4.5 Mbps Data Compatibly Transmitted in 6 MHz Analog Television

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Abstract

Analog television has a long future. Cable will service these large and important markets for may years to come. The compatible inclusion of digital data in analog television signals will increase the value of the spectrum which must continue to serve analog receivers. This data can be used for inputs to computers and for set top boxes which implement "push technology" information services. The technology described makes possible in excess of 4.5 Mbps of data carriage in an analog 6 MHz signal while not interfering with the normal analog reception of television. Data is hidden in a signal in quadrature with the video carrier, amplitude modulation of the sound carrier, and use of the VBI. This has sufficient capacity to convey one, two, or even three MPEG compressed signals to implement the "Compatible Digital Upgrade".

INTRODUCTION

The National Bureau of Standards, NBS, first proposed data embedded in television signals in 1970 for the purpose of distributing accurate time information nation-wide. While that effort did not succeed, it spawned the Closed Captioning system for the hearing impaired which in turn led to Teletext. More recent efforts to embed data in analog television signals led to the formation of the National Data Broadcasting Committee in 1993 and its consideration of systems by several proponents. On June 28, 1996, the Federal Communications Commission (FCC or the Commission) approved digital data transmission in the video portion of broadcast television transmission in its Report & Order (R & O), "Digital Data Transmission Within the Video Portion of Television Broadcast Station Transmissions", in MM docket No. 95-42. This R & O amends FCC rules to allow ancillary data *within* the video portion of the NTSC signal in four formats.

ANALOG REQUIEM?

It might be assumed that this FCC's action in allowing systems which add data to analog television is too late to be of commercial value. With the emphasis on Digital Television, DTV, some might consider analog television's demise imminent. This is hardly the case!

The recent adoption of an accelerated schedule for DTV deployment in the US has caused some in the popular press to suggest that the sole surviving technology for terrestrial domestic broadcasting will be digital and that analog NTSC will rapidly fade away. There are several reasons this may not happen at all and even more reasons why the notion of an accelerated schedule may not be realistic.

The deployed base of NTSC television receivers in the United States is huge. More than 250 million receivers plus another 175 million VCRs --- all of which are exclusively analog NTSC --- exist in about 100 million American television households. Additionally, Americans purchase about 25 million receivers and about 15 million VCRs each year. The Half Life of these receivers is on the order of 12-15 years! If the average television receiver is a 19" model, it's approximately 15 inch wide screen will be contained in a cabinet about 18" wide. All of the existing U.S. TVs set side by side would stretch 71,100 miles, several times around the earth. And 7,100 miles worth of new sets are sold in the US each year – more than enough to go coast to coast a couple of times! VCRs are in about half that quantity and would stretch about half that distance again.

The American viewing public has yet to be exposed to broadcast DTV. Broadcasters have yet to ascertained a viable business plan for the new capital expenditures. Early predictions by the Consumer Electronics Manufacturers Association, CEMA, of the Electronic Industries Association, EIA, project first DTV receivers to have a cost of around $5,000. New VCRs will be required as well. These will be at least $1,000. The consumer's willingness to spend such unprecedented sums on a large scale for television has not been tested. There is the promise of digital set top adapters which consumers may purchase to obtain the digital programming on their existing receivers. These will be around the cost of cable set top boxes, but with a retailer's profit margin added in. This will make cable's $400 box cost at least $500. What motivation would drive consumers to spend this kind of money to get this programming? If they can afford it, they already have cable or DBS. If they can't afford cable or DBS, they certainly can't afford to purchase an expensive digital set top box adapter or and multi-thousand dollar digital TV receiver. Will those who concern themselves with the plight of the economically disadvantaged allow this ripe cause to pass? How can the government take away the utility of one of the disadvantageds' only sources of entertainment and information? The politics of this situation have not yet been seriously weighed. Long range business plans in such an environment cannot be credible.

It will take at least three years of availability at market for any uptick of consumer acceptance to materialize. Given the optimistic schedule of 40 top market stations on the air with digital signals by mid 1999, the migration won't be a national rush but rather a market by market crawl.

Color TV suffered for thirteen years from its introduction in 1954 until the full color prime time of NBC's 1967 season. Only then did the marketplace favorably respond. It should be noted that monochrome TV was a great improvement over radio. Color TV is a lesser improvement over monochrome TV. The High Definition Television, HDTV, flavor of DTV is a still lesser improvement over color TV. Digital "standard definition" television, SDTV, may be no improvement at all to a good analog NTSC signal!

Surprisingly, there is very little talk of, HDTV. Most of the broadcaster interest seems to be in SDTV. So the offering to consumers is not better TV, but more TV. That may not be an attractive trade off for the high costs of the new television receivers and VCRs.

While the FCC is postulating the return of analog broadcast spectrum, it has no authority to forbid cable from continuing to serve the huge installed base of analog TVs and VCRs. Such a vast marketplace cannot be ignored. Cable will continue to service this important audience.

From the broadcaster's point of view, it will be politically unacceptable to be denied access to analog television receivers if cable operators continue to have that market place.

From the consumers' point of view, it will be politically unacceptable to disenfranchise the consumer's television set. Consider the furor raised over the problems of cable's set top box and the potential interference with features of television receivers. Imagine rendering the television useless and requiring the purchase of an expensive new digital receiver or a digital set top box adapter!

THE MOTIVATIONS

Why at this late date when it appears that everyone is talking about digital television is there a reason to be interested in embedding digital data in analog signals?

Clearly, if analog television is not going to disappear quickly, there is a strong motivation to maximize the utility of the spectrum which must continue to be allocated to serving the existing market of analog television receivers and VCRs.

The Broadcaster's Opportunity

There are a number of opportunities for broadcasters. During the period of transition, when an analog and a digital channel are available, the digital capacity of the analog channel should not lie fallow. It could be put to good economic use.

If a digital signal is hidden in the analog signal, the value of the spectrum increases. Not only does the spectrum continue to serve those who cannot afford new receivers or adapters, but it also serves those who can make such a purchase. The electronics for digital reception is complimentary to that needed to access digital signals hidden in analog. When a digital receiver or set top box is not accessing a digital part of the spectrum, most of those same circuits can be extracting the digital signal out of the analog signal at little additional cost.

The broadcaster may find this double value of the existing spectrum to be a compelling political reason for retaining it when the appointed time for surrendering it arrives.

The Compatible Digital Cable Upgrade

Cable's digital video migration plans usually do not include comprehensive replacement of all analog channels because of the horrific expense of the digital set top boxes. Instead, a hybrid service, part analog, part digital is planned. Two approaches are possible. The first expands bandwidth and uses most or all of the new bandwidth for digital services. This entails considerable construction expense and may not be practical for smaller systems or in tight economic times. In the second approach, there is the intention of converting a few of the channels to digital and leaving the remainder as analog. In this strategy, the channels converted to digital will have previously been occupied by low penetration services. Subscribers wishing to continue with those services will need a digital set top box. If these subscribers take no new services, just the ones they had previously taken, their costs go up considerably while there is no increase in revenue. Subscribers who do not wish the new advanced services will not receive a new digital set top box. However, they will lose programming previously carried on the analog channels which are converted to digital. This can be a serious loss for low capacity cable systems.

Techniques which hide the data in the analog signal are an attractive alternative for the carriage of digital signals. Since television tuners are relatively inexpensive, multiple tuners can be provided so that data can be collected from more than one channel. That data can then be assembled to provide the MPEG streams needed to create new synthetic channels. Statistical multiplexing can be used to advantage. In this approach, all of the analog channels are preserved for those who are satisfied with the existing service. The existing analog subscribers will notice no difference other than the advertising programs promising more programming if they add digital services to their existing analog service. Only those willing to pay for more will incur the extra cost of the new set top box.

In recent years the metaphor of the "Chicken and the Egg" has given way to "Field of Dreams" concept of "Build it and they will come". Each equally points up how progress is frequently suppressed by codependent events. "Build it and they will come" requires an act of faith which is difficult for those who have to sign checks. While there will be some building, the process is helped along considerably if the methods of construction are cost effective.

It will be some time before any meaningful penetration of receivers for the DTV format emerge. It is axiomatic that these receivers will be compatible analog television. The need to support NTSC will be so important that a non NTSC compatible DTV receiver is not expected to be a starter in the US market. While the receiver is tuned to an analog channel, the digital circuits are idle. The Compatible Digital Upgrade allows those circuits to be put to use to provide a data stream for other purposes. This sharing of resources gives extra value to the investment in digital electronics.

The Compatible Digital Upgrade can be the bridge between the massive installed base of NTSC hardware and the yet unproved DTV Service. The building blocks that make up a DTV receiver are intrinsically compatible with the needs of the Compatible Digital Upgrade. A high quality tuner, good signal processing and an MPEG engine provide an ideal environment to support the Compatible Digital Upgrade.

Applications

There are a variety of applications for data in analog signals. Data can be supplied as just data. Alternatively, if sufficient capacity is available, data can be used to deliver digital video or digital audio services. These can result in an expansion of broadcast or cable capacity without interference to ordinary analog reception.

The data can be used with personal computers, special television sets or set top boxes or versions of the "net computer". When computers and computer adapters for television receivers are used, there are two modes: "pull" and "push". The "pull" mode is the traditional Internet approach where sites are accessed and data retrieved. This requires a two way connection. The "push" approach can be implemented in a one way system. Here, the user indicates his fields of interest and the data is retrieved from the data stream and loaded into storage. It then is displayed. In a two way media, "push" can be supplemented with web site access for more details.

A related application involves Datacasting. This is the inclusion of data in the broadcast television signal for use with a personal computer. The most aggressive such implementation is Intercast whose main partners include Intel and NBC. HyperText Markup Language (HTML) formatted Web pages are delivered in the VBI of the television signal. HTML is a method of linking information. Highlighted words or phrases can be "clicked on" and relevant information appears on the screen. In some cases, this is achieved by going to another location in the same document. In still other cases, data from another document is displayed. In other cases, locations on the World Wide Web are automatically accessed and information retrieved. A personal computer with a television tuner receives the signals and displays the video in a small window. The rest of the screen displays the HTML pages. The computer's hard disk can capture and store pages of interest. Since HTML pages are around 50 Kbytes each and most personal computers now come with at least a 1 GB hard drive, capacity is not a problem. In a major application of this technology, the pages downloaded pertain closely to the video programming. When several hundred pages are downloaded, the access speed is governed by the hard disk, not a modem. In affect, the server is built into the personal computer! However, a high speed data link keeps the contents of the hard drive fresh and yields a fast response to a new inquiry for information. The HTML nature of the pages makes accessing different parts of the data downloaded easy and familiar to any Web surfer. The HTML can include embedded links to related Web sites accessed with the computer's regular phone or cable modem. Access to these sites is automatic.

Cable vs Broadcast Data

Since cable's spectrum is much more well behaved than the broadcast spectrum, several significant advantages accrue. A time domain equalizer may not be necessary. If one is included, it may have relaxed specifications leading to lower cost. There is no "airplane flutter", i.e. Doppler effect from approaching or receding aircraft. Because the spectrum is better behaved, less error detection and correction is required for a given level of performance. This was well demonstrated in the Advanced Television Grand Alliance's modulation scheme. While 8-VSB is used for broadcast, 16-VSB was developed for cable allowing two HDTV signals in 6 MHz on cable. 16-VSB does not have twice the data capacity of 8-VSB. The doubling of payload comes because 16-VSB requires significantly less data protection. If this same approach is applied to the techniques proposed for data carriage in analog television signals, more of the raw data capacity can be harvested for payload purposes. This approach has not been well explored and offers a significant opportunity. An additional advantage is cable's availability of multiple channels to carry data. The data carrying capacity of a cable system is just huge!

HIDING DATA IN ANALOG SIGNALS

A few years ago, the question was asked if it was possible to hide enough data in an analog video signal to allow carriage of a separate digital video signal. At first, the prospects seemed dim. There are at least two reasons for this. First, it was thought that 5 or 6 Mb/s would be required for a digital television signal. Secondly, the early analysis was based on binary signals; i.e. signals with just two logic levels.

Subsequently, several things happened. First it became clear that MPEG encoding has improved dramatically so that fewer Mb/s are required for good quality results. Secondly, the use of multi-level coding makes it possible to convey multiple bits simultaneously. Advanced tuner technology makes it possible to consider two or more tuners in a receiver to extract data from more than one channel simultaneously. Lastly, very sophisticated processing is affordable in receivers. This processing allows compensation for problems introduced by extra data signals.

Data Under Visual

The new approach involves a data signal which is double sideband amplitude modulated onto suppressed carrier which is in quadrature phase with the picture carrier. If both the video signal and the new data signal were normal double sideband, they could be separated with synchronous detectors by conventional methods. Since the television signal is not all double sideband, but vestigial sideband, a television receiver includes a Nyquist slope filter to properly weight the upper and lower video sidebands around the carrier so that the correct amplitude is available for detection. A Nyquist filter is one which has an anti-symmetric characteristic about a critical frequency which is called the

Nyquist frequency. The exact shape of the filter is not specified, only that it is anti-symmetric about the critical frequency. The receiver manufacture has some latitude in the implementation of this filter.

The Nyquist filter is a serious problem for a double sideband signal which is modulated onto a quadrature carrier. In the course of its normal functions, this filter would convert a plain double sideband modulated signal (with opposite sidebands equal in amplitude to each other) into a double sideband signal with asymmetrical sidebands. Vector analysis reveals that when the two sidebands are symmetrical, there is only a resultant signal in phase with the carrier. Conversely, when the two sidebands are not symmetrical, there is an additional component in quadrature with the carrier. This newly formed asymmetrical sideband set would have an undesired component in phase with the video carrier which would cause interference. Stated another way, even though the new sideband set was initially placed on a suppressed carrier which is in quadrature to the picture carrier at the origination point of the signal, after being operated on by the receiver's Nyquist filter, a detector extracting the video signal would "see" unwanted components from the new sidebands. Consequently, quadularity would not be preserved between the visual carrier and the added data signal.

This problem can be averted by properly shaping the spectrum of the added data signal so that when it passes through the receiver's Nyquist filter, a double sideband spectrum in quadrature with the visual carrier and possessing equal amplitude sidebands will be obtained. Under these conditions, there will be minimal cross coupling of the quadrature signal's energy to the receiver's video detector. Therefore the receiver's detector will respond essentially only to the video signal. If the receiver utilizes a synchronous or similar behaving detector which inherently is immune to quadrature components, the added data signal will be essentially ignored.

The pre-shaping of the added data signal is done with a compensation network which includes a Nyquist filter representative of those found in the population of receivers exposed to the added data signal. In the event that the population consists of a mixture of differently shaped Nyquist filters, a composite signal optimizing the result can be implemented either with a parallel configuration of Nyquist filters fed with signal strengths in proportion to the numbers of the respective filters in the population or with a Nyquist filter designed to optimize the result using standard filter synthesis techniques.

In order to maintain a relationship that allows synchronous detection to separate the data signal from the video signal, the data signal should be limited to the frequency region over which the Nyquist filter operates. This is $\pm$ 750 kHz around the visual carrier. Two level data will accommodate 1.5 Mb/s of throughput. However, the signal to noise environment required to present acceptable pictures will support better than two level data. Four levels of data will allow two simultaneous bits of data for 3.0 Mb/s of throughput. While higher data rates may be possible, the signal levels required make the problem of avoiding interference with the video very difficult. Since going to three simultaneous bits would involve discriminating eight levels of signal, the point of diminishing returns may have been reached.

The addition of a data signal in quadrature with the video carrier will modulate the envelope of the resulting signal. If the receiver's detector is not a pure synchronous detector, that is, if it exhibits sensitivity to the envelope of the resulting signal, the data signal will contaminate the video. The problem is that there is a huge population of receivers already in existence whose performance must not be seriously impacted.

The solution to this problem is the introduction of abatement signals to counter the impact of the data. Since the phenomena are non-linear, the optimum abatement strategies will involve non-linear techniques. A couple of year's of intensive development work has resulted in successful techniques for achieving this goal. Just as in the MPEG model, the expensive processing is done at the point of signal origination. The receiver circuits are very cost-effective.

Data Under Aural

Additional information may also be added on the aural carrier of the NTSC television format. This is achieved through amplitude modulation of the aural carrier which is already frequency modulated by the TV audio and BTSC signals. The first caveat is that the AM modulation may not be full depth without corrupting the aural program information. The allowable depth of modulation is limited by the worst signal to noise ratio to be encountered in the service area of the broadcasts. To be approximately equivalent in both program material and data performance at the FCC "Grade B" contour a downward modulation depth of about one half voltage (6 dB) which corresponds to 33% modulation is appropriate, but other values can be used. At this depth of modulation multilevel data signals may be employed increasing the data carrying capacity of the channel. Modern television receivers generally perform with full limiting when receiving noisy video signals.

More efficient use of the available spectrum is achieved by multilevel encoding of data. In the aural data system, 2, 4, 8, and even 16 levels are appropriate for different signal quality environments. In an NTSC (type M system) the highest chroma frequencies utilized are 5.43 MHz above the lower band edge. This is arrived at by the visual carrier being 1.25 MHz above the lower band edge, the chroma subcarrier being 3.58 MHz above the visual carrier and the highest frequency chroma sidebands extending up to 600 kHz above the chroma subcarrier (1.25 + 3.58 +0.6 = 5.43). If it is desired to maintain the sanctity of this spectrum, the aural data, 8 level, 1.5 Mb/s signal will be implemented.

With four level data under visual contributing 3.0 Mb/s and eight level under aural contributing another 1.5 Mb/s, a total of 4.5 Mb/s is achieved.

Other Data Resources

Neither the data under visual nor the data under aural interferes with Vertical Blanking Interval (VBI) data transmission. Approximately another half Mb/s can be achieved in that manner. There are other methods for hiding data under consideration by others. Some of these methods can be employed along with these methods to achieve still greater total capacity.

The combined data capacity per analog channel is a significant resource which should not be ignored. The electronics for extracting that data is very cost effective. It is a trivial cost addition to a digital set top box or personal computer mother board. It is well within the customary prices paid for personal computer after-market plug in cards.

When two or more adjacent channels are simultaneously utilized, statistical multiplexing techniques can be employed to pack still more programming into the analog spectrum.

THE AUTHOR

Dr. Ciciora is a technology consultant specializing in Cable Television, Consumer Electronics, and Telecommunications. He serves on several Boards of Directors, Technology Advisory Boards, and does expert witness work.

Most recently he was Vice President of Technology at Time Warner Cable. Walt joined American Television and Communications, the predecessor to Time Warner Cable, in December of 1982 as Vice President of Research and Development. Prior to that he was with Zenith Electronics Corporation, starting in 1965. He was Director of Sales and Marketing, Cable Products, from 1981 to 1982. Earlier at Zenith he was Manager, Electronic System Research and Development specializing in Teletext, Videotext and Video Signal Processing with emphasis on digital television technology and ghost canceling for television systems.

He has ten patents issued, two more allowed but not yet issued and several more pending. He has presented over two hundred papers and published about a hundred, two of which have received awards from the Institute of Electrical and Electronic Engineers (IEEE). His papers have been translated into Japanese, Chinese, German and Spanish. Walt wrote a monthly columns for Communications Engineering and Design (CED) magazine and for Communications Technology (CT) magazine for three years each.

He currently serves on the Executive Committee of the Montreux Television Symposium. He was a member of the board of directors of the Society of Cable Telecommunications Engineers (SCTE) for six years. He was inaugural Chairman of the Technical Advisory Committee of CableLabs for four years and Chairman of the National Cable Television Association (NCTA) Engineering Committee also for four years. He was president of the IEEE Consumer Electronics Society for two years and is a past chairman of the IEEE International Conference on Consumer Electronics. He chaired the Joint Engineering Committee of the NCTA and the Electronic Industry Association (EIA) for eight years. He has served on several industry standard-setting committees. He currently co-chairs the Cable Consumer electronics Compatibility Advisory Group to the Federal Communications Commission and its Decoder Interface subcommittee.

Walt is a Fellow of three engineering societies the IEEE, the SMPTE, and the SCTE. Other memberships include Tau Beta Pi, Etta Kappa Nu, and Beta Gamma Sigma.

Current interests center on competitive technology, the consumer electronics interface with cable, Digital Video Compression, Interactive Television, Multimedia, and High Definition Television.

Walt received the 1987 NCTA Vanguard Award for Science and Technology and was named "1990 Man of the Year" by CED magazine. CED also named him "1993 Man of the Year". He was the Fall 1994 Levenson Memorial Lecturer at the National Cable Television Center at Penn State.

Walt has a Ph.D. in Electrical Engineering from Illinois Institute of Technology (IIT) dated 1969. The BSEE and MSEE are also from IIT. He received an MBA from the University of Chicago in 1979. He has taught Electrical Engineering in the evening division of IIT for seven years.

Hobbies include helping his wife with her horses, reading, wood working, photography, skiing, and a hope to someday become more active in amateur radio (WB9FPW).

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