COMMERCIAL DATA COMMUNICATIONS OVER A CABLE TELEVISION SYSTEM

Robert V. C. Dickinson, Consulting Engineer
Sterling Manhattan Cable Television
New York, N.Y.

Sterling Manhattan Cable Television is franchised to operate in New York City south of 79th Street on the West side and 86th Street on the East side. This area includes some 350,000 dwelling units and encompasses the entire midtown Manhattan business district and the concentrated Wall Street financial community. This represents one of the world's highest concentrations of business and financial offices. In seeking sources of revenue outside of domestic television service, carriage of commercial data became a prime candidate. A good deal of effort has been expended by Sterling Manhattan and other interested parties in surveying this market potential. The conclusions have been very encouraging to the point of initiating technical studies, tests, system design and equipment development. An overview of this data system with emphasis on the technical aspects and the particular concerns of the cable operator will be presented.

DATA REQUIREMENTS

The data transmission environment in New York City, as one might expect, is almost totally interconnected by telephone circuits. With the enormous growth of electronic data processing over the past few years the telephone network is having difficulty keeping pace with the mounting requirements. One group of typical data users is the banks. One bank may have as many as 30 branch offices in the franchise area which must communicate extensively with a central computer and with each other. These are generally polled systems where the central computer interrogates the terminal at each branch office stimulating a responsive transmission of data back to the central computer. The central computer also transmits data to each branch office. These systems currently utilize synchronous and asynchronous data transmissions with rates to 50 kilobits per second. Many of these signals are carried in multiplexed form where several lower rate channels are combined into a single high rate data stream. The same type of service is often required by businesses for control of finances, inventories, shipments, and the like. The financial community employs extensive data communications between branch offices and central computers. In addition, hundreds of low speed circuits are employed with teletype-like terminals used in financial information services and buy and sell communications to brokerage firms.

Facsimile is another area of broadening interest. With the advent of high speed facsimile machines, letter size documents may be transmitted in just a few seconds; however, transmission bandwidths as high as 50 kbs are required. Many firms have found that duplicate orders, etc., transmitted by facsimile are more useful than ordinary data transmission between offices due to the convenience of complete standard forms rather than hard to handle lists of received data. Use of facsimile frees the computer while utilizing only the fax transmitter on one end and the receiver on the other end of the link.

In the future some long haul data services may need local trunking and distribution. These circuits might utilize data rates to 250,000 kbs.

The results of the market surveys indicate the following technical bounds for profitable involvement in commercial data transmission.

1. Full duplex capability

2. Synchronous transmissions only

3. Serial data rates from 1.2 to 50 kbs. Below 1.2 kbs does not appear profitable. Above 50 kbs should be available when the market demands it. Low speed circuits can be accommodated if premultiplexed.

4. Perhaps 2000 terminals within five years.

CABLE OPERATOR'S PERSPECTIVE

With the background of possible markets for a CATV data service, let us assume the perspective of the cable operator. In this case Sterling Manhattan Cable Television has viewed the potential market with its existing CATV system clearly in focus.

SMCTV is not only unique in the fact that its residential service surrounds an enormous commercial community, but it is also one of the few cable systems which have been built totally underground. SMCTV's 54 miles of trunk serving approximately 60,000 subscribers, is routed through a maze of underground ducts running beneath city streets. For the most part the trunk is accessible only by manholes. Amplifiers are often housed in these underground facilities or, at best, in sidewalk boxes accessible by lifting heavy steel plates which cover them. Much of the distribution system also runs in these ducts before being routed into the basements of hundreds of buildings all over the city. This may seem to be academic information at this point, however, it becomes a serious consideration if the implementation of the data system requires placing of sensitive equipment at best in someone's cellar and at worst in what is very nearly a sewer.

Also to be considered is the depth of the operator's involvement in the sophisticated realm of electronic data processing. Reviewing the systems previously described it can be seen that many phases of data communications are involved. Such terms as Time Division Multiplex, Store and Forward, ARC, CRC, etc., are encountered and we find that the modes of transmission used are far from uniform. In this regard it was the desire of SMCTV that direct involvement in the details of user's data transmission systems, data formats, etc., be avoided to the greatest degree possible.

A switched type of data service could be provided. However, this is very expensive and sophisticated. A headend computer would be required and bring with it the headaches of software and foreign equipment maintenance.

With these negatives in bold relief SMCTV has avoided such involvement wherever possible. The basic philosophy of SMCTV's data system can be summarized as follows. The desired system should:

1. Provide point-to-point service

2. Be sold and utilized strictly on a bandwidth requirement basis without knowledge or manipulation of the customer's data formats

3. Require investment and equipment modification more or less in proportion to the number of customers avoiding large initial equipment expenses

4. Be easy to operate, dependable, and easily maintainable by CATV technicians.

With these goals in mind an investigation of present systems and methods was initiated.

The normal methods of data transmission applicable to the New York City situation are largely those developed and used by the Bell Telephone Company. Starting at the customer's terminal they provide a direct dial line or a leased line with the proper frequency response characteristics. Where transmission of several channels is required they are normally combined by frequency division multiplexing into banks of 12 voice channels, called groups, which may be further combined into super groups, master groups, etc. One transmission carrier for microwave or coaxial cable may contain in the order of a thousand voice channels or equivalent. This type of arrangement requires modulation (multiplexing) and remodulation at every point of group compounding.

Applying this technique to the CATV environment we can picture combining, let us say in every block of the financial district, recombining sets of blocks and perhaps combining a third time before entering the trunk. This immediately requires the installation of expensive multiplexing equipment some of which must be located in the undesirable locations mentioned before. Thinking this system through also shows the need for "uncombining" in the same manner for the down stream signals. For the projected data loading of the system this approach could be extremely complex. To make a long story short this may be fine for "Ma Bell" but it is not the answer for the CATV operator.

The use of Time Division Multiplexing has been explored and suggested by some. This would mean that a basic timing system must be set up in the data channel of interest (this would have to be in some RF channel or for the sake of discussion some Television channel). Each terminal in the system would then be assigned a specific time slot and could transmit or receive its data, bit by bit, each time the assigned time slot occurred. There are two major disadvantages of this approach. First the timing of a "tree" type system, such as a CATV system, becomes quite complex. Secondly, the TDM "modem" becomes a rather sophisticated device especially when the timing system must include operation at RF frequencies. It is estimated that a terminal will cost in the order of $2000 in reasonable quantities after development. The TDM approach was seriously considered but was not accepted due to these limitations.

SMCTV SYSTEM CONCEPTS

After all the above the following rather simple system was formulated and steps taken to achieve its implementation. The system concept involves single level frequency division multiplexing. That is, each customer is assigned a certain frequency slot in the data portion of the RF spectrum on both upstream and downstream systems. This slot will be of a bandwidth sufficient to carry the maximum data speed. Many such channels will be required so that the frequency band allocated to data will contain many discrete carriers. Since repeated modulation of one signal onto another generates unwanted mixing products, it was decided to generate each customer's carrier frequency at his location and passively couple each of these signals into the cable system. In this way no spurious products will be produced.

The basic mode of operation is to transmit upstream all signals originated by terminals, passively combining in the distribution system before entering the trunk. All signals will be assigned frequencies within a block, probably within the assignment of one unused TV channel. This block will then be up-converted with a standard CATV translator to some unused downstream TV channel, probably near the high end of the spectrum. All transmitted signals will be on the downstream system and receivable at all locations. Point-to-point communication will then exist upon assignment of compatible transmitter and receiver frequencies at each end of the link. Full duplex operation may be utilized and multiple reception of any transmission can be provided. The data terminal can be given any serial binary signal and modulate its RF carrier accordingly without concern for any of the parameters of data, coding, formating, and the like except for the maximum baud rate which determines the required bandwidth. This then does not require the cable operator to get any deeper into the data transmission schemes than providing the channel and modulator/demodulator functions.

The first reaction to this concept was "Surely, this is a simple system requiring no complex computer control, equipment in manholes or expensive overhead and monitoring paraphernalia. The hardware should be simple and straightforward and certainly is manufactured by someone." To find this someone was a "horse of a different color." It seems that everyone makes "modems" but modems, in today's form, are built for operation over the telephone lines and are completely unusable in this situation. Unfortunately nobody makes this type of simple FDM equipment for the frequency range involved. Consequently the decision was made to develop the equipment needed. Estimates for equipment development and production of the data interface in relatively small quantities fell under $1000 per unit.

DATA INTERFACE DESIGN

The major factors in the design of the Data Interface modules are:

1. Frequency selection and stability
2. Modulation method and bandwidths
3. Automatic and unattended operation
4. Self-testing and maintainability.

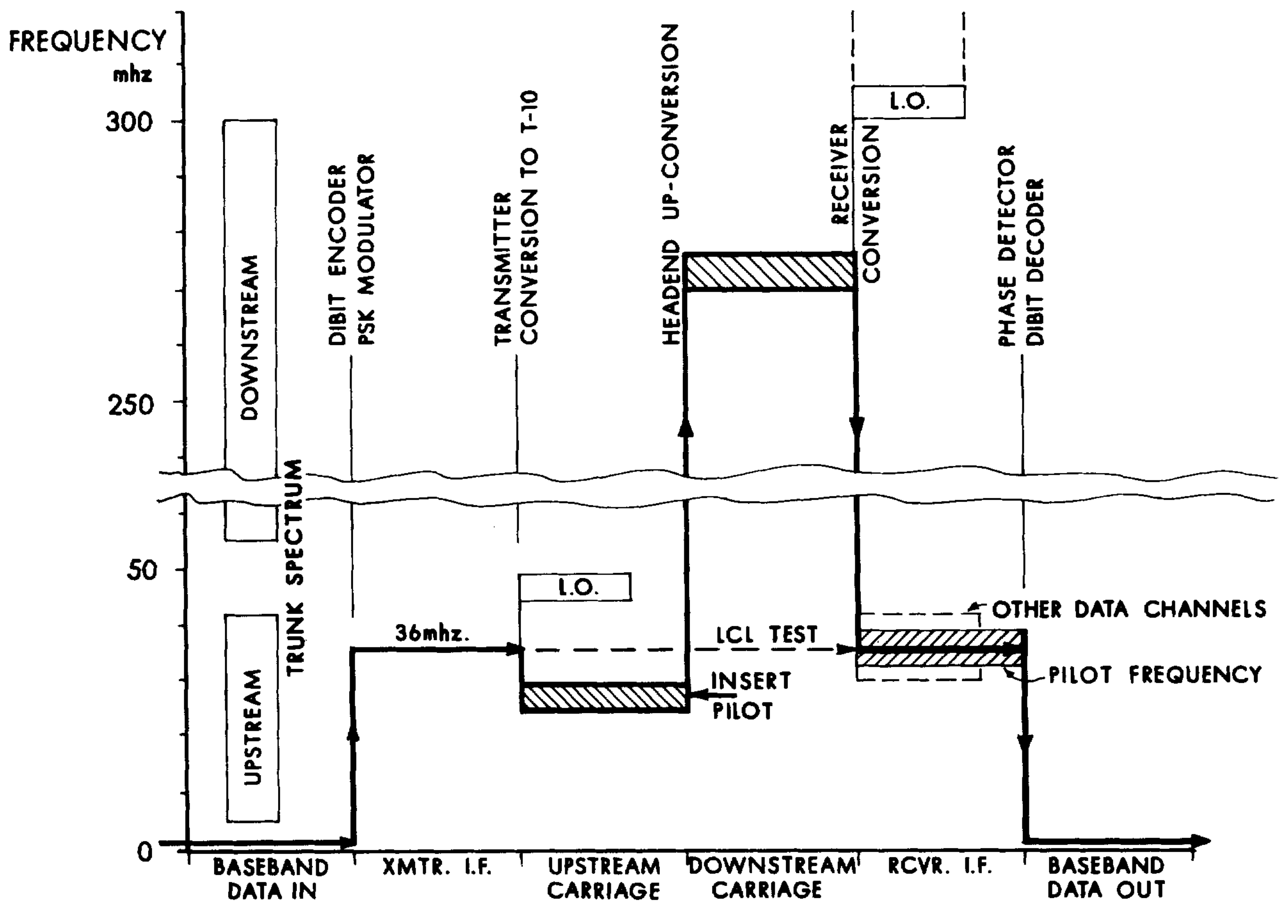
Assuming proper system environment, which will be discussed later, the above factors dictate the design strategy. Since all origination signals will proceed upstream on the cable system at a low frequency stability of the transmitted signal can be easily achieved. In the SMCTV system the sublow T-10 channel was chosen for initial data utilization. This channel was chosen because the group delay in this frequency range on a 5-32 MHz reverse carriage system precludes its use for video. Any of the other sublow channels can be used.

In this range crystal controlled oscillators having overall frequency tolerances of ±.0005 percent are readily obtainable. Carriers may then be easily located and stabilized to within ±500 Hz (including local oscillator tolerances). Now the entire data spectrum can be up-converted as a block from channel T-10 to a higher channel (in this case channel R at 264 to 270 MHz was chosen). Before up-conversion a pilot carrier of high stability is inserted for final frequency control. Since the pilot is accurately maintained relative to the data carriers, high frequency stability in up-conversion is not required. The pilot carrier will be used to locate the correct data channel amidst all of the others when receiving the block of signals in channel R. In the receiving section of the data interface a frequency conversion of the block is made to allow reception and demodulation of the proper data carrier.

Let us take a closer look at the details of the system operation and the requirements of the transmitting and receiving sections of the data interface. Referring to Figure 1 the various steps of modulation, frequency conversion, and demodulation can be followed. The baseband binary data, as it is received from the computer or data terminal, modulates a 36 MHz carrier. This carrier is then translated to the T-10 channel (23.75 to 29.75 MHz). The local oscillator frequencies for this conversion lie in the CATV system "crossover frequencies" between 32 and 54 MHz. Should any of these leak into the system (which they should not), they would be harmless. The data signal then is introduced into the upstream CATV system and transmitted to the headend. At the headend the highly stable pilot carrier is introduced. Standard CATV equipment is used to translate the block and pilot preserving the amplitude and frequency relationships. The data block is then transmitted downstream like a television signal.

The receiver portion or the data interface is tuned to the assigned receiving channel. Due to the close spacing of the data channels it is very difficult to distinguish one channel from the next, therefore frequency selection is accomplished by use of the pilot carrier. The receiver signal IF frequency is exactly 36 MHz. The pilot carrier is greater in amplitude than the data carriers (the specifics of this will be discussed later). Knowing the frequency of the data channel desired and the frequency of the pilot carrier a crystal is selected to establish oscillations at a frequency equal to the frequency of the data channel minus the frequency of the pilot carrier plus 36.0000 MHz. A local oscillator frequency is established in the band of 300 to 306 MHz. This local oscillator when compared to the frequency of the data channel must produce a 36 MHz output. To achieve this the 300 MHz local oscillator beats with the pilot carrier and the difference is compared to the frequency of the crystal previously selected. The output of this comparison is used to correct and finally phase-lock the 300 MHz local oscillator and bring the proper data channel carrier into the 36 MHz IF. Examination of the diagram and the crystal selection equation will help clarify this operation.

With the desired data channel at exactly 36 MHz it is further amplified and limited in a narrowband IF. The bandwidth is assigned depending on the customer's maximum data rate. Beyond that a phase detector and digital circuits restore the original data stream which was introduced at the transmitting end of the circuit.



Data System Frequency Chart

fig. 1

In passing it is well to note that the transmitter and the receiver have common IF frequencies allowing "local loop" operation for test purposes. In this mode it is possible to check operation of most of the interface circuitry. In normal operation the transmitter and receiver sections operate independently in a full duplex mode.

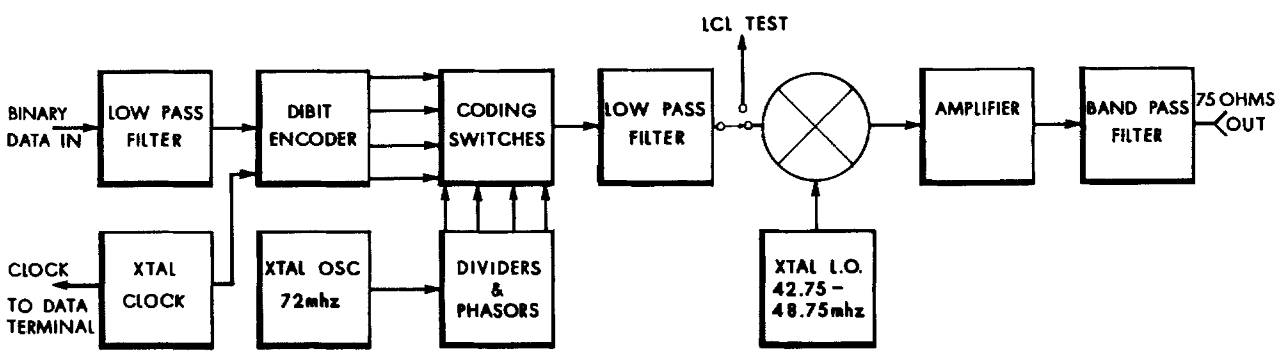
With these general principals of operation in mind let us look at the block diagrams of the transmitter and receiver portions of the data interface as shown in Figures 2 and 3. So far we have not mentioned the type of modulation on the bandwidth required for transmission of data. As previously explained synchronous data at rates from 1.2 to 50 kbs will be handled. An FM or Phase modulation system would be in order due to superior noise immunity. The minimum possible bandwidth for any such system is equal to the baud rate of the system. (The baud rate is the number of bits per second and the maximum modulation frequency is one half that figure.) Add to this the requirement of guard bands between channels and we find that our maximum data speed is in the order of one half of the bandwidth occupied. It is desirable to make this somewhat more spectrum efficient. Therefore, a system of bandwidth compressions is employed using four phase PSK modulation. This will allow modulation bandwidths of one half the baud rate to occupy spectrum at the rate of one bit per second per Hertz of bandwidth allowing for 100 percent guard bands (100 percent guard bands are quite generous).

With this modulation system the data interface will accept data to be transmitted in a binary form from the data terminal or computer. The data rate will be preset and an internal clock will generate the clock signal for the data terminal. As data bits are received they will be separated in pairs. Each pair has only four possible combinations (i.e., 00, 01, 10, or 11). The dibit encoder takes the code of the bit pair and uses this information to select the proper phase advance or retardation to represent this combination. Since a change in modulation takes place only once every two bits of input data, the maximum bandwidth required is halved. Therefore, instead of requiring a bandwidth equal to the baud rate only one half the baud rate is required.

Since the transmitter IF operates at 36 MHz we must supply a source of 36 MHz energy from which we can select four equally spaced phase conditions. In order to achieve this a 72 MHz crystal oscillator is used for timing. Since there is an axis crossing every half cycle we have enough timing information to establish four periods of 90 degrees each at 36 MHz. These four phases are directed to gates which are selected one at a time as required by the output of the dibit encoder. This phase modulated signal is then passed through a low pass filter and mixed with the appropriate local oscillator frequency and translated to the assigned carrier frequency in the T-10 upstream channel. This signal is amplified, passed through a bandpass filter, and trapped to assure complete removal of the local oscillator signal and is ready for insertion into the cable system. The output level of this section will be in the order of +60 dBmv. This level will generally be sufficient to overcome system losses and provide injection at the proper level into the upstream trunk.

The block diagram indicates a tap-off point for local tests. A signal extracted at this point can be fed to the receiver section to accomplish the local loop test previously mentioned.

The receiver section of the data interface accepts the downstream signals in channel R



Block Diagram — Data Interface Transmitter

fig. 2

(264 to 270 MHz). The receiver is equipped with a bandpass filter for this channel and a trap to remove any local oscillator feed-through. The first mixer converts the desired data channel to 36 MHz and the pilot carrier to some frequency between 33 and 39 MHz. This is followed by a broadband linear IF covering this frequency range. The output of this IF is split. One side goes to the AFC phase detector where the pilot carrier is compared to the output of a crystal oscillator whose frequency has been selected (described previously) to center the data channel on 36 MHz.

The output of the AFC phase detector controls the frequency and phase of the local oscillator in the 300 to 306 MHz range. Since the amplitude of the pilot carrier is a good deal greater than any of the data carriers the phase detector will immediately seek and lock onto this signal. The pilot carrier will carry an audio frequency AM modulated at low level. The presence of this synchronously detected AM tone will indicate pilot carrier lock by a pilot lamp.

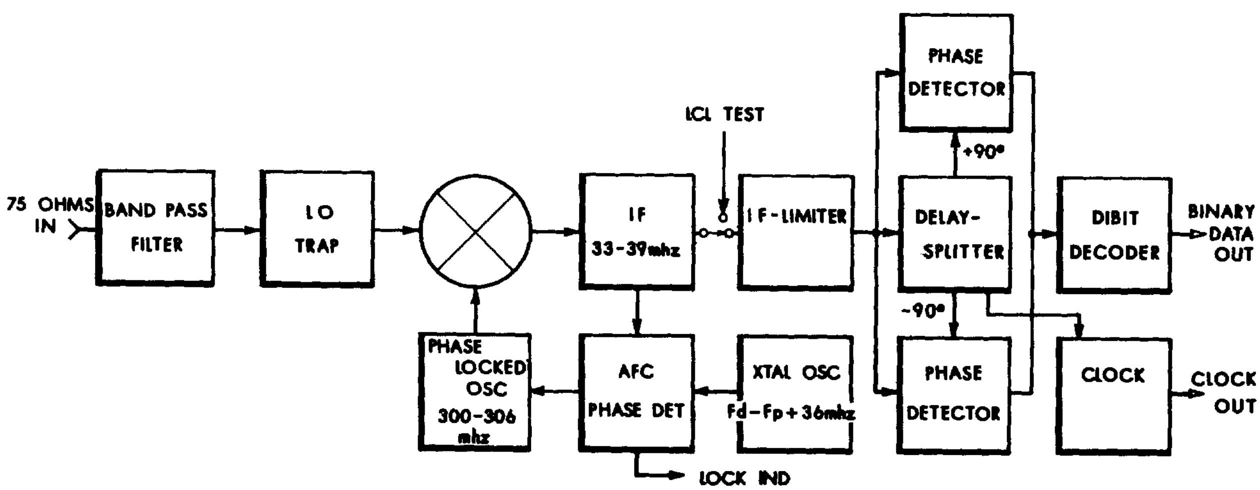
The other output of the wideband IF feeds the 36 MHz narrowband IF amplifier. This bandwidth is controlled to match that of the customer's maximum data rate assignment. This IF selects the single data channel and hard limits to reduce the effects of amplitude disturbances in the system. At the output of this IF the signal branches three ways, the center line goes to a network giving a 90-degree phase shift while the other legs go to separate phase detectors. The phase delay circuit also phase splits the signal resulting in outputs leading and lagging the input signal by 90 degrees. These signals are used for reference in the phase detectors. Combination of these phase detector outputs produces a signal which indicates which phase transition has just taken place. This phase transition, which has been differentially detected, positively identifies the dibit transmitted. The decoder produces a pair of bits for each phase transition thereby reassembling the transmitted message. If a clock output is necessary for the local data terminal this information exists in the phase detected signals and is used to generate the output clock signal.

It can be seen that the electronics of the interface are relatively straightforward. There are no operator controls except for the test switches. Many of the functions are achieved by low cost integrated circuits. Many of the RF functions are achievable by digital techniques producing a straightforward design of high reliability.

One physical configuration of the data interface is illustrated in Figure 4. This is a desk top unit with only two switches and two pilot lights. The pilot lights indicate receiver lock to the pilot carrier and a data being received. One switch allows self-testing in the local loop condition as previously described. The second switch is reserved for a system test feature which is to be incorporated in the future development of the system. These units are maintainable on a plug-in board basis. The power supply, transmitter, and receiver sections are separate and easily accessed and serviced.

SYSTEM CONSIDERATIONS

Several points should be discussed which bear on the operation of the cable system when



Block Diagram — Data Interface Receiver

fig. 3

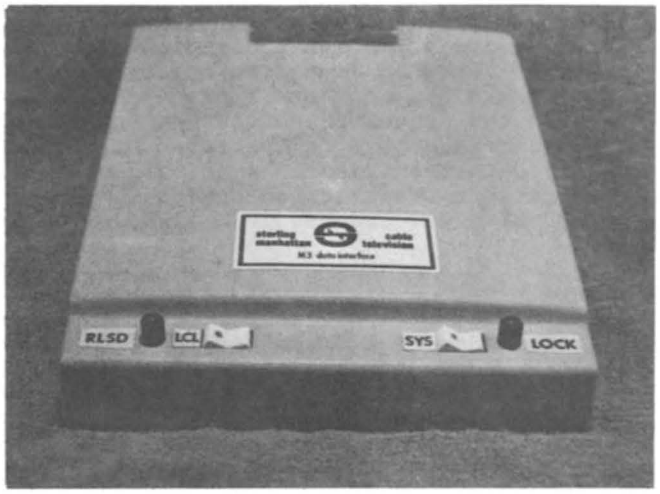


fig. 4

carrying data. The following three items are important considerations.

1. Data channel signal level, signal-to-noise ratio and error rate

2. Upstream noise buildup

3. Incidental system disturbances

The matter of data channel signal level and the consequent S/N ratio of the system must be handled together. As described in the previous section a data rate of 1 bit per second per Hertz of system bandwidth can be accepted when using the modulation system and guard bands described. Let us start by saying that the total power of the full data channel should be roughly the same as the equivalent power in a television channel. For reference use the amplitude of a normal TV carrier and fix it at 0 dB. Assume that the maximum system noise at any point (based on 4 MHz bandwidth) is 40 dB below this. The total power in any TV channel is essentially the picture carrier and there is only one picture carrier for each 6 MHz of bandwidth. The average power per Hertz of bandwidth is the one 6 millionth of the picture carrier or -68 dB. By the same token the noise per Hertz will be -108 dB (-68 dB carrier -40 dB S/N).

On this basis consider the signal levels which are appropriate for the data channels, pilot carrier, and the S/N ratios which will result. Let us start by making the total power in our data channel equal to that of a standard 6 MHz TV channel. This will assure that we will not produce any overload in the system but yet that we will provide maximum possible S/N ratio for data transmission. With the knowledge of the power density which we have calculated above we can simply assign each data channel a power which is equal to its portion of the total TV channel power according to the bandwidth assigned. For instance a 50 kbs channel uses 50,000 times the bandwidth of one Hertz (as established in previous discussion) therefore it can be assigned 50,000 times the average carrier power per Hertz of bandwidth. As 50,000 times is 47 dB this means that its carrier power can be -21 dB (-68 + 47 dB = -21 dB). The noise in the channel will be increased by the same factor so that the 40 dB S/N will be maintained. This is a consistent scheme of proportioning which provides the same S/N ratio for each data channel and therefore should produce the same error rate.

Let us look at the pilot carrier. We said before that it should be greater in amplitude than any other signal; therefore let us arbitrarily assign it one half the total channel power. This will mean that it will operate at a level of -3 dB and that we must then reduce all other carriers by 3 dB in order not to overload the channel. This however does not affect the noise level. Therefore, the S/N ratio is degraded by 3 dB to 37 for all data channels. For the type of modulation we are using and considering various other factors affecting the modulation, Information theory predicts an error rate of one in one hundred million (10^8) for a 17 dB S/N ratio. This means that the 37 dB which we are providing produces a vanishingly small error rate figure. It is so small in fact that it would not be unreasonable to reduce all the levels in the data channel or to allow for noise levels considerably higher than proposed. Obviously data is a lot more forgiving than video. There is also a good deal of headroom for noise buildup in the reverse carriage of the system. Some cases may require that some of this margin be used.

As all who have contemplated two-way CATV systems are aware there is a noise buildup occurring when many inputs are combined into an upstream channel. In the case of SMCTV system the problem of combining 60,000 subscriber terminals is not of immediate concern relative to the data transmission system. In this case a total of perhaps 2000 inputs will comprise the upstream carriage and these are distributed to several localities so that no density is particularly high. Standard techniques will suffice in reducing this effect. One inexpensive expedient which can be used in this application is to sectionalize the system and allocate a small block of frequencies to a given area. This will add noise to only a fraction of the total bandwidth which will not be duplicated elsewhere. Upstream noise buildup although often a big headache, is not considered as a serious problem in this application.

In order to sell CATV data transmission services, it is obvious that high system reliability is required. This means that all possible steps must be taken to increase the system reliability. At SMCTV steps are being taken to provide redundant trunk feeds to critical areas, remote monitoring equipment for better system control and anticipation of problems, automatic switching of standby equipment in case of localized failures, and other high reliability techniques.

Some of the problems which are not yet clearly defined include those of low frequency intrusion and transient conditions which have not been a problem with TV carriage but may well be factors producing data errors. An effort is being made to anticipate and measure this type of problem at the present time. Some low frequency intrusion data exists since the system now uses a 5 to 95 MHz origination trunk traversing one of the longest runs in the city. Some amount of intrusion has been noticed in these channels but the levels are considerably lower than those reported by others, perhaps due to the fact that this is an underground system. Intrusion also has been traced to drop cables, connectors and the like. Fortunately in the SMCTV case, the local signal levels in New York are extremely high and therefore high quality multi-shielded cable has always been employed. The same will be true for wiring of the data service customers, perhaps even to the point of using aluminum sheathed small diameter cable instead of flexible.

There is one traditional CATV ritual which may end up being a culprit in the data business, this is Summation Sweeping. Basically FM modulation systems with hard limited receiver IFs are immune to amplitude type disturbances, however, a coherent swept interference, such as the summation sweep, operating 40 or 50 dB above the data carrier is no mean disturbance and may turn out to be a villain. With this eventuality in mind a simple device for momentarily disabling the summation sweep as it passes through the data block, is being constructed. Initial tests on the system using upstream and downstream carriage have demonstrated high quality data transmission with extremely low error rates a transmission speeds up to 250,000 bits per second.

SUMMARY

The potential for CATV commercial data transmission in New York City is very good. A simple FDM data transmission system has been conceived and is currently being developed to serve this market over the Sterling Manhattan Cable Television System. The data transmission components are simple, straightforward, automatic, and inexpensive. They will handle synchronous data transmission in the range of 1.2 to 50 kbs. Higher data rates can be achieved with the same equipment but at this time are not required. Lower data rates have been considered economically unsuited. The cost of this service to the customers will be less than equivalent telephone charges, while error rates will be at least an order of magnitude better. System reliability will be higher and flexibility to change and particularly to increase the amount of service required by any customer will be far better and faster. The hardware involved is installed at the customer's location and does not require extensive additions or modifications to the CATV plant.

The basic system has been designed and specific hardware development is now under way. Operating tests with interested commercial data users are scheduled for the very near future. Formal inauguration of the data service with a substantial number of subscribers is expected within a 12-month period.