DIGITAL AUDIO APPLICATIONS IN COST-EFFECTIVE CABLE TV SYSTEMS

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ABSTRACT

Cable television performance must periodically be upgraded to meet new requirements. The application of digital devices and techniques to provide improved security, multichannel audio and other features is described. Basic cable equipment functions, reasons for selecting digital techniques, audio and video multiplexing, constraints encountered, functional blocks developed, encryption, synchronization and overall performance obtained are reviewed. The outcome is a system which provides audio with stereo or bilingual capability. Furthermore, the digitized and encrypted audio is transmitted on the same carrier as the video signal.

INTRODUCTION

New technical developments continue to generate products with improved performance at moderate cost. Today we have many high performance products including audio, television and computer equipment, which were not previously affordable, due largely to these developments.

Existing industries, including the cable-TV industry, are also affected by technical advancements. For example, multichannel sound capability has been recently introduced and impacts directly on the performance requirements for cable television. Fortunately, techniques and devices are available for processing and transmitting audio signals, which ease the incorporation of multichannel sound and other features into cable TV equipment. These techniques and devices provide cost-effective means for upgrading the equipment to include these capabilities.

A brief review of a typical cable television system is followed by a comprehensive summary of the design goals and efforts leading to a complete operating system which is now in use and utilizes state-of-the-art digital audio techniques. Reasons for specific selections are illustrated along with some basic computations to support the choices made.

BASIC SYSTEM DESCRIPTION, ENCODER--DECODERS

Figure 1 illustrates a basic cable television system utilizing encoders and decoders for processing video and audio signals. Typically, an encoder is used at the headend of the system for every channel which will be subject to scrambling. For the Sigma system described herein, the encoders provide both audio and video scrambling and transmission of both signals on the same RF (radio frequency) carrier.

After distribution through the cable system, decoders are used to receive the RF carriers, demodulate the selected carrier and unscramble both the video and audio signals. Finally, both signals are used to modulate carriers on a preset, standard channel and delivered to a TV receiver.

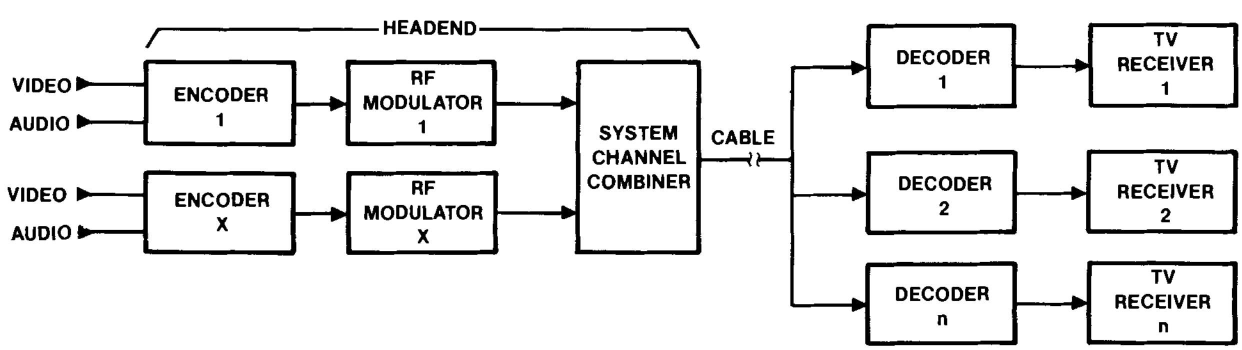


Figure 1. Basic Cable Television System

TECHNICAL DISCUSSION

Selection of Digital Approach

During the preliminary design of the cable TV equipment described in this paper, a digital approach was selected for handling the audio functions. The main reasons for this selection included:

1. Availability of techniques for digital encryption.

2. Feasibility of using a common RF carrier for both video and audio transmission.

3. Readily available techniques and devices for stereo, bilingual and other multichannel audio processing functions.

4. Improved dynamic range, noise immunity, fidelity and other audio quality features readily attainable with digital approach.

Multiplexing of Audio With Video Signals

A conventional video signal generated in conformance with NTSC (National Television Standards Committee) standards includes a sequence of sync and blanking signals for synchronization of receiving equipment. However, the method of scrambling selected for the video system resulted in the complete deletion of blanking and sync pulses. This left all of the time, normally used for horizontal sync, available for transmitting other data. In the system described, this time is used to transmit groups of pulses, which carry the digitized and encrypted audio signals.

Figure 2 is a simplified diagram illustrating the use of a switch to alternately select either the scrambled video or the digitized audio signals for delivery to the output. The technique of combining signals in this manner is called time division multiplexing. The resulting combination of signals can be readily transmitted on a single RF carrier. At the decoder a reverse switching function separates the audio and video signals.

Bit and Sampling Rate Constraints

The maximum bit rate for transmitting audio data is determined by the maximum bandwidth of the existing video channels which is typically 4.18 MHz. On this basis, as well as providing a multiple (x 260) of the TV line rate (15,734.26 Hz), the bit rate selected for the system was 4.09 MHz. With an NRZ (non return to zero) digital format the maximum fundamental frequency for this bit rate is 2.045 MHz. However, special low-pass filtering can be used to limit the rise time and otherwise restrict the bandwidth of the digital signals, within channel limits, while still maintaining good recoverable pulse shapes (approximately raised cosine). This enabled a conservative time-bandwidth product, approaching unity, to be realized for comfortable communications link margins under a variety of channel impairments.

Examination of Figure 3a illustrates the maximum time available for transmission of audio data, 6.75 μs for each line of video data. This includes the time during which the normal NTSC video signal provides the front porch, sync and part of the back porch, up to the beginning of the color burst.

For this system the actual time assigned for transmission of audio data was selected at 6.6 μs as shown on Figure 3b. This is a multiple (x 27) of the bit period selected (0.244 μs) and allows some time for smooth transitions between video and digital audio signals.

A total of 15,734.26 lines per second are generated for NTSC video transmissions. This number, multiplied by 6.6 μs, is 0.103844 second, the total time available for transmission of audio data during each second.

With a bit rate of 4.09 MHz each bit period is 0.244 μs. The quotient of 0.103844 s/0.244 μs = 424,818, which is the maximum number of bits that can be transmitted during each second of video transmission.

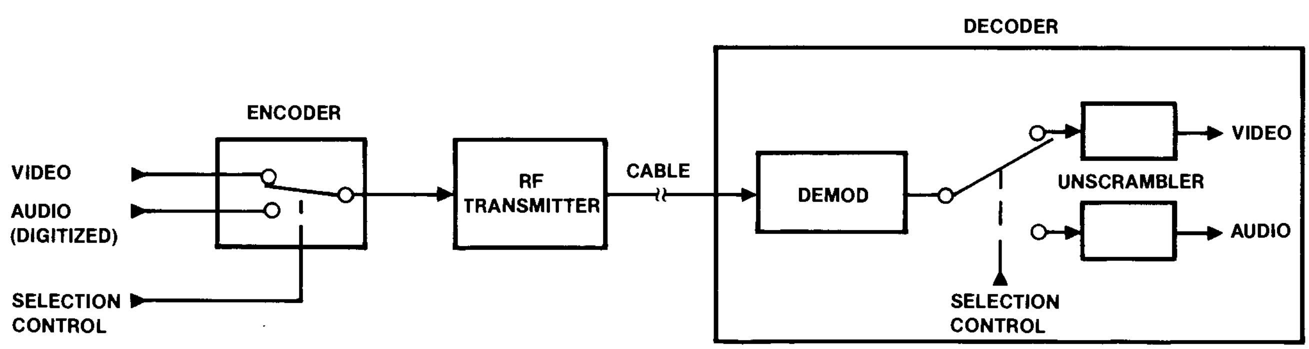
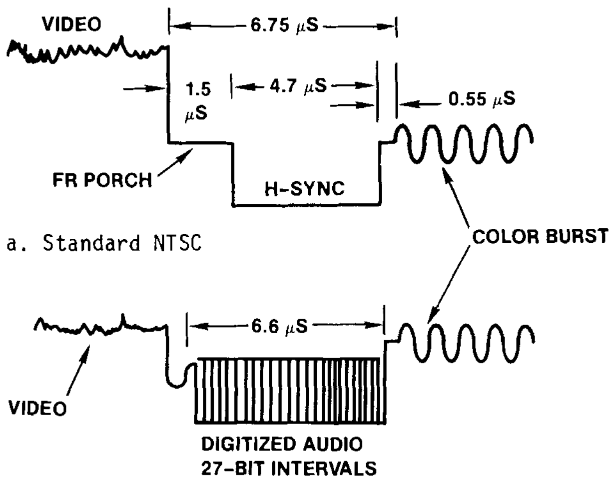


Figure 2. Time Division Multiplexing



a. Standard NTSC

b. Scrambled

Figure 3. Horizontal Blanking Time Interval

The current design transmits a total of 27 bits of data for each television line transmitted, as shown on Figure 3b. This includes a start bit, a squelch bit, 24 bits (3 samples) of audio data and a parity bit. Thus the actual system transmits a total of 15,734.26 x 3 = 47,202.78 samples per second. For two audio channels, the sampling rate for each channel is 23,601 samples per second.

Audio Performance Optimization

In order to provide optimum audio performance within the bit rate and sampling constraints described above, the following elements were included in the design:

Companding. Companding techniques are used in the A to D (analog to digital) conversion circuits which provide finer resolution for the least and coarser resolution for the most significant bits, compared to linear conversion. This results in amplitude resolution and dynamic range performance, with 8 bits, which approaches that of 12-bit plus sign, linear conversion circuits. The devices are used to accomplish this companding function in accordance with the Bell System-developed u-255 Law, defining the resolution of conversion at different levels.

High Performance Filters. In order to provide the maximum audio frequency response within the sampling constraints, high-performance low-pass filters were designed for use in both the encoding and decoding ends of the system. These filters, utilizing elliptic configurations, achieve a 70-dB attenuation slope within 800 Hz. This assures performance approaching the theoretical maximum response (per Nyquist criteria) of one-half the sampling rate without incurring distortion due to aliasing errors.

Encoding Functions

Figure 4 is a simplified block diagram illustrating the main elements involved in the encoding functions of the system, especially the audio processing. This includes input audio amplification, A to D conversion, encryption, time buffering and insertion into the video signal channel.

Through remote control, typically from a control computer or terminal, the selection matrix determines whether the system is to operate in a monaural mode from either the A or B input, generate A + B and A - B signals for stereo, or select both A and B inputs for bilingual operation.

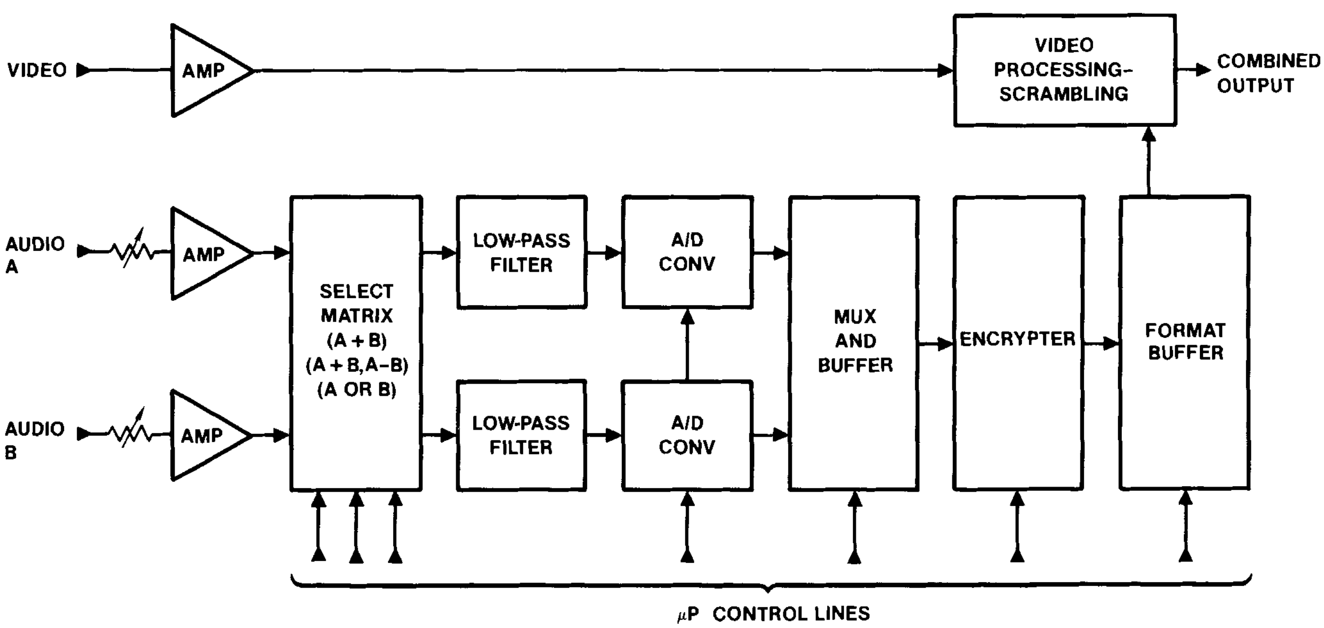


Figure 4. Encoding Functions

The main reason for the time buffering is the requirement for sending the digitized audio data in bursts, during the time normally assigned for horizontal sync, yet sampling the audio signals at a continuous unbroken repetition rate. This technique is known as "sound in sync." Buffers are also required to handle other digital data which is inserted into the video channel during the vertical sync time interval.

Decoding Functions

Figure 5 is a simplified block diagram illustrating the main elements involved in the decoding functions of the system, again with emphasis on the audio processing.

The tuner is used to select one of the many channels typically available from the cable TV system. The IF (intermediate frequency) and demodulator stages recover the baseband video-audio signals. After separation, the video signal is unscrambled and the audio is decrypted.

Recovering the audio signals involves reversal of the encryption process, time buffering, D/A conversion, filtering and other audio processing. The time buffering takes the data arriving in bursts and delivers it to the D/A converters at a constant rate. The output filter smooths out the steps on the recovered analog audio signals from the D/A converters. This filter removes spectral image signals which are generated at multiples of the sampling frequency by the digital processing.

Figure 5 also indicates elements of the decoder which have been incorporated into specially designed LSI (large scale integration) devices. This design was undertaken to reduce the cost of these functions in decoder units since they are manufactured in large quantities.

Encryption

Encryption of digital data is becoming commonplace wherever privacy and security are desired while sending this data through public or other readily-accessible transmission media.

Figure 6 is a block diagram illustrating the basic functions of devices at the sending and receiving ends of a cryptographic system, serving to provide security through the use of encryption techniques.

At the sending end, the input digital information, called "plain text," is applied to an encryption device. The device utilizes a group of bits K (for key), in processing an algorithm which performs a nonlinear mathematical function on the plain text input. The mathematical function involves a complex series of permutations and substitutions to the plain text, resulting in an encrypted output called "cipher text." The operation performed is a one-way mathematical function since it is easy to perform, yet the inverse function is exceedingly difficult to perform, even if the key and output encrypted data are available.

At the receiving end, the decryption device uses the cipher text and K data as inputs and performs the same algorithm as the sending device. The output of this device is the recovered original plain text.

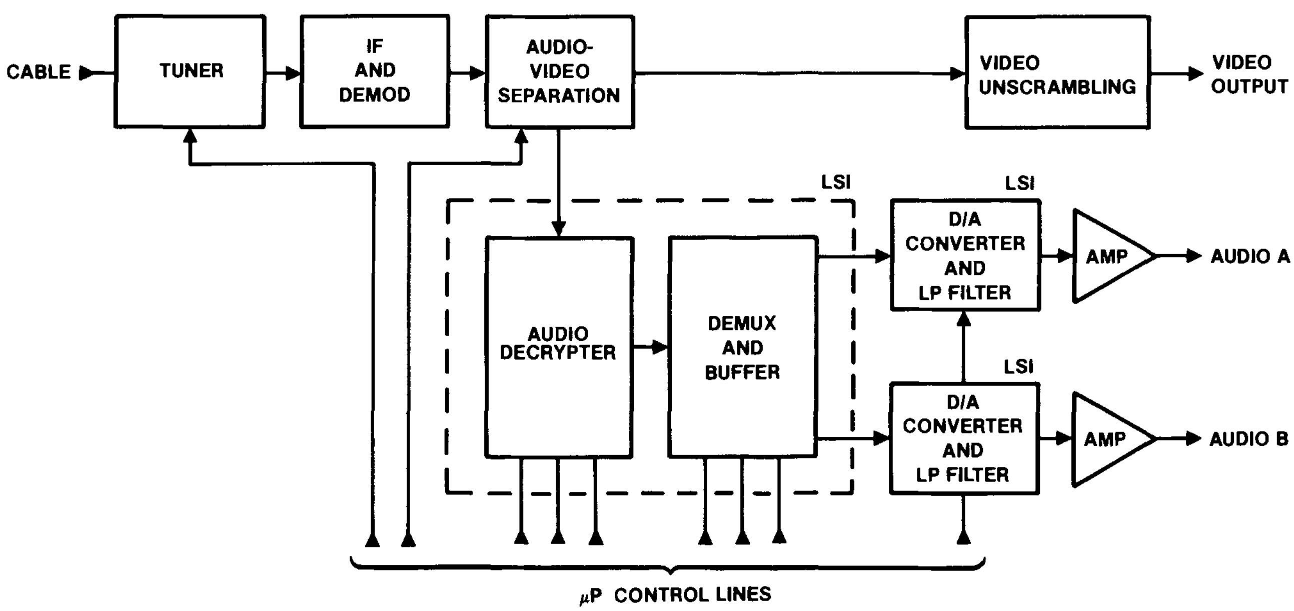


Figure 5. Decoding Functions

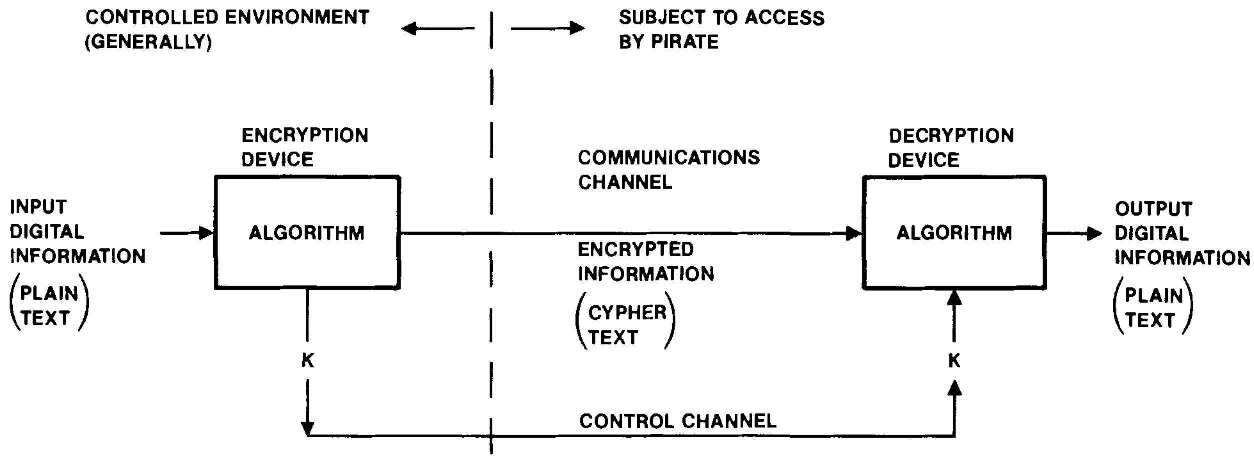


Figure 6. Classical Cryptographic System

Figure 7 illustrates an enhancement of the basic decryption system described above and used on the decoders. The enhancement is realized through multilevel key distribution. Input information together with a stored unique box key generate a second key (variable) using one decryption algorithm. This second key together with other channel information and a second device generate a third key (also variable). Finally a third device, using the third key, decrypts the service data input to produce the service data output. This output includes the clear digital audio and data for unscrambling the video signals.

To further frustrate the efforts of even a skilled cryptologist attempting to unscramble the incoming data, the keys can be changed periodically, as often as once per second.

Synchronization Functions

In systems transmitting digital signals between two or more stations, successful recovery of the digital data at the receivers is dependent on accurate synchronization between the stations. This is typically achieved by generating internal, accurate synchronized clock signals.

As shown on Figures 8 and 9, in the Sigma system both the encoders and decoders utilize PLL (phase-lock-loop) techniques, to lock-in a VCXO (voltage controlled crystal oscillator). In both cases the VCXO serves as a clock generator and is locked to a specific reference input signal.

In the case of the encoder the input reference is the composite TV sync signal derived from the

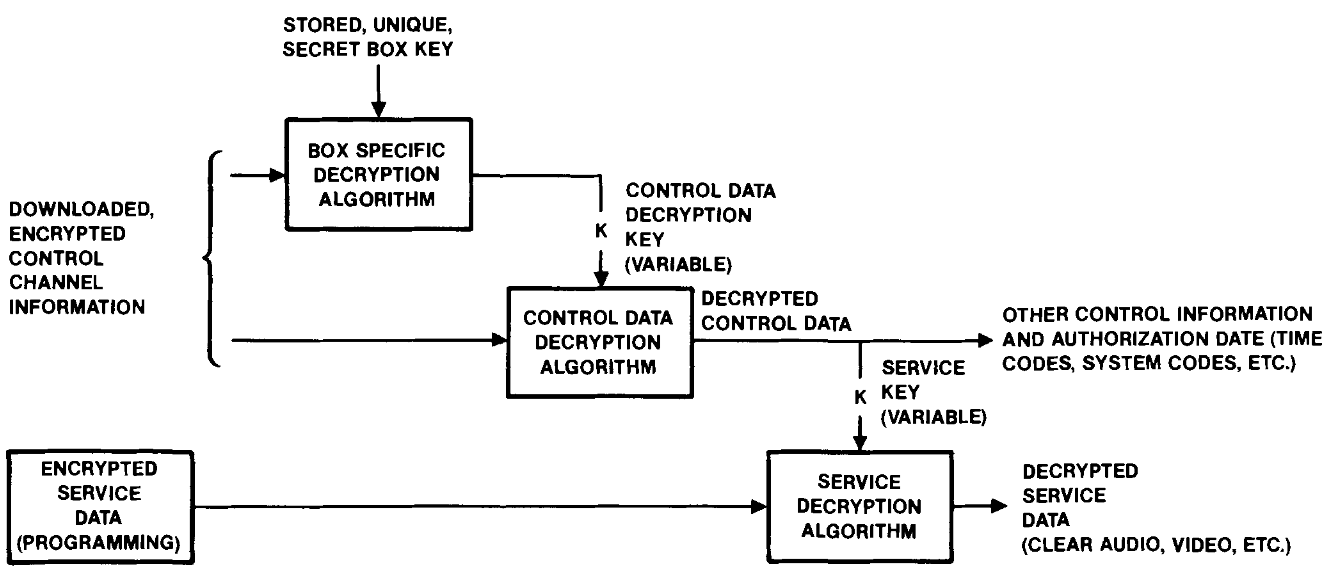


Figure 7. Multilevel Key Distribution

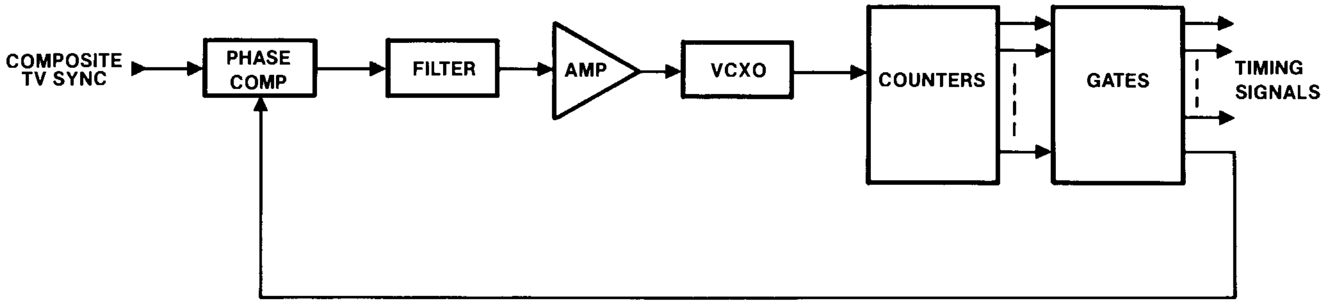


Figure 8. Encoder PLL

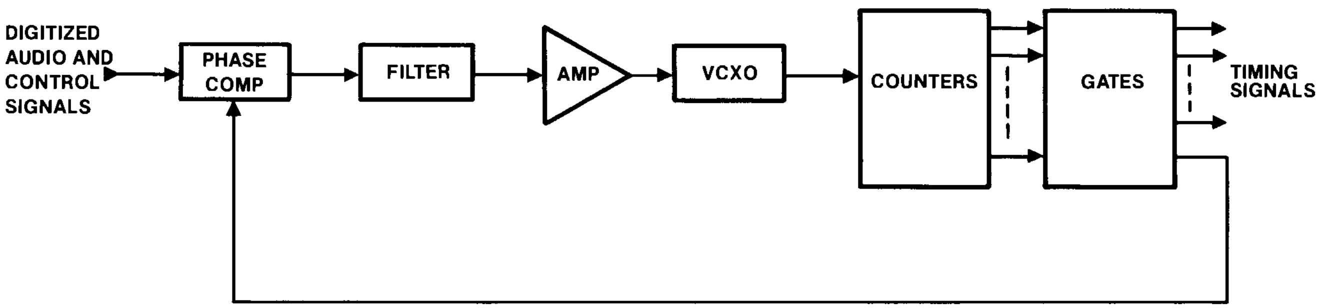


Figure 9. Decoder PLL

incoming video signal. This assures that the digital signals generated in the encoder are synchronized to the video signal, thus allowing time division multiplexing and other synchronous functions essential to the system's successful operation.

For the decoder the input reference to the PLL constitutes the digitized audio and control signals. This synchronization enables the successful separation of the digital data from the TV signals and the unscrambling functions of the decoder described earlier.

Performance Considerations

From extensive laboratory and field tests conducted on the Sigma system, with data collected from operation in actual cable TV facilities, considerable performance data has been obtained. The usual minor circuit problems were uncovered and corrected, but overall performance has been outstanding. The overall system from end-to-end has displayed more than adequate margin against channel impairment (fading, multipath interference, etc.) and intra-network processing such as AML/FML links.

An area of concern during the development of the system was the amount of audio performance degradation which would occur with decreasing video signal (multiplexed with digitized audio) to noise ratio. Many of the tests involved measuring BER (bit error rate) versus video carrier-to-noise ratio. The results demonstrated that non-degraded audio performance is achieved down to a 32-dB carrier-to-noise ratio, a level where the picture quality displayed is marginal (grade 2 picture).

Physical Configurations

Figure 10 shows the Sigma Encoder, an assembly designed for installation in a standard electronic equipment rack. The assembly features a modularized configuration using plug-in circuit boards and power supply, all replaceable from the front. The circuit board dimensions and connectors conform to the Eurocard standards, highly favored in Europe and increasingly popular in the United States.

The Sigma Decoder assembly is enclosed in a thermoplastic housing with a sheet metal base (see Figure 11). A keypad facilitates local control and channel selection. An infrared receiver in the assembly enables remote control from a compact hand-held controller. Other decoder features include:

1. Selection of up to 128 channels.

2. Favorite channel memory to recall channels in a prearranged order.

3. Parental control to lock out selected unwanted channels.

4. Remote volume control with mute capability.

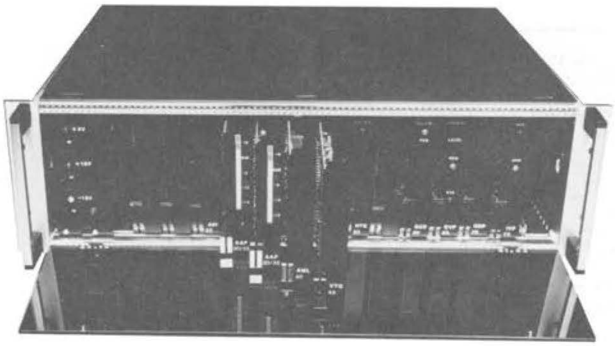


Figure 10. Sigma Encoder

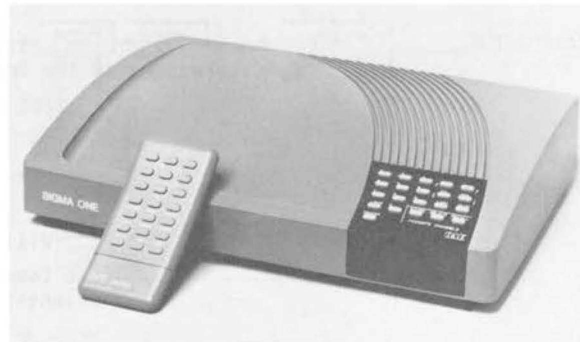


Figure 11. Sigma Decoder

SUMMARY AND CONCLUSIONS

A summary of many of the design decisions and the rationale behind them has been presented. Also some computations which led to the selection of specific modes of operation, such as bit and sample rates, have been reviewed. Generally, the design used state-of-the-art technology and therefore no unexpected surprises were encountered.

All of the features designed into the system are operating successfully. These include:

1. Monaural, stereo and bilingual modes of operation.
2. Digital transmission of audio signals.
3. Encryption of audio signals.
4. Use of common carrier for video and audio transmission.
5. Cost of decoders competitive with other addressable units on the market, even considering the advanced level of technology implemented.

REFERENCES

For additional related information refer to the following publications:

1. M. Davidov and V. Bhaskaran, "Digital Audio in Cable Systems," Oak Communications Inc., December 1983.

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3. B. A. Blesser, "Digitization of Audio," Journal of the Audio Engineering Society, Vol. 26, No. 10, October 1978, pp 739-771.