing a carrier similar to the visual carrier in analog NTSC. Note that the DSB signal will have a much larger bandwidth than 6 MHz, and is used only for this setup: typically another filter will remove one of the sidebands as used, for example, in an NTSC modulator. For the demodulation, a Tektronix VSB demodulator with sufficiently wide bandwidth filters is used to obtain the signal at baseband. A separate frame synchronization waveform can also be generated by using the HP 1133A. The receiving HP 89410A is then set to trigger on this sync and a time-record is generated which is sufficient to capture the entire transmitted signal, as shown in Fig. 2. This captured time record is then converted to a vector spectrum in the frequency domain. The spectrum contains both amplitude and phase information for every frequency component of the test signal. Fig. 2 also shows the amplitude spectrum of the time-record, which has a small attenuation over the 4 MHz bandwidth.

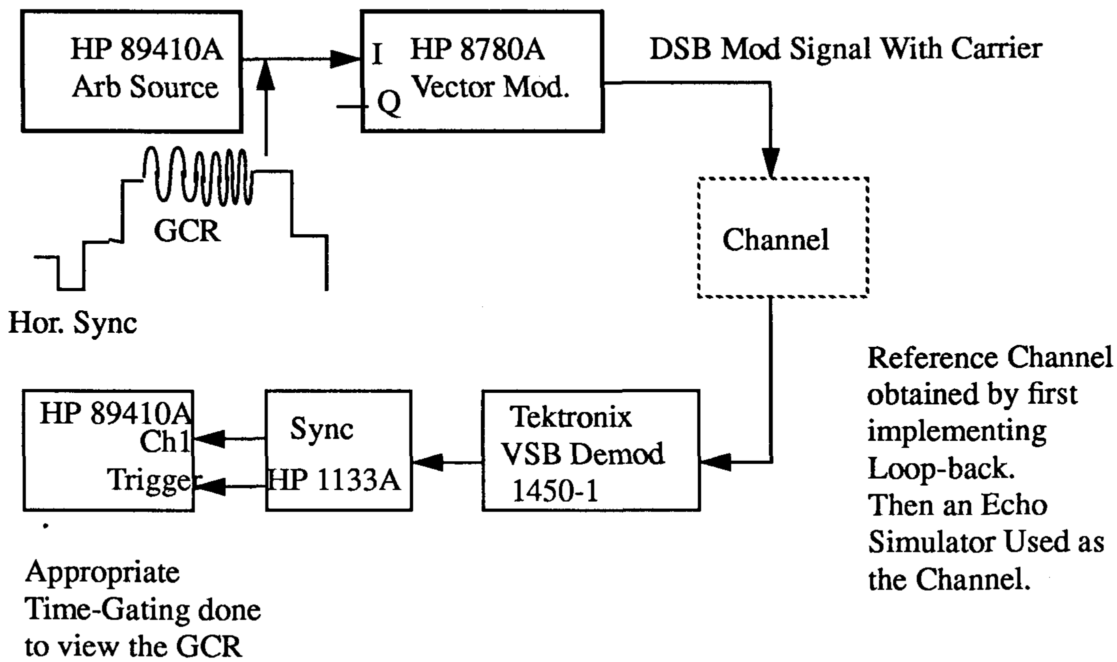

Fig. 1: Laboratory Setup Used for Channel Measurement.

For the purposes of calibration, the reference measurement is made by using a loop-back technique, i.e., the DSB modulated signal is fed directly into the Tektronix demodulator. This ensures that the frequency responses of the different instruments have also been taken into account. Fig. 3 shows the amplitude and phase variations across the entire frequency band. After creating this reference, the spectrum of the channel is measured. Dividing this spectrum by the previously measured reference yields the transfer function of the channel with an arbitrary delay term (phase ramp). The actual propagation delay cannot be measured with this technique: however, in most applications, the delay is irrelevant and only the deviation from linear phase is of interest. If necessary, improved signal-to-noise ratio is achieved by time averaging several measurements. Because the noise is not correlated with the repetitive test signal, the noise averages to zero over time. Due to the use of the HP 1133A sync generator, timing jitter is kept small which allows for such averaging to be done without any degradation to the measurement.

For measurement over a CATV network, when empty channel-space is available, a different arbitrary source generator must be used since the instruments are at different locations. For the case when analog NTSC is present, the trigger for HP 89410A is the frame sync passed through a divide-by-8 counter. This is because the GCR signal is sent with different phases over an eight field sequence to compensate for the dc offset and the color burst [5]. This will be described in more detail in the following sections.

VALIDATION TESTS

To validate the channel measurement technique, a single-echo simulator was used as shown in Fig. 4. The HP 8753 network

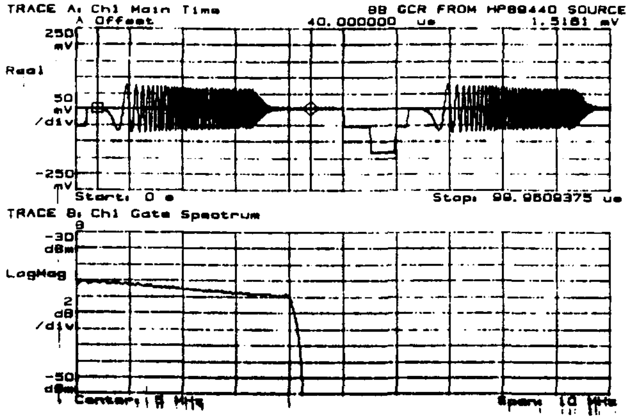

Fig. 2: GCR With the Timing Pulse.

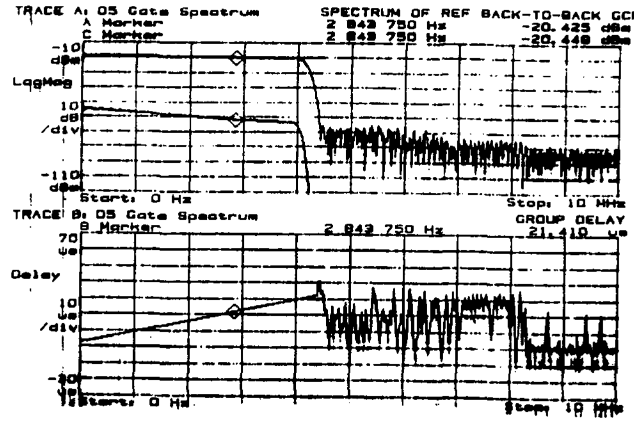

Fig. 3: Reference Amplitude and Group-Delay Response.

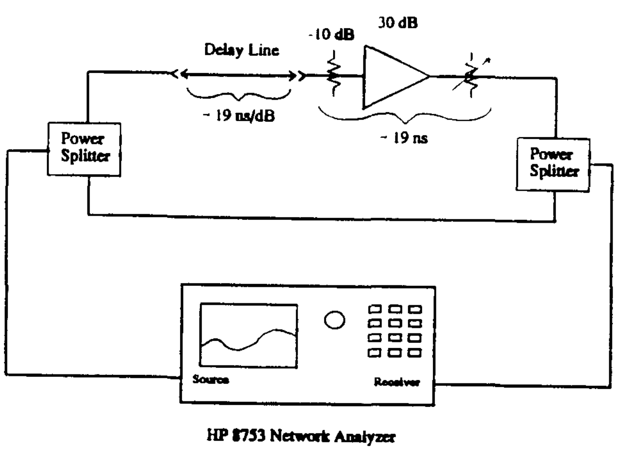

Fig. 4: Single-Echo Generator.

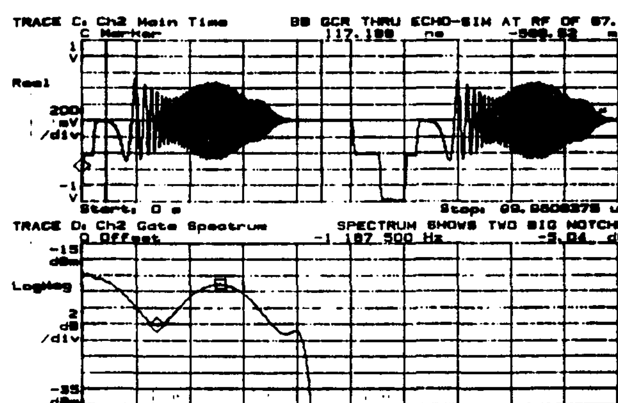

Fig. 5: GCR With a 10 dB Echo at 420 nsec.

analyzer was used to obtain the amplitude and group delay variations across a frequency band of 12 MHz, which is compared with our results.

Fig. 5 shows the GCR pulse received at the HP 89440A when a 10 dB attenuated echo was added to the main signal at a delay of 420 nsec, along with the amplitude spectrum of the appropriately gated time-record. In Fig. 6, amplitude and group delay measurements are shown for a section of 12 MHz bandwidth between 60-72 MHz using the network analyzer. This can be compared with two 4 MHz measurements shown in Fig.'s 7 and 8, between 61.25-65.25 MHz and between 67.25-71.25 MHz. Note that there is a small ripple in the group-delay measurement. This is because the dc offset in the signal was removed by subtracting the signal by a constant and then performing an FFT as can be seen by the expression shown in Fig.'s 7 and 8. Unfortunately, the AGC control in the VSB demodulator was not very accurate and this level jitter caused a ripple in both the amplitude and the group delay response. A simple method of removing this jitter will be described in the next section.

Fig. 9 shows the amplitude and the group delay measurements obtained using the network analyzer when the echo amplitude is 25 dB below the main signal. Note that the peak-to-peak variation in both the amplitude and the group delay is smaller than the 10 dB case. The corresponding measurements using our setup are shown in Fig.'s 10 and 11 which are close to the measurement made by the network analyzer.

CHANNEL MEASUREMENTS

The channel used is as shown in Fig. 12. The sixteen amplifier cascade is part of an in-house cable system with a bandwidth of 50-600 MHz. The output of this cascade was then passed through a 21 dB 8-way splitter, seven of which were unterminated. To simulate possible home-wiring the output of this splitter was passed though another splitter, the attenuation of which was varied between 0 and 3 dB for two different experiments. The other end of the 3 dB splitter was left open-ended.

Fig.'s 13-16 show the amplitude and group delay measurements performed at different bandwidths for the 16 amplifier cascade only. Note the flat spectrum in Fig.'s 14 and 15 for mid-range frequencies of 295.25-299.25 MHz and of 567.25-571.25 MHz. Also note the expected attenuation and increasing ripple for both the low frequncy of 67.25-71.25 MHz and 627.25-631.25 MHz.

Fig. 17 shows the case when the bottom path is selected for the channel shown in Fig. 12, i.e., a 3 dB splitter is used. As can be seen the amplitude ripple for 567.25-571.25 MHz is only 0.5 dB. Finally, in Fig. 18, the amplitude and group delay response for a 0 dB splitter is shown, where an open-ended cable of RG-59 of length 56 inches is used at the other end. This causes a deep null to occur near the 572 MHz frequency, as is seen by as much as 3 dB attenuation in the amplitude response as in Fig. 18.

In most of the figures on channel measurement, the effect of incorrect dc offset is observed clearly at the low frequencies. As explained earlier, this dc offset is because of the AGC present in the VSB demodulator. This dc offset can be removed quite easily by using the HP 89440A delayed trigger mode. The arbitrary source generator is used to send the GCR signal of opposite phases at successive intervals. At the receiver, a synchronization trigger to the HP 89440A is created by passing the frame sync from the HP 1133A through a divide-by-2 counter. The received baseband signal is fed in to both the Ch1 and the Ch2 inputs of the HP 89440A. The gated window for Ch2 is set to be a time-offset win-

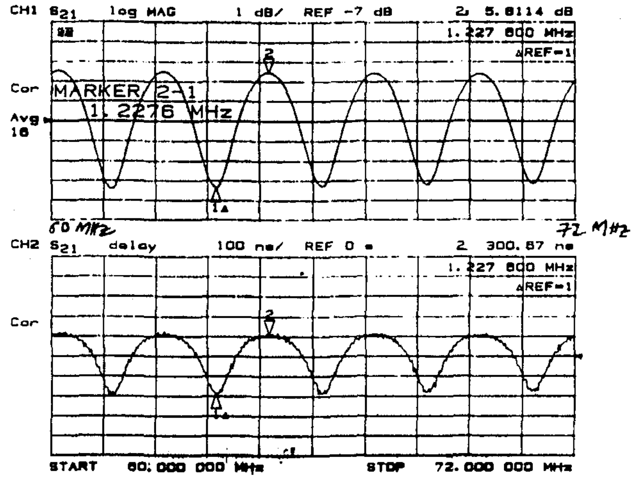

Fig. 6: Amplitude and Group Delay Measurements Using a Network Analyzer for 10 dB Echo.

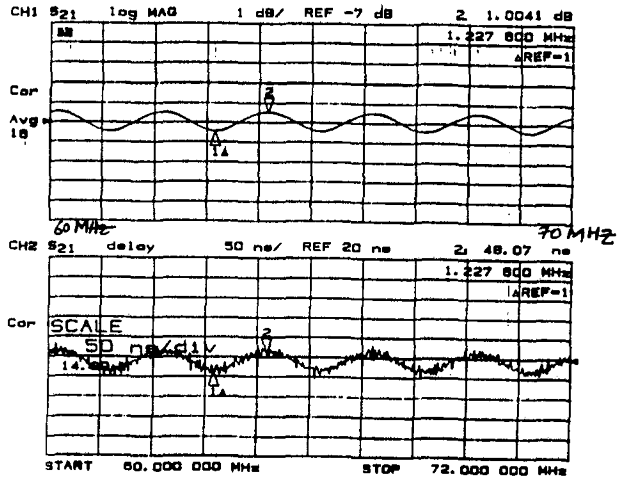

Fig. 9: Amplitude and Group Delay Meas. Using a Network Analyzer for 25 dB Echo.

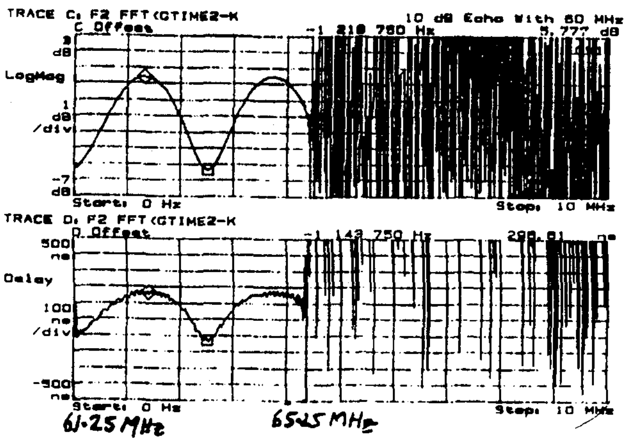

Fig. 7: Amplitude and Group Delay Meas. From 61.25-65.25 MHz for 10 dB Echo

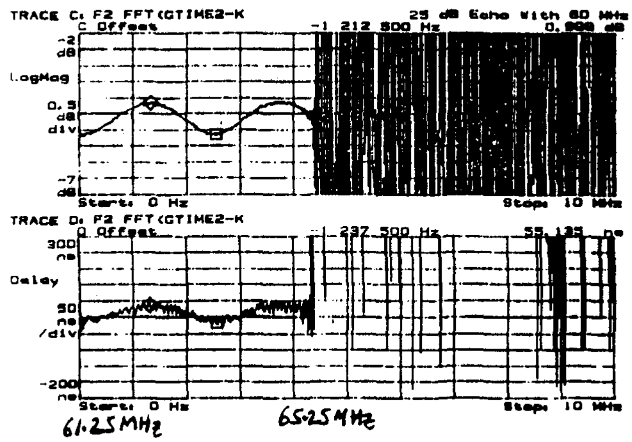

Fig. 10: Amplitude and Group Delay Meas. From 61.25-65.25 MHz for 25 dB Echo.

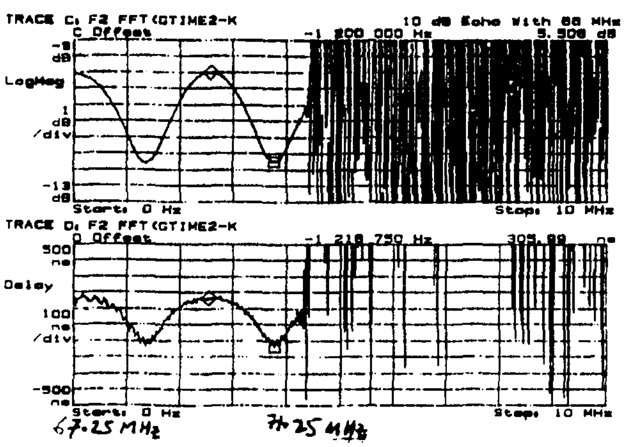

Fig. 8: Amplitude and Group Delay Meas. From 67.25-71.25 MHz for 10 dB Echo.

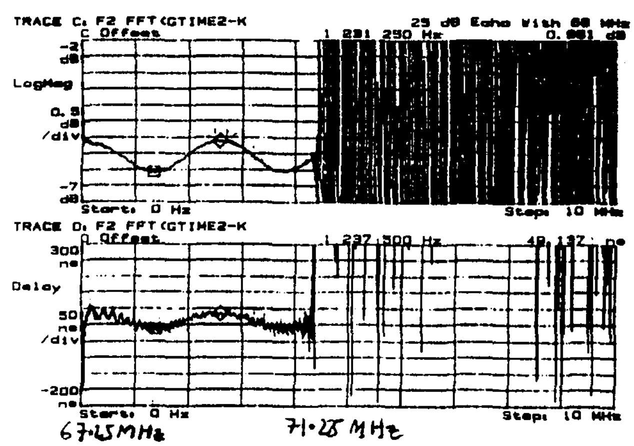

Fig. 11: Amplitude and Group Delay Meas. From 67.25-71.25 MHz for 25 dB Echo.

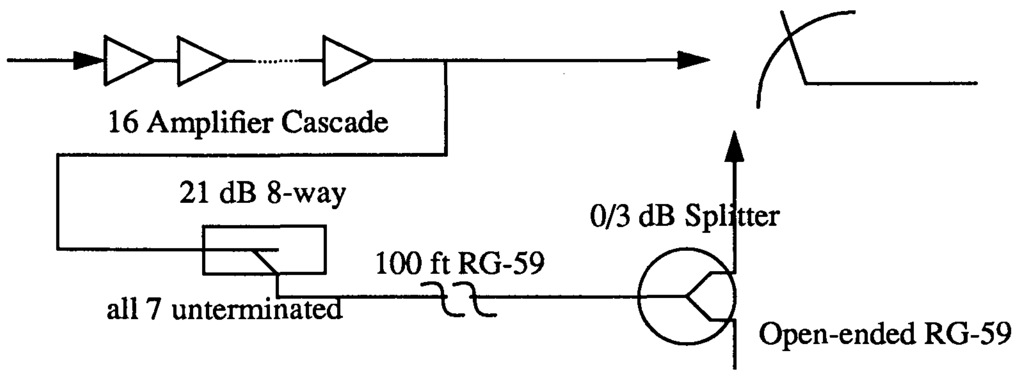

Fig. 12: Channel Setup for CATV Measurement

dow of Ch1 so that now a difference between the gated window of Ch1 and Ch2 removes the dc offset but does not cancel out the GCR. This technique can also be used with the analog NTSC GCR 8-field signal sequence, where the opposite phase is present every fourth field, and, now, a divide-by-8 counter is used. Another technique to remove this dc offset is by observing the trailing edge of the time-gated signal and using the mean value of the samples of this trailing edge to calculate the required dc offset. This trailing edge can be obtained as a time-gated signal on Ch2. A software program which performs such an averaging can be easily written using the BASIC programming options available with the HP 89440A. This investigation will form part of our future work.

CONCLUSIONS

Using the GCR signal, proposed for echo-cancellation, a channel characterization technique is described. Assuming that digital modulation techniques could be used over channels currently used for NTSC, it then becomes necessary to characterize these channel with 6 MHz bandwidth. The channel characterization technique described above allows for non-intrusive channel characterization. The measurement technique was validated in the laboratory by using a single-echo ghost simulator. Some channel measurements are shown with an in-house cable system.

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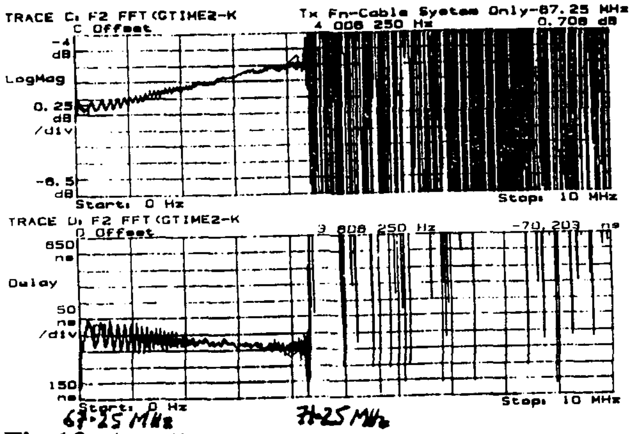

Fig.13: Amplitude and Group Delay Meas. For Just the Cable System- 67.25-71.25 MHz.

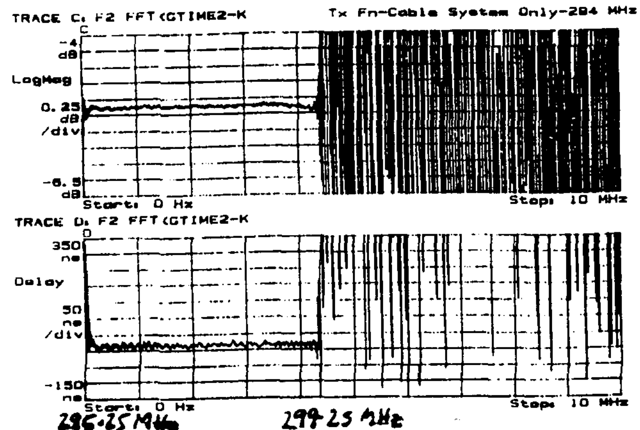

Fig. 14: Amplitude and Group Delay Meas. For Just the Cable System - 295.25-299.25 MHz.

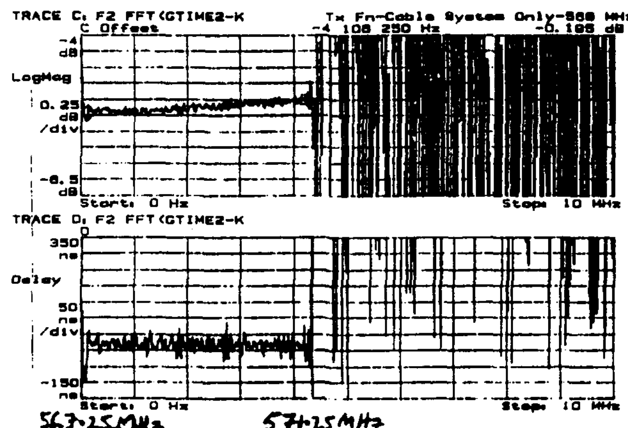

Fig. 15: Amplitude and Group Delay Meas. For Just the Cable System - 567.25-571.25 MHz.

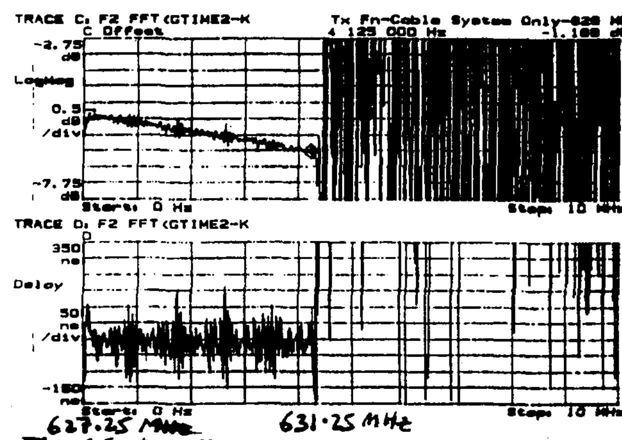

Fig. 16: Amplitude and Group Delay Meas. For Just the Cable System - 627.25-631.25 MHz.

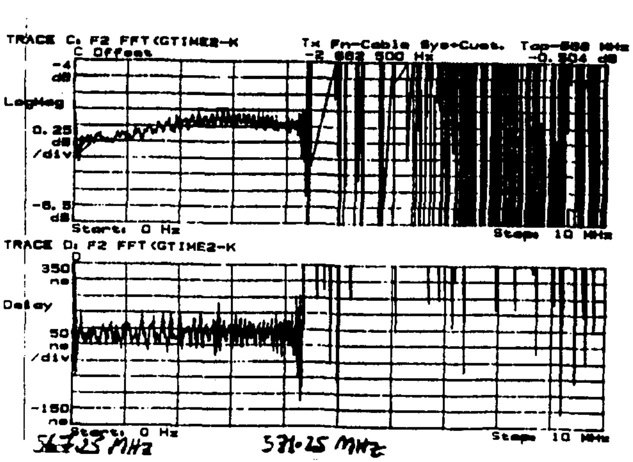

Fig. 17: Amplitude and Group Delay Meas. For Cable System+3dB Splitter-567.25-571.25. MHz.

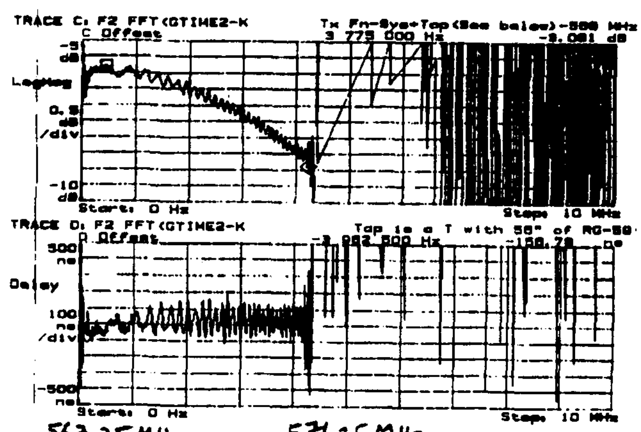

Fig. 18: Amplitude and Group Delay Meas. For Cable System+0dB Splitter-567.25-571.25 MHz.