# TIMING CONSIDERATIONS IN RF TWO WAY DATA COLLECTION AND POLLING

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## ABSTRACT

The transport of control data streams for Addressable Two Way CATV equipment can take several forms, across several different media, with a variety of data formats. The coordination and sequencing of the various data streams to ensure accurate and complete responses becomes complicated when several technologies are combined. Two parameters are of particular concern: delay through a given channel, and the jitter (or delay uncertainty) incurred for each format translation.

This paper presents several scenarios for data transport serving an out-of-band data carrier Addressable system utilizing combinations of RF band, microwave, and telephone line transmission technologies for data signal delivery. Definitions are given for both continuous and discontinuous data streams. Since discontinuous data formats are most sensitive to delay and phase distortion, special solutions are developed for compensating these parameters.

## INTRODUCTION

The maturation of Addressability as a technology, coupled with the advent of Pay-Per-View (PPV) and Impulse-Pay-Per-View (IPPV) services has effectively turned the CATV system into a two way data communications network. Regardless of the format of data transport over the cable, some basic principles of data communications govern the behavior of the data streams.

The CATV system can be represented as a tree-and-branch network. In the forward direction (controller to terminals), there is a single source, multiple destination data signal. Since various components in a CATV Addressable communication network are located at geographically distinct sites, and interconnection between the sites may be done with various media, depending on the particular geography, and availability of resources, a means to transport the addressable control data (one and two way) must be provided.

In most implementations, the forward data stream runs continuously, and is transported either on an out-of-band carrier, or in-band in the video itself from the headend or hub to the converter. If the Addressable Controller is at a business office that is located remotely from the headend or hub, data must be transported from the Controller to the headend or hub. This may be done through various media (e.g., RF cable, telephone lines, microwave, etc).

In the return direction, data is transmitted from the converter to the hub or headend site, where it is received and routed back to the Addressable Controller, over whatever media has been selected. In the case of multiple hubs or headends, return data is routed from each of the hubs back to the addressable controller, and combined for reception.

In the case of one way data, propagation and processing delays in the one way path are of no significant consequence. However, in a two way system, delays in both the forward path and the return path are critical to insure collision free high speed polling operation.

## TIME DIVISION MULTIPLE ACCESS

Time Division Multiplexing (TDM) is a technique used in communication networks to allow multiple, unrelated lower speed data streams to be transported on a single higher speed data stream. The technique provides time slots in a given, predefined sequence for segments of each component data stream to be inserted at the transmit site, and extracted at the receive site. An advantage of TDM is the ability to carry multiple signals on a single wire or channel, with the associated saving in equipment over what would have been required if each signal was carried over its own wire or channel. In a TDM system, the multiplexing operation occurs at a single site, thus delays for each component data stream are identical. A typical application of TDM is the transport of telephone signals from one central office to another.

Time Division Multiple Access (TDMA) is an extension to the TDM concept that allows each component data stream to be inserted from different geographical locations. The complication involved in designing and operating a TDMA system is the difference in propagation delays from each source to a single destination.

Since collisions would be detrimental to operation, each source must be time compensated so as to insure that the arrival of its transmission at the destination site occurs during its allocated time window. The time compensation must account for any processing or propagation delays in the path from a particular source to the destination. TDMA systems are typically used in digital telephony over wire, terrestrial, or satellite channels. The advantage is that multiple lower speed users, located at multiple origination sites, can share a single higher speed channel, with the associated saving in equipment and channel space as compared to individual channels from each source to the single destination.

## CATV APPLICATION

The typical tree and branch CATV system provides, in the forward direction, a single source, with multiple destinations. In the return direction, multiple sources provide transmission to a single destination. This architecture is analogous to the TDMA system described above. One major difference between the typical TDMA system and a two way CATV system is the number of operating nodes. A large CATV system may have on the order of several hundred thousand operating nodes in the network. Time compensating each of the nodes in a network of this magnitude would be an extremely time consuming task. Another major difference is the low cost nature of the subscriber terminal.

For these reasons, an approach requiring time compensation down to the hub level, but not to the subscriber node level is more appropriate. In addition, because the base of subscribers defined on the network is in a constant state of flux (box swaps, churn, etc.), fixed time slot assignment would slow the network down. Thus, a more efficient system allows assignment of time slots to subscriber terminals on the fly. The following sections of this paper introduce several system scenarios and describe the impacts of each technology.

When data passes through a communications channel, they are impacted by the physical properties of the channel. Of particular importance to this discussion is the propagation time of the transmission through the cable (fractions of the speed of light).

If the channel is actually comprised of several separate media with electronic translation on the endpoints of each segment, the propagation parameters are no longer the prime impact. The delay and delay parameters of each electronic translation is orders of magnitude more significant than the propagation time thru the channel.

Delays are generally incurred due to baseband data rate translations or format translations. Digital Signal Processing (DSP) operations and other digital data manipulations also contribute to delay. RF modulation and demodulation do not of themselves contribute significant delay to the channel relative to other delays.

Jitter, or delay uncertainty, is introduced whenever the clock phases of an asynchronous baseband transmitter and receiver at the endpoints of a channel differ. This occurs whenever data are reclocked (for processing by data path devices), or when data are sourced from numerous different devices running from their own, non-coherent clock sources, or located various distances from the receive point, with corresponding propagation delay differences (see Poll Format Data below).

## Transaction Formats

The most straightforward format for data transmission has been shown to be a command/response transaction. In this format each transmission of information is framed by synchronization and error-checking data to assist in interpretation. This packet format is used extensively in CATV control and other applications. The transaction format provides a coherent query-response sequence for communicating with Addressable devices. It is constrained to communication with one device at a time in that the return channel can only accommodate one packet at a time.

Figure 1 shows a transaction system. The Addressable Control system provides a query command requiring a response from the addressed device. It then waits a prescribed period to allow that device to answer before continuing with more transmission. In this fashion, a controller can maintain coherence between queries and responses. The first chart shows the timeout period for a simple RF- only system, that is, one with minimal propagation delays. The second chart includes provision for an arbitrary delay inserted at some point in the channel.

The optimum time out period is based on worst case delay time through the system. Too large a timeout valve causes inefficiency in a system where many network nodes will not respond during various activities. Too small a valve may cause some valid responses to be ignored because the reached the receiving node after the timeout had expired.

## Poll Formats (TDMA)

Poll formats can be described as transmission schemes which allow for maximum communication throughput at the cost of error-checking and framing. This technique borrows from the TDMA technique discussed above, in that several responding devices share a single response channel by synchronizing their transmission to some marker in the request data stream after their address is recognized. In this fashion, the responses are queued in the same order as requested, and each responding device is given a time slot for its response to arrive, if all delays are equal. A single command can initiate a response sequence from a range of Addressable Devices. the primary advantage in using this type of system is to achieve a very high poll rate for a given data rate.

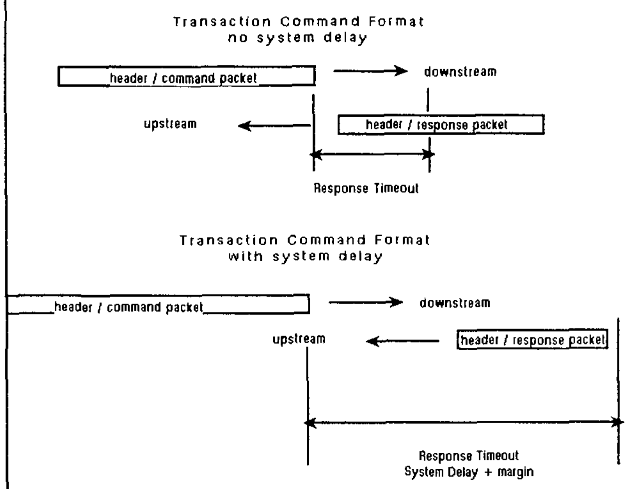
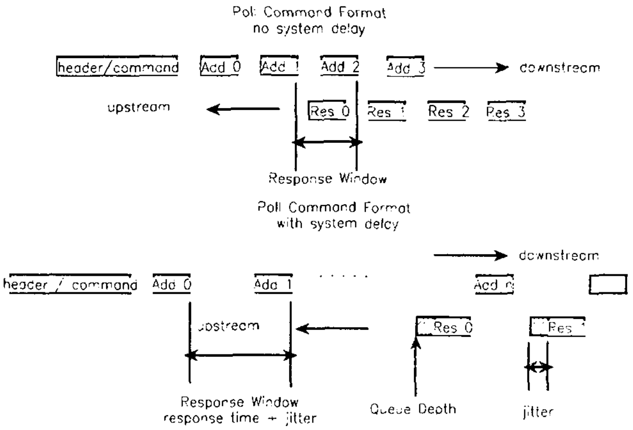


Figure 1 Transaction Command Timing Diagrams



Jitter is based on the uncertainty of the location of start bit leading edge. Caused by independent clocks, data rate and format translations, and modulation/demodulation.

Queue Depth is based on the roundtrip delay through the system.

Figure 2 Poll Command Timing Diagrams

Figure 2 shows a poll format protocol in which a command is presented, followed by the addresses of all devices expected to respond. Each device formats and transmits a response on encountering its address in the data stream following a command. As can be seen, there is then an expected order, and time slot, in which the response will arrive at the Addressable Controller. The upper chart shows the sequencing in a non-delayed system. The lower chart makes allowances for both round-trip channel delay and delay uncertainty from data translations.

In this manner, responses are pipelined, with the depth of the pipeline determined by the absolute delay in the system. If the time delay for responses from each of multiple hubs differ, they must be compensated so they are equal. This is accomplished by inserting additional delay in each hub interconnect that has an inherent delay less than the hub with the maximum delay. The goal of this process is to make the delay from each hub equal to the delay in the hub with the largest delay.

Differences in delay from each responding node on a given hub are accommodated by allowing a large enough response window to receive a response with the shortest and longest expected delay within that hub.

## SYSTEM DESIGNS

The RF plant of the CATV system is a known quantity. Any transmission delay in the signal is directly attributable to propagation delay in the amplifiers, passive devices, such as, combiners, splitters, and directional couplers, or cable. These quantities are easily calculated or measured, and are relatively small.

The opportunity for time distortion of the data streams occurs wherever there is a translation from one media to another. The most common place for this is the link between the Addressable Controller and the RF headend or hub sites. Often the Controller site is geographically separated from the Headend site. If there is a cable link, the delay will be minimal. This cable link can be a direct connect baseband connection between the Controller and headend, or an RF modem link to the headend. If there is no cable link, alternate technologies must be employed. When they are used, there is an impact on the communications system timing. Most sensitive are systems with multiple headends connected to the same Addressable Controller through different media and at different distances.

The following sections describe some of the more common interconnect options available for the link between the Addressable Control system and the RF CATV plant.

### RF systems

In systems where the Addressable Controller is located at or near the RF headend, it is possible to make direct baseband connection to the RF modulation/demodulation equipment. This is the most efficient means for transport of data. This system exhibits only cable propagation delays in the channel. This basic configuration is shown in Figure 3. RF system delays are calculated from the physical parameters of cables, and distribution equipment, like amplifiers. In addition, an Addressable Controller must compensate for worst-case response set-up time in the subscriber terminal. These

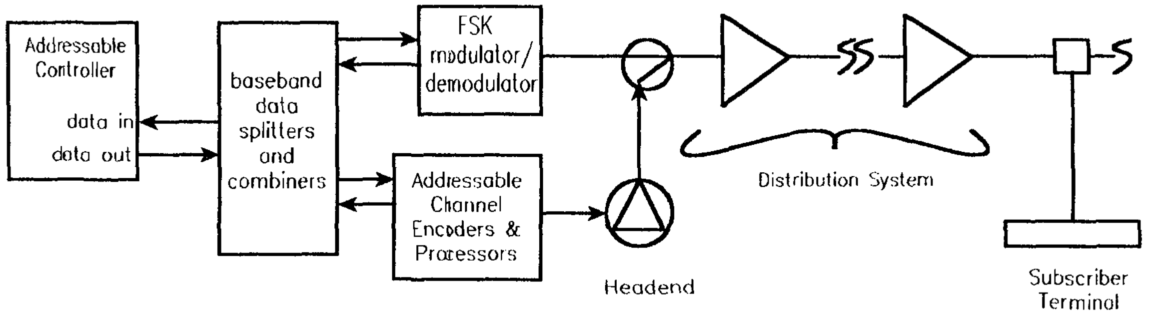


Figure 3. Colocated Single Hub Addressable System

values, once specified, become the baseline timing for the system. That is, a simple RF direct connect system defines the minimum timing compensation for any CATV data system.

More complex is the situation where the Addressable Controller is located on the cable plant downstream from the headend site. This is shown in Figure 4. To accomplish this, two additional modems must be installed in the system. Forward data intended for the terminals are modulated onto a sub-band carrier for transmission to the headend. There, the stream is demodulated and remodulated onto a carrier in the FM band for transmission back downstream to the subscriber terminals. In addition, the demodulated forward baseband stream is distributed to addressable video processing equipment within the headend. Terminal responses are received in the sub-band at the headend (on a unique frequency from that used to carry the forward stream), and demodulated. Responses from the addressable baseband equipment at the headend, along with the demodulated responses of the subscriber terminals, are modulated onto a unique FM frequency for transmission back to the Addressable Controller downstream.

RF modulation and demodulation do not add significantly to the delay found in a minimal configuration system. However, if the demodulation process is coupled to any form of error detection and/or recovery device which manipulates data at baseband, there is some effect on the overall timing of the system. In the RF non-colocated system described above, there are 3 opportunities for delay and uncertainty changes, one at each modem. These will add to the original baseline timing values. Depending on the Addressable Controller, additional delay and timing compensation may be necessary.

## Telephone interconnect systems

When there is no cable interconnection between the RF headend, and the Addressable Controller site, alternative technologies must be used to transport the data streams between the two sites. Several different systems are available for this purpose, including telephone lines and microwave.

Telephone line communications can take two forms: one within the normal telephone network using dial-up modems, or the other using dedicated point-to-point lines which are always connected. Due to the heavy data traffic and the time sensitivity of the communications, dedicated lines are used for this type of activity.

High speed modems encode data into a trellis format which allows very high bit rates to be transferred via a low

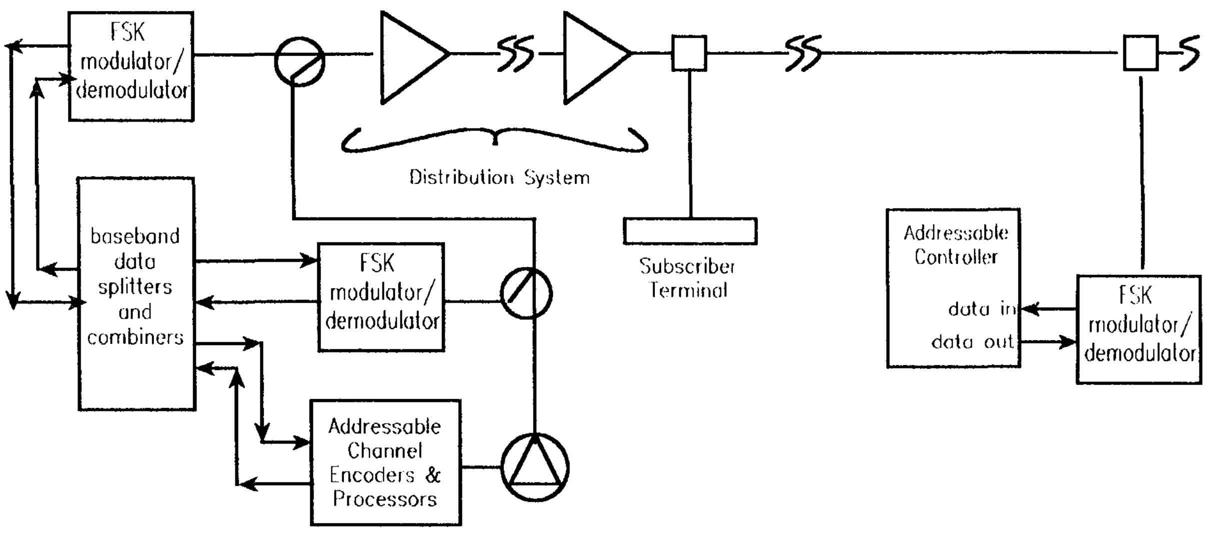


Figure 4 RF-linked Noncolocated Addressable Control System

bandwidth channel (3 Khz.). These data format and rate translations are usually the work of one or more microprocessors within the modem block itself. The delay and clock phase variations encountered are the result of not only propagation delay, but different clock rates, and phases, and nonlinear delays due to runtime variations in the formatting software of the signal processing microprocessors. In fact, these run run delays can be sizeable. For example, a 14.4 kbps. V.33-compatible trellis code modem may induce a 23-25 msec. delay in each direction. This amounts to an approximately 50 msec. roundtrip delay.

If the clock rate of the telephone modem is not identical to that of the incoming baseband stream, there are bit slippages and bit insertions which occur during encoding and decoding of the trellis-coded stream. This contributes to the jitter or delay uncertainty.

There is a final factor in the timing of a telephone linked system which needs consideration. The point-to-point telephone line connecting the Addressable Controller with the headend may be longer than the geographical separation of the two sites (see Figure 5). In fact, it is possible that a relatively short separation (<30 miles) can be connected by a very long telephone line (> 100 miles). Although propagation delays through a 4 wire telephone line are small, they are no longer insignificant in relation to the data rate when distances start to increase. This is why direct measurement of the roundtrip delay of the channel is desirable. Most modems can be placed into loopback modes. This allows the roundtrip delays in a given channel to be measured directly. If this is the last link before the RF interconnection to the distribution plant, the total delay can be calculated for that network leg.

Microwave systems

Another alternative for non-cabled data path is via microwave point-to-point transmission. A full duplex system capable of supporting two way RF terminals must incorporate transmission and receiving equipment for both directions between the Addressable Controller site and the RF headend or hub. (Two way satellite systems are generally not feasible due to large uplink costs at each remote site. One way systems are in use in several locations.)

The system design is shown schematically in Figure 6. The baseband data streams are first modulated by FSK modems and then presented to a microwave upconverter for the appropriate frequency translation. At the receiving end, a downconverter translates the stream back to its original carrier

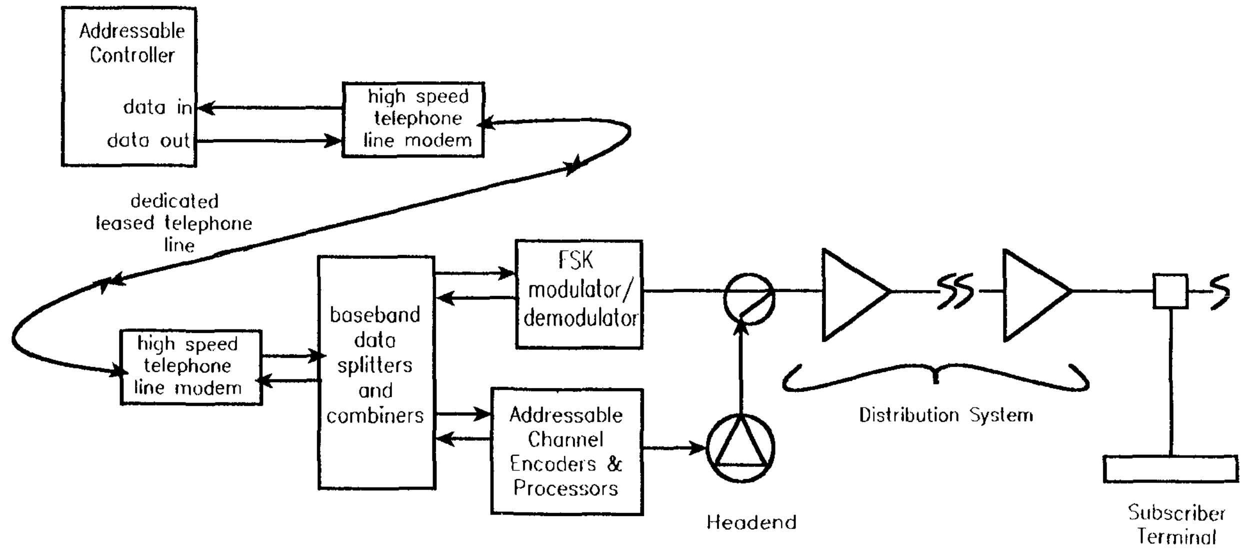


Figure 5 Telephone line-linked NonColocated Addressable Control System

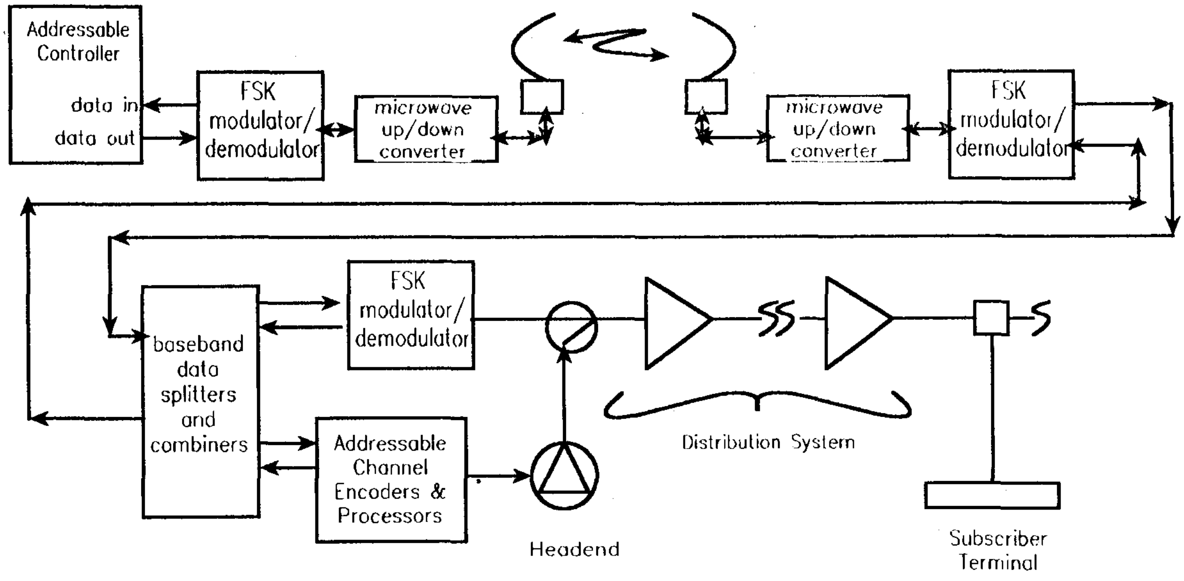


Figure 6 Microwave-linked NonColocated Addressable Control System

frequency. In most AML microwave systems, there is little discernible time delay for a continuous data stream. Propagation delays through the channel (upconverter, transmit, downconverter) are not significantly different from those in an FM band and sub-band RF system.

### Combination systems (Multihub)

A system where several headends or hubs are serviced by one Addressable Controller is the most sensitive to differences in timing from hub to hub. When there are several different transport technologies implemented, the timing becomes more complex. Figure 7 shows a multiple hub system which utilizes all of the above described transport scenarios.

If timing between terminal and hub is considered constant, then the remaining areas for timing differences are in the data path equipment. The effects can be considered a combination of each single technology impact described in the preceding paragraphs.

In a multiple hub system, if delays are not accounted for, the command data in the forward stream does not arrive at the subscriber terminals simultaneously. In many applications it is not desirable to control addresses of terminals by geographic location, thus it is possible that consecutive addresses will be on different hubs. In fact, depending on the delay in a given channel, a command can arrive at consecutive address devices at very different times. This is significant in polling command formats where the expected response position identifies the responding device. If there is disparity in the arrival time of the command, the response cannot return in the proper order and may collide with responses from other devices.

The solution in a multiple hub system is to equalize the delay in all hubs so that responses from devices on each hub arrive at the destination at the same time regardless of the delay incurred on that leg of the network. The compensation is described in detail in the following section.

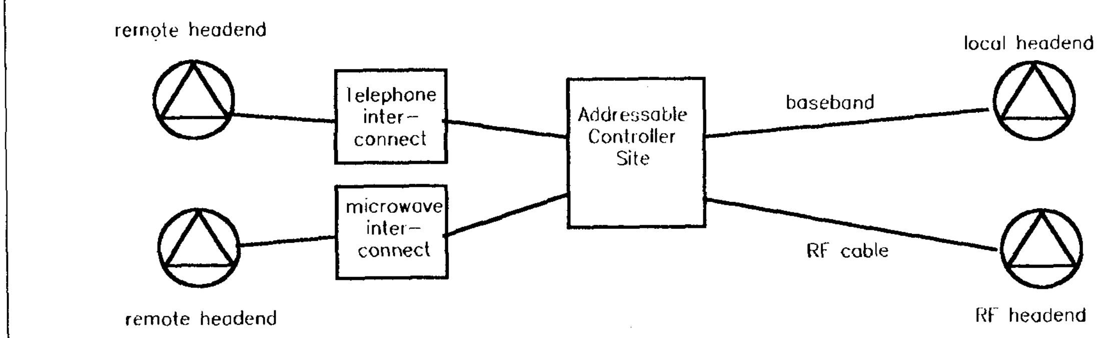


Figure 7 Multiple Hub, Multiple Data Path Addressable System

## TIMING COMPENSATION

There are two places where timing compensation is required to accommodate the various data transport technologies. The first is in the data path itself using additional electronics to provide for the delay values. The second place is within the Addressable Controller software. The data communications parameters and protocols should be adjustable for the full range of delay and jitter which can be encountered in a CATV data path and distribution system. Ideally, in the Controller, this adjustment should be automatic. That is, the Addressable Controller can determine the type of network it is using, make timing measurements, and provide automatic compensation.

In single hub systems, the compensation required is minimal. Adjustment of timing parameters within the Addressable Controller is usually sufficient to assure adequate system performance. However, in multiple hub systems, timing must be equalized between hubs. The concepts of aggregate delay and delta delay become important as one deals with several differing length network leg timings.

### In the Data Path

Aggregate Delay is calculated separately for each leg of the data path network. It is the combination of data path equipment delays, delays in translation to RF equipment, the propagation delay of the distribution system, and the turn around time of the subscriber terminal.

If there is more than one telephone-linked leg in the network, do not assume that the delays are the same. Each telephone line may have different delays.

Delay uncertainty is based on the accumulated uncertainty for all data path devices in the chain. Each device must be carefully characterized, both through device specification and empirical measurement. With the resulting base of information, the delay uncertainty can be calculated for any chain of devices.

The term "Delta Delay" is used to describe the difference in delay between a response from a given leg (hub) of the network, and a response from the leg (hub) with the longest delay. This is the amount of additional delay that must be inserted in that leg to equalize it (make it equal to the delay in the longest leg).

Delay insertion can be implemented using a programmable device under addressable control. It should be programmable on a channel by channel basis for a wide variation of delay values. The controller can then program the device to insert the appropriate Delta Delay for each channel in the network. When unequal delays are not compensated within the data path, there is a risk of collision between responses returning from different hubs.

### In the Addressable Controller

An Addressable Controller operating in the environment presented can be thought of as a half duplex system connected to a full duplex line during transactions, and a full duplex system during polls. The controller sends a command and waits for a response for a specified length of time. This is true in either the Transaction or Poll modes of operation. The treatment of the two modes of operation is different however, and bears discussion.

In Transaction mode, the Addressable Controller addresses a single device with a fully framed request or command. The response is also fully framed. The controller can wait for a prescribed period of time for the response to arrive, or declare it failed. This wait period is the Transaction Response Timeout. The value is the maximum aggregate delay through the network. This is shown graphically in Figure 1.

Poll format commands are structured to permit one command to provoke responses from a group of terminals on the system. As delay becomes larger, there is more elapsed between the time when the Addressable Controller has sent the address of a given terminal and the return of that terminal's response. In order to keep up throughput, the controller will keep sending addresses to the remainder of the group. The delay incurred has the effect of forcing the Addressable Controller to allow more addresses to be transmitted before expecting an answer from an earlier address. This is referred to as Queueing or pipeline responses. That is, there is a set of addresses transmitted before the first response returns. The size of that set is a parameter called Queue Depth.

Delay uncertainty, or jitter in the system causes the response to move around within its expected window of response. The window is defined as a period of time in the response stream sized to the response plus some margin. The larger the jitter, the more margin is required to assure that the response will be received. This window size should be an adjustable parameter within the Addressable Controller.

## CONCLUSIONS

The data communications functions of the CATV system have been described with respect to timing variations in the network. It is possible to compensate even the most complicated networks for timing to ensure efficient, reliable data communications performance.

The various data transport technologies may cohabit a system if their delay and jitter parameters are understood and accounted for within the system. This "fine tuning" is necessary in systems where high traffic polling and RF- based data collections are necessary functions.

If the time delays are understood, and the delay uncertainty can be measured and/or calculated for each leg of the CATV data network, the integrity of data responses from subscriber terminals will be reliable regardless of the complexity of the network. This results in more accurate, and complete data collections from the terminals.

Since timing compensation is done only down to the hub level, a typical system will have a relatively small number of nodes requiring compensation.

Since compensation is based on a mathematical model, and all measurements may be done under computer control. The entire compensation process can be automated, relieving the cable system operator from the laborious calculations.

Once timed, a system should only require retiming when data path devices or configurations are changed.

While the concepts have been presented in reference to an out-of-band data path system, it is possible to extend them to in-band systems as well. If there is a means for measuring or calculating the delay in the data channel between the Addressable Controller generation of a command and the arrival of the response, the delay values can be ascertained. If real time polling or other time sensitive communication is used, it is possible to measure the delay uncertainty of the return channel. These two parameters can be incorporated to fine tune the system for maximum reliable throughput.

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