MASS DESCRAMBLING FOR HYBRID ADDRESSABLE SYSTEMS

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ABSTRACT

The well-accepted advantages of an off-premises, star-switched distribution system, like MH-II, include security of signal and reduction of equipment theft. These advantages have prompted many cable operators to plan system expansions in a theft-prone environment such as Multiple Dwelling Units (MDUs) by using the star-switched technology. This paper reviews the issues of compatibility for implementing a hybrid addressable system comprised of conventional addressable set-top units and star-switched distribution nodes.

The design of a Mass Descrambling System (MDS) that alleviates the need for a clear trunk option is described. MDUs can be placed at strategic points in the franchise area to provide clear signals to nodes where Local Distribution Units (LDUs) are located. The MDS descrambles up to eight channels and then up-converts them to unused channel slots in the distribution system's frequency spectrum. Because the frequency table in an LDU is software downloadable, the up-conversion process is transparent to subscribers. The hardware design objectives for the MDS are performance transparency, cost effectiveness, and universality of the descrambling approach.

The paper includes a discussion of integration issues involved in implementing headend control and communication functions for two systems in a hybrid environment.

INTRODUCTION

Conventional CATV systems employ tree and branch network topology. The network structure was developed as a cost-effective way of distributing a number of TV channels using the VSB-AM/FDM transmission format. The advent of premium programming created the need to control a subscriber's channel reception capabilities from an MSO's central office. Addressability and scrambling/encryption are used as the means of controlling the availability of multi-tiered premium services to CATV subscribers in the network. The demands for tighter security and the subsequent increase in the complexity of descrambling/deencryption circuitry continue to increase the cost of home terminal units (set-top converters) on the subscriber's premises.

The expensive home terminal unit ($100 to $135) undoubtedly reduces the MSO's losses in the signal theft area. However, it exposes the operator to higher equipment theft losses in a high-churn Multiple Dwelling Unit (MDU) environment, especially in metropolitan areas. This is why in the existing builds in metropolitan areas MSOs have not wired theft-prone MDUs with a conventional set-top addressable system. Providing service to these MDUs represents a major area of expansion and revenue growth potential for MSOs.

Unlike conventional addressable set-top distribution systems, an off-premises star-switched system like TFC's Mini-Hub II achieves signal security by denying a subscriber access to the whole signal spectrum. Rather, the control over delivery of service is obtained by transmitting only one or two selected and system authorized channels to a subscriber from a remotely located Local Distribution Unit (LDU). The addressability/authorization function no longer resides within the subscriber accessible equipment and does not require headend signal processing with the attendant possibility of degradation in signal quality or incompatibility with new advances in video services such as stereo audio. The characteristics of the transmission format on the drop and the removal of expensive hardware from the subscriber's premises minimize in an optimum fashion equipment and signal theft losses. Thus it is of great interest for MSOs to plan their system expansions into the MDU environment using star-switched off-premises technology.

ISSUES AND ALTERNATIVES

A "hybrid" system in which off-premises star-switched technology may be added to an existing tree-branch plant creates some compatibility issues:

Descrambling of Existing Premium Channels

Three possible methods of resolving this issue in such a hybrid system are described below.

a. Clear trunk
b. Per-subscriber descrambler
c. Mass descrambler

The clear trunk option means that a separate trunk from the headend carries all signals, including premium, in clear form for distribution to various nodes where LDUs are located. This may be an attractive solution if MDUs are concentrated in a geographic location in a city. This method does not put a limit on the number of scrambled channels. However, the cost of a separate trunk should be justified versus other methods.

The per-subscriber descrambler option implies that the selected channel on the drop for each subscriber is passed through an on-board or attached descrambler module at the RSM in the LDU. Alternatively, the descrambler can be located in the subscriber's premises. Many MSOs are reluctant to provide an unaddressable descrambler in the subscriber's premises because it can be moved illegally in the franchise. Furthermore, there are many scrambling methods, and manufacturers of converters like to maintain confidentiality of their scrambling/encryption techniques as well as communication protocols. This makes it unfeasible to provide a cost-effective universal descrambler solution.

In a mass descrambling system, a number of scrambled channels are descrambled at a node and then usually up-converted with suitable guard bands to vacant frequency slots in the spectrum of the distribution system downstream from the node. The descrambled channels are not assigned in their original frequency slots ("drop and insert") because it is extremely difficult to adequately filter out the energy of scrambled channels without causing deterioration in the frequency response of adjacent channels.

Control and Communication Protocol

Every addressable system follows a unique communication and control scheme to restrict the access of service to subscribers. In a hybrid addressable system the integration of addressability functions of constituent systems provides several options depending upon how far deep into the system various functions are combined.

Level I. The block diagram of this alternative is shown in Figure 1. In this system the billing computer drives the network control computer (NCC) of the off-premises star-switched system as well as the control computer of the addressable set-top system. The RF modems then generate forward control carriers at two different frequencies (75.5 MHz in the MH-II case) to communicate with respective addressable control modules at nodes (LDUs in MH-II) or in subscriber home terminal units (in the conventional portion). This option does not require any hardware, software and/or firmware changes in either system, except, of course, for those changes

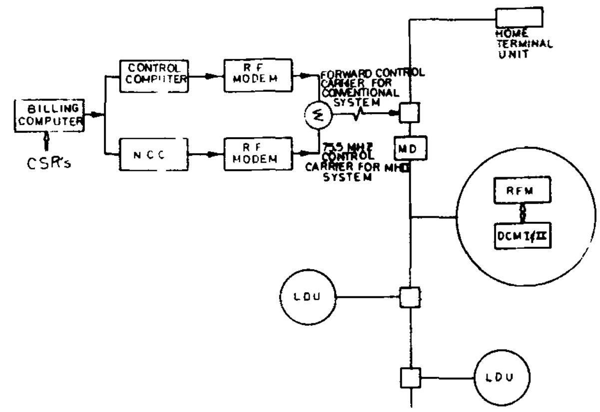

FIGURE 1. HEADEND CONTROL SYSTEM USING SEPARATE COMPUTERS FOR TWO SYSTEMS

necessary to ensure compatibility with the billing system interface and protocol.

Level II. The integration process is carried out a step further as shown in Figure 2. There is only one computer in the system in which the database and screens are integrated. However, control and communication programs as well as RF modem functions for the constituent systems are separate. Thus no hardware or firmware changes in either system's subscriber or off-premises equipment is required.

Level III. At this level, the communication and control protocols are integrated. Firmware changes now may be required in both systems to handle the unified protocol. If the RF modem function is also integrated, hardware changes may be required to achieve compatibility in modulation method and frequency.

The system described in this paper employs integration at Level I for its simplicity and speed advantages.

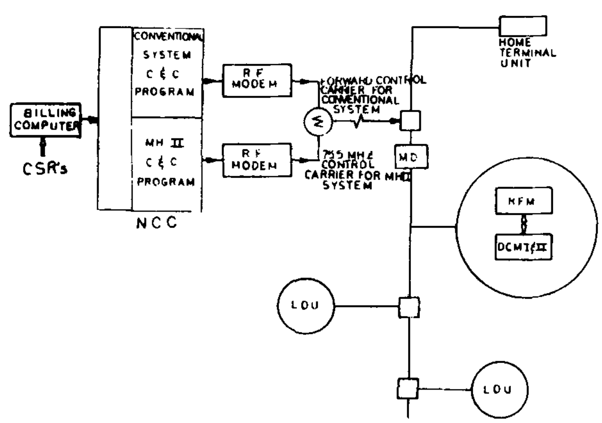

FIGURE 2. HEADEND CONTROL SYSTEM WITH A COMMON CONTROL COMPUTER

MDS BLOCK DIAGRAM AND PERFORMANCE SPECIFICATIONS

The block and level diagram of the aforementioned Mass Descrambling System (MDS) is shown in Figure 3. As can be seen, the 50 to 450 MHz feeder input is looped through with up to 20 dB of gain for system extension. Each channel to be descrambled passes through a separate chain of down conversion, fixed channel descrambling, and final up conversion. After combination, the block of up to eight channels is amplified with sufficient tilt to allow for 23 dB of cable loss at 550 MHz before levels fall below the 10 dBmV minimum required at the LDUs. There is a requirement for a 6 MHz guard band between channels to guarantee that adjacent channel spurious feedthrough falls below W-curve limits. The downstream distribution system and LDUs now have to be 550 MHz compatible.

The MDS unit uses standard MH-II hardware for the enclosure, AC distribution, FM band control carrier module, power supplies, and backplane/signal distribution passives. The decoders or descramblers are provided by the MSO with possible modification to reduce unnecessary power dissipation and eliminate the channel change function. New modules, packaged in existing castings, were developed and are discussed below.

Input RF Amplifier Module (IRFM). This is a 25 dB gain, 50 to 450 MHz line extender quality amplifier with plug-in capability for signal conditioning. To coexist with the available 15.5V MH-II DC supply, a custom hybrid was developed. The low pass filter following this module serves to remove distortion products above the highest channel that have built up in the system.

Channel Selection Module (CSM). This module tunes to one channel in the 50 to 450 MHz band and outputs it on a low band VHF channel dictated by local off air conditions. It is a modification of the existing MH-II subscriber module to accommodate DIP switch fixed channel programming in the field in 62.5 kHz steps. The standard MH-II 18 dB conversion gain SAW filter/SAW resonator based CATV tuner is used.

Variable Attenuator Auxiliary Function Module (VAAFM). This small add-on unit provides 20 dB of gain adjustment and allows the summing of a control carrier in the FM band with the down-converted channel.

Automatic Gain Control Auxiliary Function Module (AGC/AFM). This module is required for RF descramblers where output tracks input on a dB-for-dB basis. By stabilizing the signal level to the upconverter, the system CNR contribution can be maintained with drift of the descrambled channel level. Power is obtained from the upconverter module RF connector.

Upconverter Module (UCM). This module accepts the descrambled low band VHF channel and translates it to a vacant slot in the feeder spectrum usually above the existing carriers because of guard band requirements. The same fixed frequency selection technique as used in the CSM is employed. The critical element that had to be developed was a "reverse tuner" also using SAW technology that has adjustable gain for providing tilt in the final combined system output. This unique module is described in further detail in the next section.

Output RF Amplifier Module (ORFM). This unit provides 29 dB of amplification for the combined translated descrambled channels to provide sufficient level for summation with the carriers in the 50 to 450 MHz band.

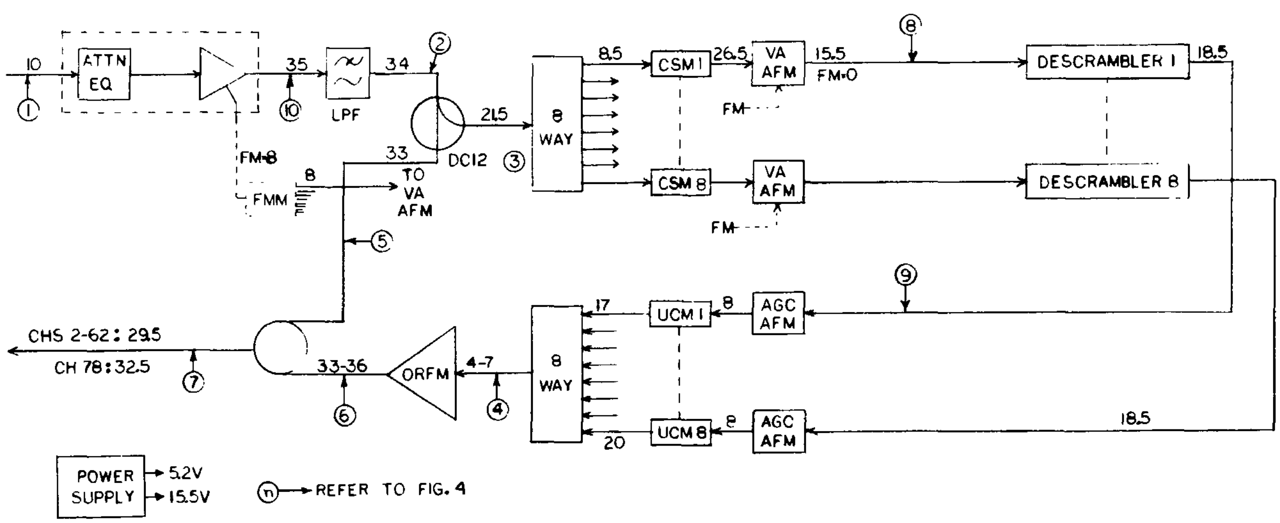

FIGURE 3. BLOCK AND LEVEL DIAGRAM OF MDS

The design goal is to make the MDS as transparent as possible in the critical areas of added noise, distortion, frequency drift, and gain fluctuations. The overall system specifications are listed below.

Return Loss (75 ohms)	
Input (50 to 450 MHz)	15 dB, minimum
Output (50 to 550 MHz)	15 dB, minimum
Input Level (nominal at install)	10 dBmV lowest carrier level
Input Level Drift Range	±5 dB
Signal Conditioning Range	Plug-in pads are available in 3 dB steps. 9 dB of positive true tilt and 15 dB of negative true tilt can be accommodated with plug-in fixed equalizers. These numbers correspond to 13 and 22 dB of cable, respectively.
Noise Figure (10 dBmV input)	18 dB, maximum (CNR contribution = 51 dB)
Insertion Gain	20 dB ±1 dB, 50 to 450 MHz, with 3 dB of tilt from 460 to 550 MHz
Distortion (+15 dBmV flat input)	
Cross mod	-63 dB
Second order	62 dB
CTB and third order	62 dB
Frequency Error and Drift	±50 kHz plus descrambler drift
Bandpass with respect to fpix	
fpix - .75 MHz	-4.5 dB maximum
fpix + 4.5 MHz	-3 dB maximum
Operating Temperature	0 to 50°C

Although the noise figure of the IRFM is 9 dB, maximum, which would lead to a CNR contribution of 60 dB at +10 dBmV input, the spec is 51 dB as this is the CNR contribution of the system for the descrambled channels.

The noise figure for a single channel to be descrambled can be derived by following its path through the loop of Figure 3. Using the data in Table 1 for an RF descrambler scenario, the cascaded noise figure equation yields 17.4 dB with the major contributor being the CSM noise figure/distribution loss term. Different decoder/descramblers would require readjustment of the AGC/AFM and UCM settings. The data in Table 1 for a baseband decoder yield a system noise figure of 17.5 dB. In this case the AGC/AFM module would not be used.

	RF DESCRAMBLING		BB DECODING	
Module	Noise Fig. (dB)	Gain (dB)	Noise Fig. (dB)	Gain (dB)
IRFM	9	25	9	25
LPF/DC12/ 8-Way	26.5	-26.5	26.5	-26.5
CSM	12.5	18	12.5	18
VAAFM	11	-11	11	-11
Descrambler (CH3)	12	3	12	- 8.5
AGC/AFM	10.5	-10.5	---	---
UCM	8	12	8	13
8-Way	13	-13	13	-13
ORFM	6	29	6	29
2-Way	3.5	- 3.5	3.5	- 3.5

TABLE 1. MDS STAGE NOISE FIGURE AND GAIN

The physical layout of the units within a 32 subscriber MHII enclosure is shown in Figure 4 for the case where the descrambler is a small stand alone unit with stable output. The upper two racks hold the common amplifiers, the 8 pairs of converter modules, and the required power supplies. The descrambler shelf assemblies contain AC power strips and metal partitioning shields for isolation between descramblers which may contain local oscillators and, therefore, be susceptible to ingress. The bottoms of these assemblies are slotted to allow proper air flow within the enclosure for cooling.

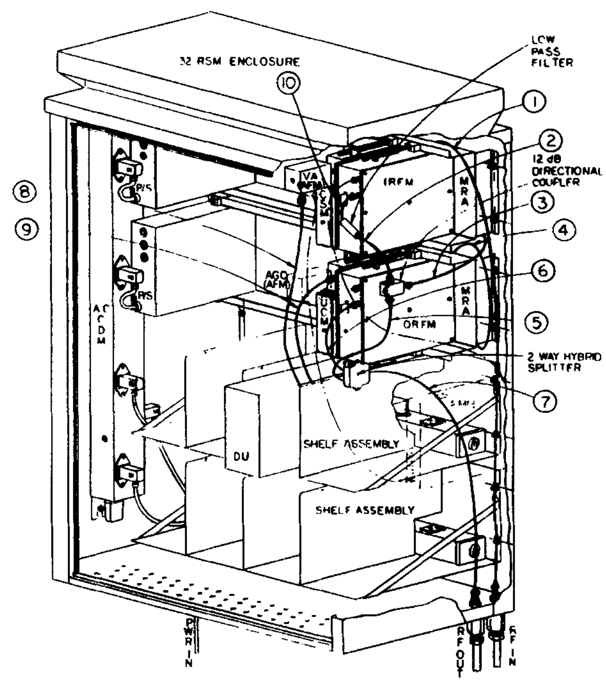

FIGURE 4. PHYSICAL CONSTRUCTION OF MDS

If the MSO chooses to use a full size set-top converter to perform the descrambling function, then a companion 16-unit MH-II enclosure must be used to hold four set-tops. Bulkhead F connectors passing through knockouts in the bottom of the enclosures are then used for the two interconnecting cables required per descrambler. The optional FMM and AGC/AFM modules required for some systems are located as shown.

UP CONVERTER MODULE (UCM)

The UCM design objective requires performance transparency (approaching that of a headend heterodyne processor) as well as low cost, which was achieved by utilizing the packaging techniques of the MH-II hardware. The UCM contains two separate subassemblies; a tuner, and a controller PCB requiring a total of 3-1/2 watts. The block diagram is shown in Figure 5. The module is capable of frequency shifting a low band VHF channel to any slot in the 300 to 550 MHz range with negligible degradation of the channel quality. The reverse tuner, like the conventional version, uses a double heterodyne technique for image rejection and elimination of in-band local oscillator (LO) spurs. The order of the fixed and variable LOs is simply reversed. The second LO is a varactor tuned type controlled by an onboard Phase Lock Loop (PLL), which uses a dual modulus prescaler to produce a stable broadband selection capability.

The PLL circuit uses a 512 divider to produce a 7812.5 Hz phase comparison frequency from the 4 MHz crystal oscillator output. Because this frequency is half the horizontal line rate, it minimizes video degradation from residual phase modulation. The PLL uses a fixed ÷8 prescaler at the VCO input, which then feeds the dual modulus counter. The combination produces a resultant frequency selection resolution of 62.5 kHz.

The first local oscillator is selected to be 612.75 MHz above the fixed input fpix and employs a frequency stable resonator using a SAW device. There is a SAW bandpass filter at the

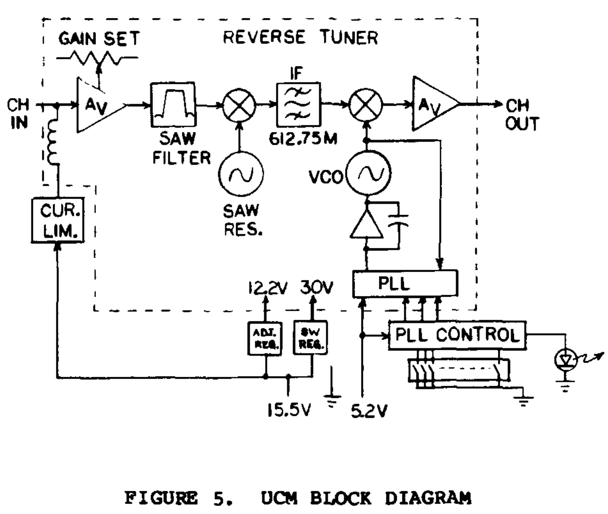

FIGURE 5. UCM BLOCK DIAGRAM

input for adjacent channel rejection. For final setting of conversion gain, the input amplifier has more than 10 dB of externally accessible adjustment range.

The reverse tuner, having only a single channel at the input, has been optimized for noise performance. The only output spur of significance in the present design results from residual first LO signal mixing with the second LO and producing a spur at fpix frequency below the output channel. This beat is maintained at greater than 65 dB below the minimum anticipated output level.

The primary distortion component of the tuner is the inband 920 kHz video beat resulting from the $f_{audio} - f_{chroma} + f_{picture}$ frequency components. This is held to 60 dB below picture carrier level. Finally, the broadband noise output must be limited such that seven other UCM outputs can be combined without appreciably degrading the noise performance of the channel.

The remaining assembly in the UCM provides the reverse tuner with the PLL commands necessary to tune to the selected output channel. The channel is programmed via a series of DIP switches for use by the MSO at the time of installation. These switches are not usually altered after installation.

The operator looks up the channel selection code and selects the DIP switches accordingly. When the UCM is powered on, the data, clock, and load commands are periodically fed to the reverse tuner PLL and a front panel indicator is lit to indicate this activity.

The reverse tuner, having a varactor-tuned second LO, requires a clean 30 volts at low current. This is provided by a flyback switching supply using a UJT relaxation oscillator. The RF circuitry uses the bulk of the power which must be tightly regulated for the tuner's transparency requirement. A three terminal adjustable regulator meets this requirement well. The remaining 5V bus is simply filtered for high frequency rejection since the PLL and control circuitry already have good noise immunity.

HYBRID SYSTEM DESIGN GUIDELINES

From the transmission performance point-of-view, a mass descrambler appears to the system as a line extender with gain of about 22 dB. The cost of descrambling a channel is around $200 to $250 in such a unit. Assuming that a system has eight scrambled channels, the mass descrambler unit may cost from $1.6K to $2K. Consequently, it is desirable that mass descrambler units are strategically located to feed clear signals to a number of LDUs to minimize the descrambling cost/subscriber. The input signal requirement of a MHII system is 10 dBmV for a 32-unit LDU. A typical system layout in a high density metropolitan environment is shown in Figure 6.

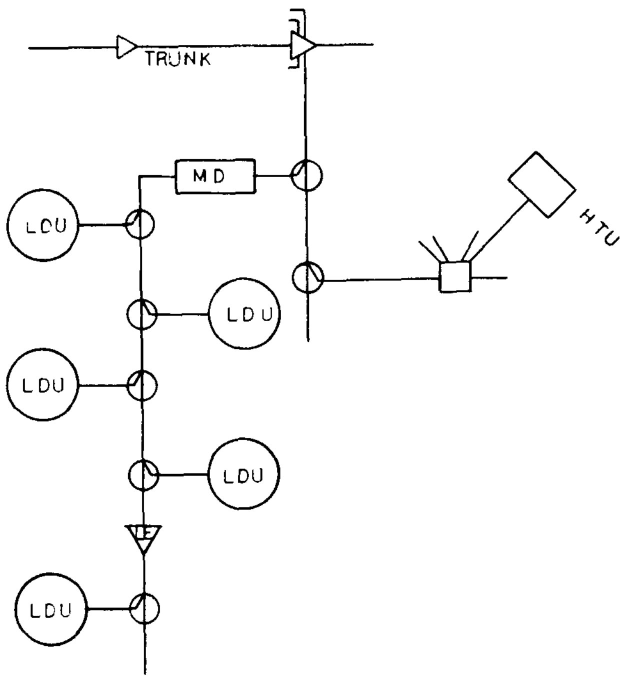

FIGURE 6 TYPICAL MDS DISTRIBUTION SYSTEM LAYOUT

The 22 dB loss budget may allow 3 to 10 LDUs (96 to 320 subscribers) to be supplied from the output of a mass descrambler depending upon the losses in the feeder cable and directional couplers. Of course, a line extender can be added to extend the range of the system. The operating output levels of the line extender should be suitably derated to meet the worst case performance objectives of the franchise.

CONCLUSION

A hybrid CATV distribution system using addressable set-top converters for single family homes and an off-premises, star-switched system for MDUs offers a very attractive solution to MSOs for secure delivery of premium services in metropolitan areas. Although the hybrid architectural concept does not provide the total optimization of a backbone trunk/feeder plant, it may be the only rational choice when offering service to MDUs in the theft-prone MDU marketplace in existing builds.

Undoubtedly, compatibility issues are raised in the areas of headend control and techniques for dealing with the scrambling required by the latter system for security purposes. These issues are resolved in a cost-effective and practical manner by the integration of control and communications functions under the billing system and by mass descrambling at key locations in the franchise area.