CHALLENGES AND SOLUTIONS IN THE INTRODUCTION OF DIGITAL SERVICES IN HOME COAX WIRING

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Abstract

It is well recognized that the home coax wiring is a most variable and challenging element of a CATV network, particularly when handling digital signals. This paper identifies a wider than previously described range of issues and how these issues may be effectively dealt with without the need to rewire the home. Variable or intermittent home wiring performance, caused by subscriber changes in equipment configuration, is an additional challenge. A solution set to these and other issues is proposed which keeps the cable company in control, provides for maintenance, and permits existing and variable home coax distribution to be used for digital services without additional truck-rolls. The paper concludes with some results of lab measurements and plans for field transmission robustness verification.

CHALLENGES

Upstream Transmission

Transmission of upstream commands or data from set-tops or future home data modems creates a very significant challenge to the cable industry. A very high signal level is required from a set-top converter in order to deliver (via the home wiring, splitters, drop and tap) an adequate level to, for example, a line extender return amplifier. This signal level is likely to interfere with TV set video, particularly if upstream frequencies in the 30 MHz to 40 MHz band are used. In addition, any coax connection looseness or poor shielding may cause unacceptable radiation or signal egress. Furthermore, any unintentional (or intentional) continuous upstream transmission from a set-top in one home could easily disable upstream signals from many or all other homes served from the same node. This would leave the cable company with a very difficult maintenance issue.

Downstream Transmission

Downstream analog transmission impairments create gradual TV picture quality reduction. In contrast, digital transmission works exceedingly well up to a given degree of impairment and then totally fails beyond this threshold. Use of Forward Error Correction (FEC) techniques, normally required in the cable feeder plant, extends the available interference susceptibility margin in the home wiring by 5 dB to 10 dB, however the threshold of non-performance becomes steeper. A solution is required which overcomes potential problems of interference into the downstream path of home coax wiring.

Sources of interference include conducted emissions from "cable ready" TV sets, ingress from local broadcast stations and hand-held cellular equipment, domestic electrical appliances, etc. The solution must also work effectively in home coax wiring which has been installed or changed by the consumer. Even if the local cable company were to re-wire the home and install improved performance splitters, subsequent changes in TV set, set-top or VCR configuration by the consumer may still result in varying digital transmission performance requiring ongoing cable company action. A more radical approach is needed to ensure digital performance and flexibility without the need for ongoing cable company maintenance of home coax distribution.

Spectral Efficiency

While trying to resolve digital downstream issues in the home wiring there is a need to retain or improve upon spectral efficiency in the feeder plant. This is required initially to defer the cost of feeder plant upgrades requiring amplifier respacing. However there is also a strong need to provide unlimited service variety to compete in the TV services marketplace.

TECHNICAL SOLUTIONS

Upstream Transmission

A proposed total solution to the set of upstream issues requires that the upstream signals from each home or MDU be gated or regenerated before being transmitted up the drop.

A small network interface module (NIM), located at the entry point of each residence (or MDU) and preferably locally powered, rapidly polls each device within the home(s) and accumulates messages or data. At fast but somewhat less frequent intervals the headend communicates with each NIM and receives the contents of its buffer. If the NIM buffer was previously filled to capacity this enables it to again poll home devices. Since the headend determines the order and priority of transmission from each NIM, it can assign, dynamically, individual upstream bandwidth from each home or MDU This is important in a multiple application services architecture.

The headend can also control each NIM in order to determine its frequency of polling home devices. Thus the headend also has the ability to deny upstream transmission from specific device within any home or MDU. Homes not subscribing to digital services should be fitted with 5 MHz - 40 MHz traps to prevent their interference with the new services. If required a bypass may be provided to accommodate specific existing RF IPPV devices.

A wide range of advantages accrue from the above upstream system design :

- since the upstream signals need only pass from the home devices to the NIM, much lower signal levels are needed - typically 30 dB lower than those needed to also overcome the drop, tap and feeder losses. This lower signal level has potential to reduce radically the home wiring leakage (egress) impact.

- since home wiring upstream signals have exclusive use of local spectrum, very robust, low cost, binary modulation techniques may be employed. In effect spectrum is reused in each home or MDU. Moving the return channel spectrum in home wiring to a much higher frequency, where interference is less prevalent, avoids the need for spectrum management in the home wiring, thus simplifying set-tops or other home devices.

- upstream transmission performance from the NIM to line extender reverse amplifiers is relatively noise-free (no home wiring ingress). Thus a greater proportion of the upstream spectrum is usable . Also higher order modulation methods may be used - QPSK universally today, probably 16-QAM in modernized plant. Thus the overall upstream capacity of cable feeder systems can be increased significantly. This creates the opportunity to defer the need to use top-of-band return channels in the feeder, thus avoiding the need to change out the line extenders.

- dynamic management of feeder upstream spectrum, to avoid dynamic sources of interference, becomes simpler since this does not involve controlling the frequencies of set-tops or other home devices. Thus there is some potential to reduce set-top complexity and cost.

- since upstream signals from each home or MDU are only transmitted on the cable feeder from the NIM, consumer equipment cannot intentionally or accidentally interfere with the upstream service of others. Furthermore, this means that any home having excessive electrical interference sources, such as hairdryers, electric tools, etc., will not interfere with the upstream transmission of other homes.

- since the headend provides control, the upstream bandwidth from each home, and even individual devices within a home, can be varied according to service needs.

- since the upstream spectrum from home wiring is filtered out and replaced by buffered digital signals from NIMs which transmit one-at-a-time, aggregation of interfering sources common to a neighborhood, such as Ham or broadcast transmitters, is much less likely.

Downstream Transmission

Downstream transmission in cable feeder and in-home coax wiring have mutually conflicting requirements. In the feeder where transmission performance is good there is the need to optimize for spectral efficiency with potential deferral of re-engineering the coax plant until traffic needs expand.

In home wiring where interference and disrupting conditions generally exist there is the need to provide very robust transmission. However spectrum is abundant if only the channels being viewed exist on the home wiring. Additionally, if a single digital band containing fewer, time multiplexed, channels is transmitted, its level may be higher than when the total available spectrum carries many broadcast digital bands.

For the feeder, the cable industry is relatively confident that 256-QAM or 16-VSB digital modulation may be used, offering between 6 and 7 bits per second for each Hz of bandwidth (b/s/Hz). However the maximum level of each 6 MHz digital band needs be kept to about 8 dB below that of AM VSB vision carrier levels to avoid intermodulation with existing services.

By the time a 750 MHz band digital signal reaches the home it will have been attenuated to a level of around 600 µV. In average home wiring this level will likely be of the order of only 300 µV at a digital set-top. For 64-QAM a signal to interfering carrier ratio of at least 25 dB (under typical conditions) is required to achieve acceptable Bit Error Rates (BER). Thus the maximum permitted level of an interfering signal introduced into the home wiring near to the digital set-top is only approximately 16 µV (-36 dBmV). However, measurements of samples of "cable ready" TV sets indicate "antenna terminal", in digital band, conducted emissions in the hundreds of microvolts, in some cases in excess of 1 mV (0 dBmV).

Using the above numbers, there would seem to be a strong case to tune and demodulate a QAM (or VSB) band at a NIM and to re-transmit the acquired digital signal in a more robust, low-cost, less spectrally compact, manner in the home. This has a number of advantages and trade-offs :

- provides a solution to conducted or radiated interfering signals from TV sets, broadcast transmissions in same band as digital cable services, etc.

- offers robustness against electrical interfering sources such as hairdryers, vacuum cleaners, etc., particularly when connectors are not fully tightened or coax is improperly crimped, or where shielding braid is insufficient or damaged.

- a single, simply modulated, digital band in the home wiring allows much higher carrier signal level but since energy is spread across a greater bandwidth this level meets with accepted practices and standards.

- much lower cost digital set-top boxes as no tuner, echo-canceling or error correcting circuits are required (Tuners for high order modulation digital signals are much more costly since very low phase noise performance is required). Only a single tuner, QAM demodulator and error correction circuits are required (in the NIM) per home or MDU. Thus when more than one digital set-top per NIM exists or the QAM receiver provides any additional non-video service, overall system cost is lower than in conventional digital cable architectures. The small cost of providing service selection and modulation at the headend becomes absorbed by reduced network upgrade costs and, at the same time, variety of services is unlimited - a definite advantage in competitive markets.

- the cost of housing and powering the QAM and home wiring modem circuits can be shared with the need to have a NIM for the upstream transmission. Where two or more digital video services per NIM exist (multiple set tops / home or MDU situations) or as soon as other services are considered, the overall economics and flexibility of the proposed architecture has advantages over conventional, piecemeal, approaches. Examples of added services include data, energy management or second telephone service. A combination of voice, data and two-way video could provide an excellent multimedia work-at-home capability. The architecture described is one which will enable cable companies to compete effectively as broadband telecommunications access carriers of choice, primarily for residential customers but also for medium or small businesses.

- transmission of only requested services on each 6 MHz digital band, serving perhaps 8 to 12 homes each, reduces the opportunity for piracy.

Choice of in-home Digital Modulation

The simplest, most robust and lowest cost digital modulation is generally of binary form. Phase, rather than amplitude, modulation is generally more tolerant of interfering signals and non-linearity. Differential Binary Phase Shift Keyed (DBPSK) modulation allows a choice of very simple non-coherent or simple coherent receiver techniques. While micro-reflection cancellation is possible, the robustness of DBPSK techniques make this non-essential. Thus the choice of DBPSK modulation, using today's silicon technology, offers lowest cost as well as good potential for future demodulator technology evolution.

The choice of bit rate is dependent on service requirements. A bit rate which exceeds that of 256-QAM (or 16-VSB) in a 6 MHz band (approx. 38 Mb/s, allowing for FEC) simplifies both NIM and system design.

An in home wiring bit rate of around 52 Mb/s provides sufficient reserve capacity for passing control or polling signals from the NIM to the set-top and for a traffic and control return path using Time Compression Multiplexing (TCM), or "ping-pong", transmission techniques. TCM also offers lower filter costs and provides for future upstream/downstream bit-rate flexibility

The choice of spectrum for the 52 Mb/s DBPSK TCM signal is governed by available spectrum in the home wiring. A center frequency of around 930 MHz avoids the cellular telephony transmission spectrum and passes, albeit with acceptable additional attenuation, through existing domestic coax cable and splitters. Although this frequency is relatively high, the robustness of DBPSK allows for transmission in plant unsuitable for other modulation formats. PSK demodulators are, like those of FM, particularly insensitive to level variations and signal distortions.

OVERALL ARCHITECTURE

A summary of the proposed architecture is illustrated in Figures 1 to 4 :

The proposed Cable System Architecture is shown in outline form in Figure 1. At the headend, digital services received from fiber or satellite facilities, or stored locally, are selected for each 6 MHz band of modulation.

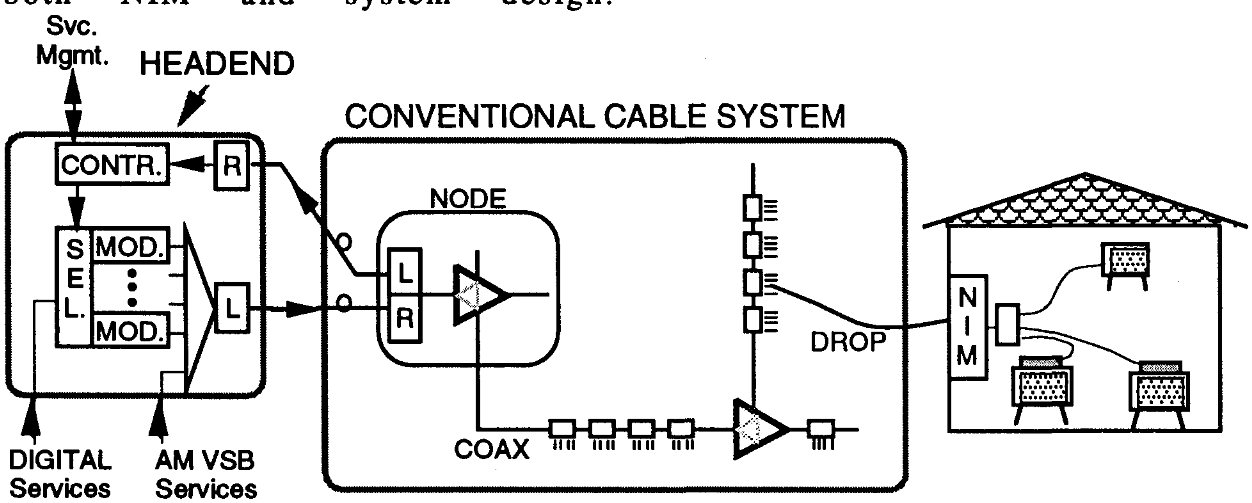

Figure 1. Cable System Overview

Integrated circuit 64 / 256-QAM or 8 / 16-VSB modulator outputs are combined and, together with AM VSB CATV Channels, passed to a laser for fiber transmission to its associated node. Upstream control signals received from the node provide, with negligible delay, control of selection of services into each downstream digital band. For requests involving authentication, usage billing or parental control, the control messages are passed via a local or centralized service management function (not shown).

The node would typically serve 600 homes passed. Line extenders must be fitted with 5-30 MHz (or 5-40 MHz) return amplifiers. Taps are preferably 1 GHz types to provide for future broadband upstream capabilities.

The home wiring should remain unmodified except for the insertion of the NIM between it and the drop. Domestic wiring and splitters should, in almost all cases, provide sufficient performance for the robust and level-insensitive DBPSK transmission.

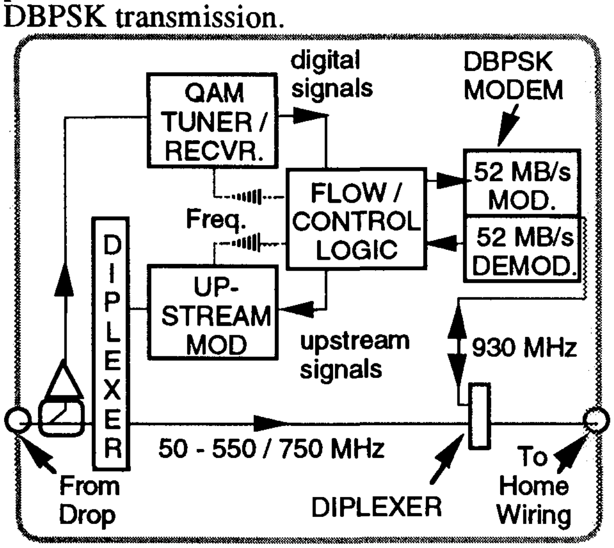

Figure 2. Network Interface Module (NIM)

The NIM illustrated in Figure 2 uses a diplexer to provide low-loss through routing of signals between 50 and 550 (or 750) MHz to the home wiring. Signals in the band 5 to 40 MHz from the upstream modulator are fed to the drop. An active directional coupler is used to tap the signal from the drop and feed this to the 64 / 256 QAM tuner/receiver This receiver contains low-phase-noise tuner, microreflection echo canceler, demodulator and forward error correction (FEC) functions. In traditional configurations these costly functions are needed in every set-top box rather than per home or MDU.

The flow control logic provides simple buffering between the QAM receiver bit-rate (27 Mb/s, 38 Mb/s or higher) and the 52 Mb/s TCM burst rate used in the in-home wiring. This function also inserts polling signals to trigger responses from set tops, etc.

The simple DBPSK modem provides upstream and downstream home wiring transmission. The associated passive diplexer is designed for very low loss below 750 MHz to avoid loss in the AM VSB path to the TV sets and provides the 930 MHz bandpass filtering for the DBPSK modem. The diplexer offers high through-path attenuation below 800 MHz to minimize unwanted upstream flow of in-home DBPSK signals into the QAM receiver and/or the drop.

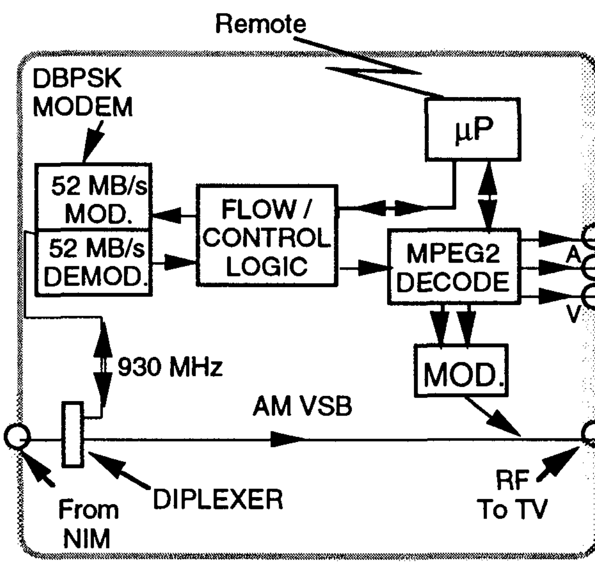

Figure 3. Low-complexity Digital Set-Top Box

The digital set-top box shown in Figure 3 uses diplexer and DBPSK modem functions similar to those used in the NIM. The flow logic buffers, selects and formats signals for the MPEG2 decoder and messages for the microprocessor. The flow logic also buffers upstream messages and responds to polling from the NIM. Other functions shown are similar to those in used in conventional set-tops. The most significant cost improvement over conventional designs is due to the absence of tuner, echo canceler, complex demodulator and FEC functions.

Options exist as to how to configure the set top box. Assuming that most "cable ready" TV sets tune all of the analog channels on cable, it is possible to add the output of the modulator in figure 3, to the incoming cable spectrum. This would likely be done either at the high end of the spectrum or at channel 14 (120-126 MHz). In order to overcome the noise on the incoming cable, it is desirable to supply the output of the modulator above the expected levels from the cable plant. This means that one channel must be unused between the modulator output and any analog channels, to prevent adjacent channel interference and to permit compliance with FCC rules. (The modulator channel is also not used in the downstream plant. This configuration is optimum, as it permits any watch and record scenarios, including those involving the digital signal. Alternatively, a switch to select either the modulator or incoming AM VSB band, is possible. An isolated MPEG2 RF output (in addition to the switched output) is also a possibility.

If it is to be assumed that a significant number of TV sets will not tune all of the cable channels, then a configuration which includes a basic or descrambling set top function is desirable. This raises costs and limits the ability to watch and record. However, since the decoded output is available at baseband, it is possible to route the descrambled signal to a VCR while watching something else, or vice versa if baseband inputs on the TV are available. With basic converter functions built in, it is possible to include a watch and record switch at low cost.

Service Capacity

A significant advantage of assignment of QAM digital bands to digital subscribers, rather than to services, is that a very wide range of services can be provided initially and while subscriber digital service-take builds. This arrangement offers pay-as-you-grow headend and fiber/coax plant upgrade investment.

The curves shown in Figure 4 indicate average capacity per home served. Curve A applies to one laser feeding nodes offering service to 2400 homes passed. Curve B applies to a laser per 600 home-passed node. Curve C offers extremely high digital capacity which may be achieved using a separate fiber per node output port, i.e. serving 150 to 250 homes passed.

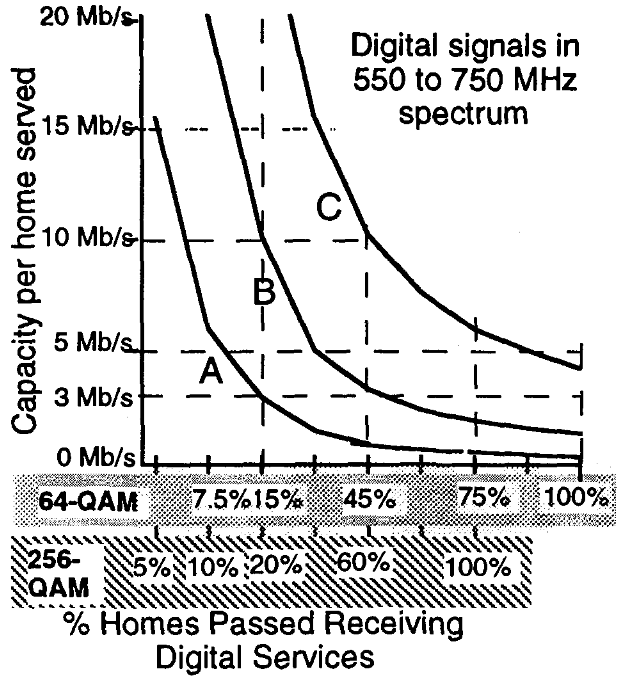

Figure 4. Digital Service Capacity

The two horizontal scales indicate the relative capacity of commonly proposed digital modulation schemes. Using silicon technology a single QAM modulator and up-converter will cost less than a typical QAM tuner/demodulator. Between 6 to 12 homes could be served from each modulator, according to service and video quality requirements.

LAB AND FIELD TRANSMISSION VERIFICATION

Lab Testing of digital demodulator robustness

Initial lab testing of the comparative robustness of a simple, non-coherent DBPSK demodulator and relatively costly, tunable, 64-QAM receiver with echo canceling and FEC indicates close to expected performance for each type.

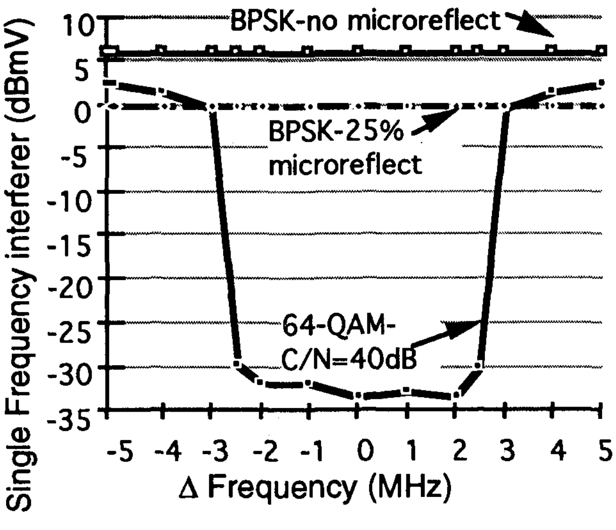

Figure 5. Comparison of QAM and DBPSK receiver single frequency interferer immunity

Figure 5 shows, on a ±5 MHz scale centered on each receive frequency, the comparative immunity of a simple, non-coherent 52 Mb/s DBPSK demodulator (without microreflection echo canceler (EC) or FEC functions) with 27 Mb/s 64-QAM receiver (with EC and FEC) for single frequency interfering signals in a 40 dB CNR environment. These tests indicate that the simple DBPSK approach is well over 30 dB more tolerant of single frequency interferers than that of directly received 64-QAM.

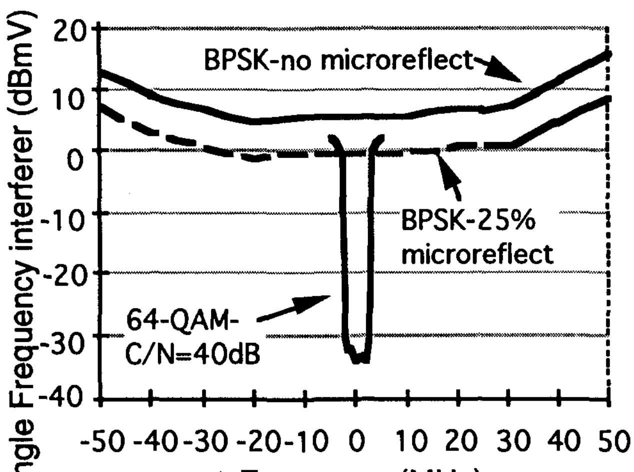

Figure 6. Comparison of QAM and BPSK receiver single frequency interferer immunity

Figure 6 shows the same data plotted on a ±50 MHz frequency scale and confirms the comparative robustness of DBPSK transmission over its full bandwidth. Note that the carrier level of the TCM DBPSK signal is higher than that of a typical, directly received, 64-QAM signal. This is acceptable since its energy is spread across a wider bandwidth.

Tests of the compatibility of the higher level DBPSK signals with a variety of "cable ready" AM VSB TV sets indicate no visible artifacts even when pulsed DBPSK signal levels of 30 mV are applied to the input of "cable ready" TV sets receiving 1 mV AM VSB signals. The immunity of analog set tops to this signal is now being verified. Set tops are expected to be even more tolerant of DBPSK signals due to their generally tighter specifications.

Field Transmission Plans

The comparative robustness of the two-way TCM DBPSK in-home wiring signals relative to that of directly received 64-QAM and 256-QAM is, at the time of preparing this paper, about to be tested in a selection of customer homes.

Signal generators will be used to represent interfering sources. In all cases the in-home wiring is not to be disturbed or improved. Subsequent tests are expected to confirm that known upstream home wiring ingress and egress issues have been fully resolved.

The spectrum of signals in each home will be monitored to identify degree of transmission margin remaining when interfering "cable-ready" TV sets are tuned across a range of AM VSB channels. Bit error rate testing will be performed in the presence of electrical interference and use of cellular handsets. Tests will also include consumer observations of the insensitivity of TV sets and analog set tops to much higher level than normal DBPSK signals.

Overall headend to Digital Set-top BER tests will precede tests using pre-encoded, stored, MPEG2 video. The video tests, although somewhat subjective, are expected to endorse the relative robustness of TCM DBPSK transmission in home wiring.

HIGHLIGHTS

The known upstream and downstream transmission and system issues which are likely to impede introduction of digital services in the home can be resolved by the use of simple, robust TCM DBPSK transmission in home wiring.

Gating and buffering of upstream signals in a Network Interface Module before they enter the coax feeder network ensures that interference or faults in any home cannot affect the service of others. This also simplifies fault location procedures for the cable company.

Selection of digital services at the headend, rather than broadcast, offers economic service growth and an unlimited program variety including NVOD and VOD.

Use of headend selection also offers an attractive common service platform for a variety of non-TV services, particularly that of broadband multimedia work-at-home.

We believe that the proposed digital cable architecture has the potential to help MSOs become Broadband Telecommunication carriers of choice for both residential and small business markets.

Laboratory testing has been used to verify the proposed transmission and system approach. Initial field testing in feeder and home wiring is about to commence.

The proposed and soon to be verified architecture should help keep the cable company in control, provide for maintenance and enable existing and changing home coax distribution to be used consistently for digital services.

A major benefit of the proposed digital cable architecture is overall cost reduction in a real-world home wiring cable environment, both when installing service and through lowering of operating costs due to fewer subsequent truck rolls.