THE ROCKFORD TWO-WAY CABLE PROJECT: EXISTING AND PROJECTED TECHNOLOGY

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ABSTRACT

As more systems investigate and implement the expansion of services via two-way cable, the need for a systematic approach to the development and deployment of this technology becomes apparent. This paper presents the four-generation model used in the development of the Michigan State University-National Science Foundation-Rockford Cablevision Two-Way Cable Project, concentrating on the first two generations of the plan which are currently operational in Rockford, Illinois. Significant space is devoted to a discussion of the initial cable system design philosophy, two-way cable system design precautions, experimental system operational design, spectrum assignment of services, return system operational levels, activation procedures of the return system, and finally maintenance of the plant. In addition to a discussion of the technology employed in the Rockford Project, a report on the performance of that technology is also presented. The upward expandability of the Rockford technology is discussed, with focus on the third generation prototype terminals now being developed to address utility automatic meter reading and load management energy problems.

INTRODUCTION

The most significant developments in two-way technology began in the early 1970's, when entrepreneurs such as Broadband Technologies (formerly Coaxial Scientific Corp.) developed and demonstrated the feasibility of two-way broadband cable communication. Broadband Technologies began by converting one of the four Columbus, Ohio, cable systems to two-way capability. A minicomputer was employed to scan the cable system, monitor and control four per-program pay-TV channels, and bill customers on a per-view basis.

Another example of both the technical and economic success of two-way broadband cable is found in the TOCOM, Inc., system serving Woodlands, Texas. Also one of the early innovators in two-way technology, the TOCOM systems provide for the monitoring of smoke detectors, security and medical alarms connected to subscriber-owned terminals. More recently, Warner Cable has announced the technical success of their new two-way system (QUBE), also in Columbus, Ohio. Finally, a number of other cities such as Dayton, Ohio, and Syracuse, New York, have expressed an active interest in the use of two-way cable for purposes of monitoring alarms.

Michigan State University became involved in the development of two-way cable technology in 1974, when it proposed using a two-way cable system in Rockford, Illinois, for training firefighters in pre-fire planning. In early 1975, MSU began working with the Rockford Fire Department on a video tape series to be used to instruct firefighters in the techniques of pre-fire planning. The proposal, funded by the National Science Foundation, called for four of the fire department's 11 stations to be wired into the two-way cable system to enable men in those stations to respond to questions presented on the video tapes via a modified (Jerrold SX-2) cable television converter.

Before becoming deeply involved in developing a new two-way system, MSU researchers decided to examine both the existing state of the art, as well as the future of two-way cable to determine the economic and technical viability of such a venture. In the past, the development of two-way systems has failed because the technology was isolated to a single service, and prevented major economies of scale through the multiplexing of applications for cost-sharing the two-way plant. Thus, a step-at-a-time approach was needed.

MSU researchers, Broadband Technologies, and Rockford Cablevision, conceived a four-generation evolutionary approach to the design, development and deployment of two-way technology over a variety of existing and potential services. Briefly, those four generations are as follows:

Generation I: The development of a combination Frequency and Time Division Multiplex (FDM/TDM) data collection system for two-way cable TV, where data is continuously transmitted from subscriber's terminal devices. Through the use of code operated switched deployed throughout the plant, it would be possible to control the return, or subband (upstream), signal from areas of the system which serve approximately 100 to 150 homes. From an operational standpoint, a computer at the headend would address a code operated switch, then direct a receiver in the computer to sequentially tune to each transmitter frequency and process the digital message from each household in that area. This process would be continued until all areas were surveyed by the computer. Applications of this technology would include per-program pay-TV, audience measurement, alarm and detector monitoring.

Generation II: The modification of the home terminal/converter to include a multi-position switch which allows the cable TV viewer a choice between the standard analog and new digital structure. Selection of the standard mode would render the terminal equivalent to its current analog logical function. When, however, a response channel is selected, the channel-selecting function of the terminal/converter is bypassed, and the television set is automatically tune to the appropriate channel. The selector keys can then be used to transmit digital data. Applications of this technology include interactive educational programming, public forum, consumer marketing questionnaires, etc.

Generation III: Development of the intelligent terminal via the introduction of a receiver logic circuit and microprocessor. As more and more applications are added to the two-way system, an efficient method must be found to handle the increased data flow. The receiver logic circuit allows the terminal to accept data from the headend, while the microprocessor would be programmed to control the data format. The increased flexibility of this stage allow such new applications as automatic meter reading and power load management, in-home shopping, complex questionnaires, video games, etc.

Generation IV: Currently the last projected stage provides for an increase in the information processing technology of the system through the addition of low cost "bubble" memory storage in either the terminal or in on-line logic gates such as the code operated switches. This will allow for the transmission of time-compressed digital signals to a memory in a specific location such as an individual subscriber terminal. With the increased data storage capacity, applications such as on-demand catalogs and newspapers would not be unlikely since it would be possible to "page" a portion of the downstream data channel for local display on the home television set.

The first two stages of the above four-generation plan are currently operational in Rockford, Illinois. The remainder of this paper will deal with some of the considerations involved in the design and deployment of that technology, as well as a discussion on the performance of the system to date.

DESIGN PHILOSOPHY

In our assessment of all the ills that beset the two-way cable system operator, both real and imagined, we drew a few personal conclusions from which the Rockford system design proceeded:

1. It is unlikely that there will be "a TV studio in every living room" due to (a) the limited need, and (b) the high cost.
2. It is equally unlikely that there will be a need for a audio communication circuit into the home as (a) the telephone adequately provides for this specialized need, and (b) the nature of a cable system is not conducive to such a service.
3. There is, or can be, a great deal of data collected from a home both to aid in the routine operation of that home, and to interconnect it with the active outside world (i.e., to provide it with an "interactive" capability).
4. There are a number of existing or potential video sources scattered around most communities.
5. There is a need for a local broadband distribution network for intracity data transmission to points scattered around the community.

If we consider the above list, and throw out the "blue sky" schemes, we arrive at a number of services which have a possibility of being sold, and which can be technically accommodated within the capabilities of a practical two-way cable television system.

We will discuss elsewhere in this paper specific system design problems and precautions. In considering these problems in conjunction with the several service applications listed above, a fundamental decision was made to use the system distribution "feeder" cables for data acquisition only, and to use the system transportation "trunk" cables, for remote video and business data acquisition. This decision permitted us to choose a system of feeder-return switching, under which the cable system is divided into small areas of about 150 addresses, and each is sequentially interrogated for its data content. As this data return signal is formatted as an FSK (FM) type of transmission and is narrow-band, it is unusually immune to the interferrence to which the distribution system is most susceptible. A 20 db signal-to-noise ratio provides an extremely reliable data circuit, and only occasional errors result to a 10 db ratio.

The switched data acquisition system chosen, developed by Broadband Technologies, was designed to operate in TV Channel T-7 (i.e., 5.75 to 11.75 MHz), and this suggested a further refinement of the cable system return path, limiting the feeder return bandwidth of this channel while keeping the trunk return at the full 5 to 30 MHz bandwidth. This was done with the overall result that no feeder return data or noise can be injected into the trunk return path except during interrogation, at which time the 12.5 to 30 MHz feeder noise contribution is attenuated by at least 25 db. This technique permits the trunk return, which has a relatively low "ingress" suseptability, to be maintained at "video quality" with respect to its signal-to-noise ratio.

DESIGN PRECAUTIONS

In anticipation of the then-known problem associated with two-way cable, Rockford Cablevision system designers were especially attentive to factors which could contribute to interference intrusion, or ingress, and would affect the upstream signals. Obviously the active and passive equipment selected for the system (e.g., amplifiers, directional couplers, tap-off units, power-insertion units, etc.) must have high RF shielding over the entire frequency spectrum, from well below 5 MHz to well above 300 MHz. A shielding effectiveness of 140 to 150 db would seem to be a minimum acceptable rating. Torque wrenches must be used in fastening covers and lids to maintain this shielding level.

Trunk and feeder cable fittings must have a similar shielding effectiveness, and this is accomplished in part by using the available steel cable-inserts. The fitting itself must seize and hold the cable so tightly that the two become as one with relative movement prevented. Too much pressure will result in metal deformation and "cold-flow", so here too it is most important that torque wrenches be used in tightening every fitting.

As a further precaution against fitting problems, the Rockford system uses two full-sized, flat-bottomed, expansion loops at each pole -- one on the span side of all equipment. This does provide more protection than necessary in preventing cable rupture due to flexing fatigue, however, at the same time, it virtually eliminates the forces on the fittings from cable flexing, twisting, expansion and vibration, and thereby removes the major cause of loose fittings.

Service drops are obviously the most difficult potential interference ingress source to control. First, because there may be twice as many miles of such cable as the combined miles of the whole distribution plant, second because system owners traditionally let up on standards at this point to cut costs, and finally because we are at the mercy of the subscriber after the cable enters the home.

Rockford selected the eight-mil bonded construction type of cable as the only one, at the time, which provided sufficient shielding at low cost. Long ferruled fittings using a hex crimpring were selected, and the cable was installed using loops which in this application were designed to prevent vibration from causing metal fatigue. At the grounding block, the eight-mil cable ended and a double-braded cable continued on to the wall plate and to the matching transformer. As a final effort toward minimizing ingress, TV matching transformers of the high-pass variety were selected, and in the case of 75 ohm television sets a separate high-pass filter was installed. These devices provide a low frequency rejection of 25 to 40 db reading from 30 to 5 MHz.

SYSTEM DESIGN

The Rockford system consists of studio/control devices at the cable system headend, primary code-operated switches (P-COS), secondary code-operated switches (S-COS), response terminals, and test end-of-line oscillators (ELO).

The Rockford system departs from usual system design philosophy in one important respect, the feeder cable upstream path passes only the 5 to 10.5 MHz spectrum while frequencies of 12.5 MHz and above are attenuated by 25 db or more. The trunk cable passes the full 5 to 30 MHz, which includes the feeder data signals. This feeder-cable bandwidth-limiting, together with the technique of feeder switching developed by Broadband Technologies, and quadrant switching, has brought signal and noise ingress, and system amplifier noise cascading down to very manageable levels.

The General Automation computer (SPC-16) listed in Figure 1, controls the various equipment in the studio so that lessons may be given and transmitted on TV Channel B with no human intervention. From an operational standpoint, the minicomputer is used to control a Shintron 367 time code reader/switcher, plus a time code controller designed and built by members of the MSU research group. The video tapes produced by MSU in cooperation with the Rockford Fire Department, were recorded with the Society of Motion Picture and Television Engineers (SMPTE) time code on channel one of a dual track video cassette. Thus, the computer can synchronize videotaped lessons with programmed computer instructions, starting and stopping the lessons based on the responses of firefighters on their remote terminals. The minicomputer interrogates the response terminals in the field by (1) transmitting coded FSK signals at 112 MHz to addressable receivers located in each primary (P-COS) and secondary (S-COS) code operated switch, which in turn determine the select upstream path and amplifier opened, and (2) by tuning one-by-one through the various COS, terminal, and ELO FSK signals, identifying each by the unique combination of frequencies, and reading the return data content. Thus, when a multiple choice question is presented on the video tape, the minicomputer will stop the lesson, interrogate the response terminals, and when all firefighters have answered, resume the lesson.

The headend quadrant return circuit control is shown in Figure 2. The primary code operated switch (P-COS) for each of the four quadrants is located within the cable headend, with only the North quadrant illustrated for purposes of this example. From an operational point of view, a firefighter at Fire Station #1 in the North quadrant might press a button on his modified SX-2 converter/terminal and enter his response to a multiple-choice question into the return data stream. This upstream signal, modulated at some specific frequency between 7.5 and 10.5 MHz, would be filtered through the diplexer shown in the diagram, and isolated by a 5 to 10.5 MHz low pass filter, and routed to a diode switch operated by the computer-controlled P-COS. A P-COS identifying tone is made to go through this switch as verification of its operation. All quadrant return diode switch outputs are brough together at a four-way mixer, with only one "on" at a time. After passing through a second (band pass) filter and an amplifier, the return signal is finally fed to the FSK scanning receiver at the minicomputer.

Figure 3 shows the basic two-way cable plant as used in this experiment and indicates its expo-

FIGURE 1: ROCKFORD CABLE HEADEND

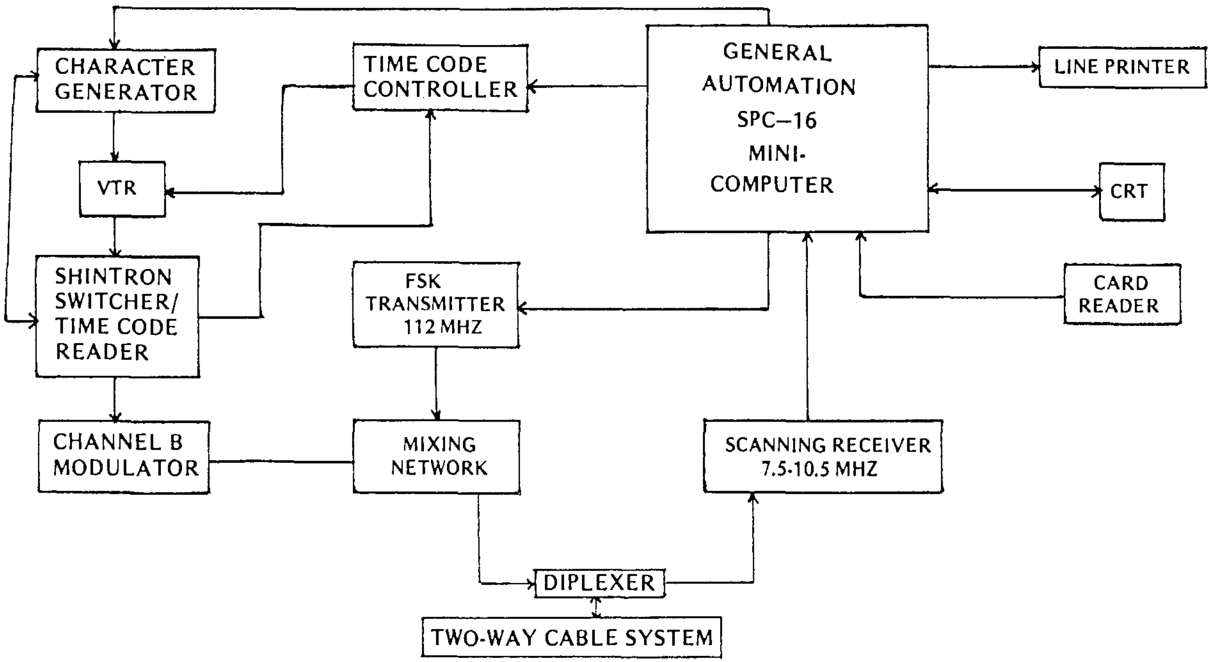


FIGURE 2: HEADEND QUADRANT RETURN CIRCUIT CONTROL

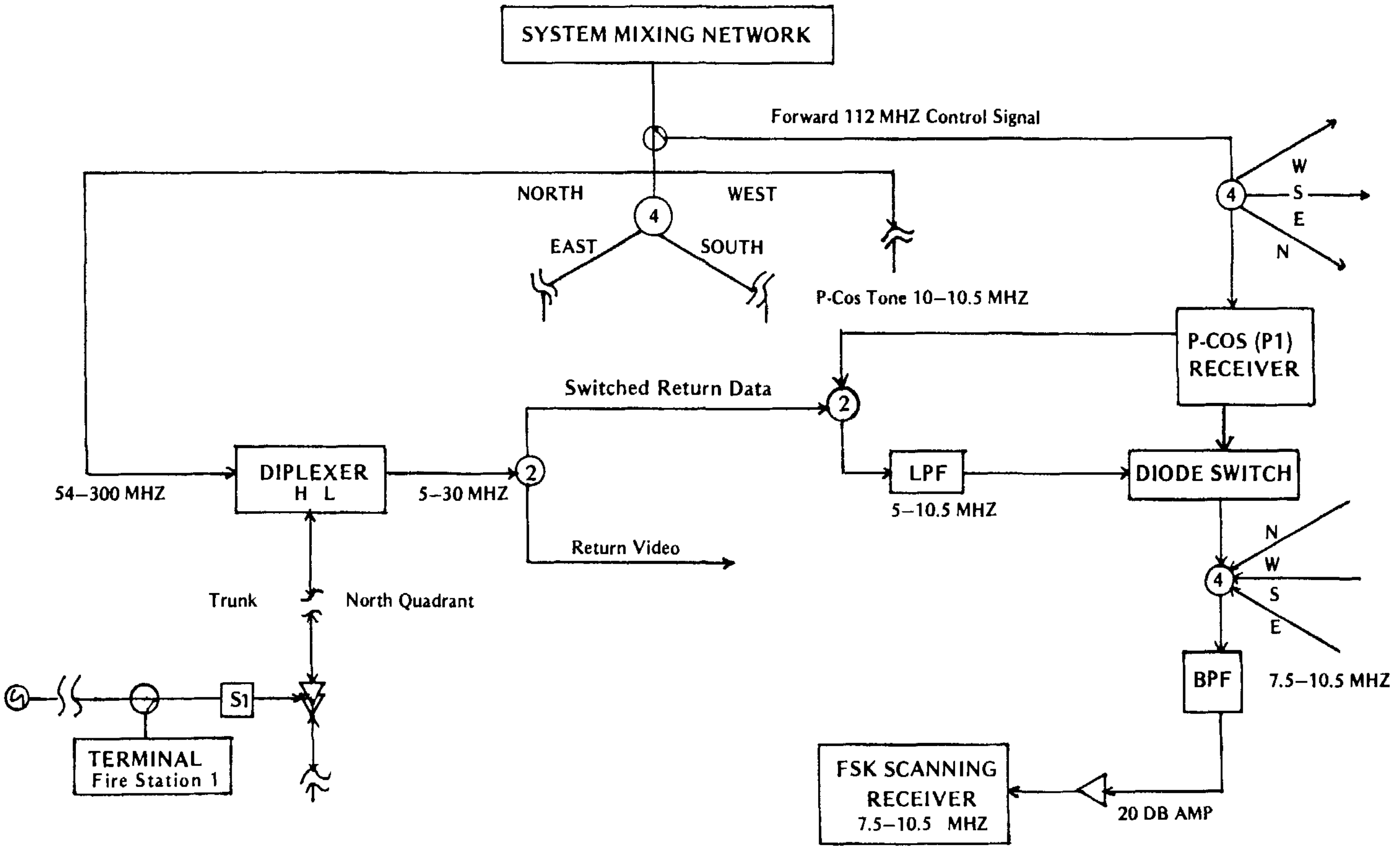
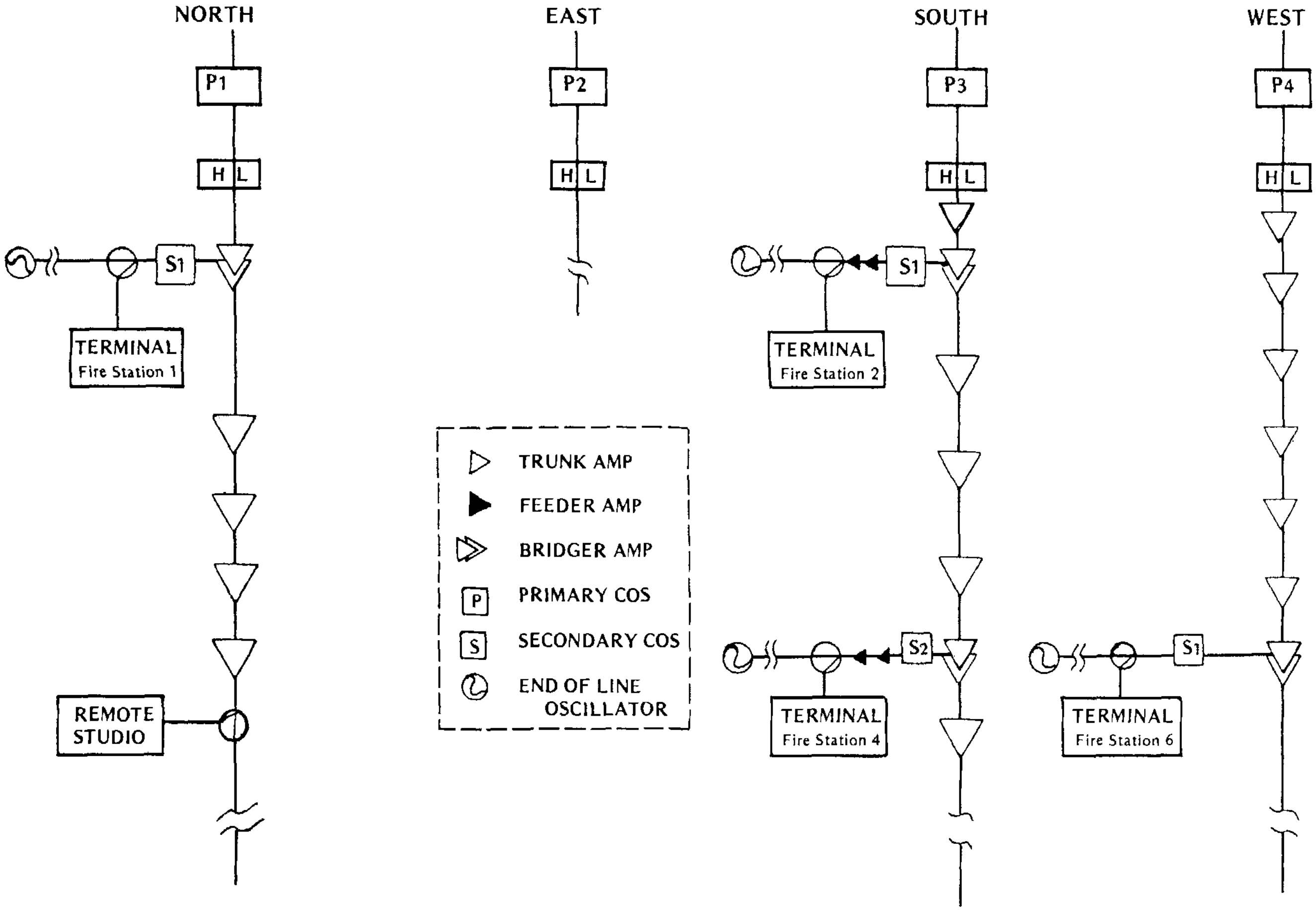


FIGURE 3: QUADRANT MULTIPLEXING



sure to ingress interference. At any instant of terminal interrogation, about 4,000 feet of feeder cable, 9,000 feet of trunk cable, and 15,000 feet of subscriber service cable (e.g., 40 subscribers) is "on" and is a potential source of short-wave radio or electrical interference.

In this experiment the feeder cable and subscribers-per-amplifier is low due to the turning-up of only enough amplifiers to effect the desired return path. A normal fully operational amplifier would have about 8,000 feet of feeder and 65 subscribers with an ingress-exposure factor about twice as great.

The terminal houses an FSK transmitter which is "on" all the time and which is modulated by activating any of several push-buttons on the modified Jerrold SK-2 converter. This causes a data word, which is also continuously transmitted, to change its content accordingly. The ELO is a test signal transmitter located as its name implies, at the end of the line. Initially this signal was simply monitored for its presence and amplitude, however newer units will be used shortly that have a forward signal monitoring capability so that total plant maintenance will be greatly improved.

The amplifier and S-COS configuration used in Rockford is shown in Figure 4. A Magnavox 4-MC-2 series amplifier was factory modified to (1) limit the feeder return to the 5 to 10.5 MHz frequency band, and (2) include a feeder return disable capability which is accessed through the amplifier's unused 7th port. A modified COS incorporates the FSK receiver and addressable logic which provides the control voltage to the feeder return switch. This S-COS also injects a special frequency into the return path which functions for test and identification purposes.

OPERATIONAL LEVELS

The manufacturer specifications for upstream television signals call for return amplifier output levels of +30 dbmv for four channels. This level generates extremely low intermodulation products and, in our system of switched feeders, results in an intrinsic signal-to-noise ratio of about 50 db. A change in level setting techniques should be mentioned here, in which one uses the return amplifier inputs as the equalization and control point rather than the amplifier outputs as in normal forward transmission. This is mandated by the multiplicity of signal sources all arriving at the amplifier by different paths with random lengths and attenuations.

The +30 dbmv television signal was used as the starting point and four such signals accepted as the desired amplifier loading. By assuming a 9 db gain as required for a "worse case" situation, an amplifier input of +21 dbmv for television becomes the specified level for the television signal trunk return amplifier inputs.

Assuming a 10 KHz data signal bandwith, and a 10 KHz guardband, the 4 MHz television channel will accommodate 200 such data channels. By operating these 200 channels at -2 dbmv (amplifier input), we load the amplifier approximately as heavily as one television channel at +21 dbmv, and this then becomes the specified level for a 10 KHz data-signal trunk return amplifier input. Line extender amplifiers are operated at a +1 dbmv input, based on the output capabilities of the various signal sources and system losses.

From these input levels we may determine the maximum permissable interference levels for each of the types of noise with which we must contend. Table I below indicates various interference levels measured over the two types of service, television and data.

Table I: Interference Levels by Type of Service

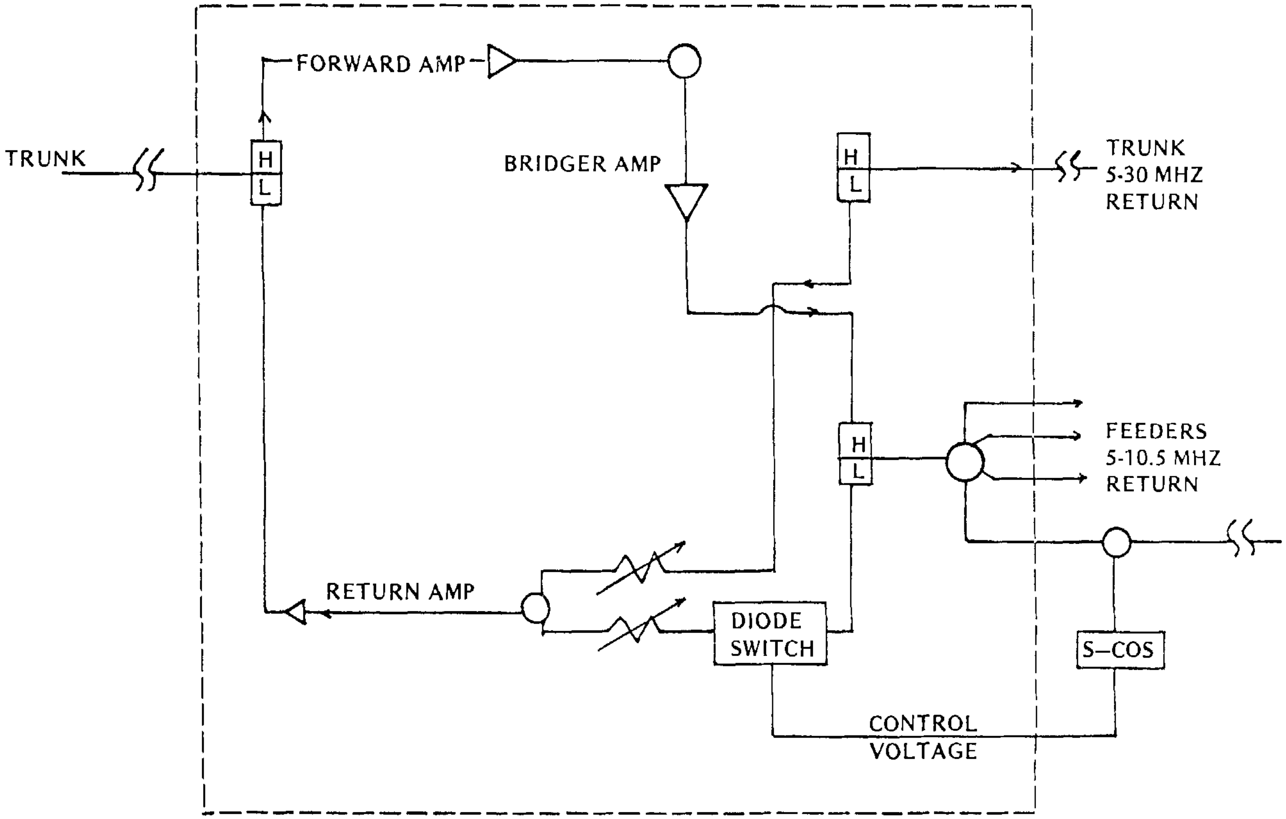
Type of Service	Trunk Amplifier Input Level (dbmv)	Random Noise (dbmv)	Discrete Radio Signals (dbmv)	Electrical Noise (dbmv)
Television 4 MHz	+21	-26	-36	-25
Data 10 KHz	- 2	-22	-22	-22

As the nuisance value of the interference is frequency related, it is necessary to list the Rockford Cablevision frequency assignments for its return system. In Table II below, the spectrum allocation of the upstream portion of the system is indicated.

Table II: Upstream Spectrum Allocation by Type of Service

Type of Service	Frequency Allocation From	To
Data Acquisition	7.5 MHz	10.5 MHz
Voice, System Alarms	5 MHz	7.5 MHz
Television	11.75MHz	23.75 MHz
Business Data	23.75MHz	30 MHz

FIGURE 4: COS/AMPLIFIER STATION



While indicated as a separate service in Table II, it should be noted that "voice" is used only in conjunction with the remote television service on trunk lines. Note also that the business data band will avoid the CB band at 27 MHz. Random noise, as an interference, is dealt with in system design and will be no problem whatever for data if it satisfies the requirements of the television service.

Discrete radio interference is a major problem in the 5 to 15 MHz band, and again at 26.96 to 27.41 MHz (e.g., CB). While FSK data and FM voice systems can tolerate interference ratios of 10 db, even up to 4 db, we have found that we have no problem holding this interference to at least the 10 db ratio and normally to a 20 db or greater ratio. Within the television channels used, T-8 and T-9, the only problem area is the 13 to 15 MHz range, and here again we are able to achieve the desired -36 dbmv (-57 db ratio) with reasonable maintenance measures due to essentially trunk-only exposure. The CB interference problem was nearly uncontrollable, and the goal became a two-fold one of avoiding the use of these frequencies, and of containing them to the extent of preventing them from contributing significant loading to the return system. This abondonment of the CB frequencies meant that television channel T-10 could not be used for television, and we have therefore assigned the resulting split-band to the business-data service.

Electrical interference, at -22 dbmv measured at 10 KHz bandwidth for data, or at -25 dbmv calculated to a 4 MHz bandwidth for television, does not pose a serious problem. The greatest exposure area, the feeder cables, are able to tolerate the highest interference level in the system, and conversely, where we need the best protection at the trunk television frequencies, we are the most protected. The business data band has no problem in that by the time we achieve the necessary interference ratios for television we are 20 to 30 db beyond the needs of a data circuit.

MAINTENANCE PROCEDURES

Initial set-up of the cable system return transmission path is accomplished by inserting a composite test signal (at 6, 9, 19 and 28 MHz) into the input of the last return amplifier (e.g., first forward amplifier) with all frequencies at the same arbitrary, let's say -2 dbmv, level. The display at the headend is monitored and the amplifier gain and slope controls are varied to achieve a flat display of an amplitude consistent with the losses built-in between the amplifier and the test point. This flat display is logged and the field person then moves back to the next amplifier and repeats the procedure and adjusts for the same display. This procedure is repeated back to the first return amplifier. A technique is being developed to allow the field man to carry a small TV set and to remotely observe the head-end display on command. Initially, all remote signal sources, such as terminals, ELO's, TV modulators, etc., must be set up using a two man team to insure that the amplifier input signals are properly balanced. The remote-controlled monitoring will serve this operational need as well as for initial set-up.

Signal intrusion into the return path of a cable system is directly related to signal radiation by the forward system. The nature of the system defect will determine the magnitude of both the signal ingress and egress, as does the frequency of the signal involved. The first step we follow in "de-ingressing" is to carefully monitor the involved area with a "Sniffer" (Com Sonics) and to correct any observed radiation down to a level usually somewhat below the FCC radiation limits. After this a technician moves one amplifier at a time, feeder by feeder, tap by tap, and drop by drop as necessary, until the ingress is some 10 db better than the minimums. This procedure results in a rigorous testing of the overall integrity of the return cable plant, excluding the forward amplifiers, and will reveal many problems that are only marginally, if at all, apparent on the forward side of the system. A welcome end-result of de-ingressing is better performance on the forward system. The Rockford experience is that once you go through de-ingressing, the results are long-term.

UPWARD EXPANDABILITY

The discussion up to this point relates to the implementation of the first two stages in the four-generation model. The MSU-NSF-Rockford Two-Way Cable Project, as a technical operation and from a cable operators standpoint, was an unqualified success. In a nutshell, after an initial period of de-ingressing the system, and of technician training, the experiment proceeded, and continues to proceed, with virtually no special maintenance attention and only nominal technical monitoring of the return signal levels and signal-to-noise ratios.

Adaptation of the Rockford system to the third generation of the plan would require minimum change. Initially, the FSK transmitter circuitry would be placed in a separate terminal box. Since requirements of the third generation dictate the terminal also have the capability to "receive" messages and act upon them, a receiver logic circuit is added to handle incoming messages. Control of these functions is accomplished via a microprocessor within the terminal. A prototype third generation terminal is currently being developed at MSU. The evolution of the system beyond the third generation is a point of speculation due to always-changing technology.

CONCLUSION

Perhaps the most important point of this paper was to demonstrate the success of the first two stages of the four-generation model, and the two-way technology employed in Rockford to date. No longer are system operators required to make a gigantic leap into two-way, testing the water with both feet. As indicated in this paper, a step-by-step approach is not only technically feasible, but cost-effective with new services added on a demand basis. In a capital-intensive industry, the upward expandability of new technologies must receive primary attention.