B-MAC, An Optimum Format for Satellite Television Transmission

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A broad examination has been undertaken of the market requirements for distribution to the home via satellite of television programming and other services. While extensive discussion has taken place on the needs for Direct Broadcast Satellite (DBS), the format selected must be capable of distribution on Cable (CATV), through Satellite Master Antenna Television Systems (SMATV) for multiple family dwellings, and via UHF terrestrial broadcast. Commercial considerations require hard encryption of the audio and data, and hard scrambling of the video, combined with broad addressing and tiering capabilities, impulse pay-per-view, personal messages, teletext facilities, and potential expansion for extended definition television. These requirements are added to the basic essentials of picture and sound quality equal to, or better than, services presently provided.

During the past two years a transmission format meeting these market needs has been developed. The decoding hardware for both professional and consumer use is currently being reduced to a set of integrated circuits scheduled for completion in late 1984. The following is a discussion of some of the avenues that were examined, a brief description of the final system selected, and some of the rationale for this choice.

A NEW FORMAT

The initial impetus for the development of the system came from two directions: (1) the investigation of an improved format for DBS transmission and (2) a parallel effort investigating means to secure signals for pay television which is fast becoming a multi-billion dollar industry.

This requirement for scrambled signals which are by definition non-standard and the introduction of a completely new direct broadcast satellite service has presented the rare opportunity for the commercial success of a new signal format.

Both NTSC and PAL were designed for Amplitude Modulation (AM) transmission with the NTSC specification finalized in 1953, four years before the first Sputnik satellite was launched. FM transmission via satellite was not seriously contemplated at that time.

In a marketplace driven in part by the need to reduce dish size, noise in the signal is of great importance. With AM transmission noise is relatively flat in relation to frequency (Fig.1) whereas FM noise is triangular, increasing with frequency (Fig.2). The human eye perceives a noise characteristic that is basically the opposite and complementary to the triangular FM noise with visibility of noise maximized at lower frequencies (Fig.3). This optimal relationship of FM and human perception is not the case with the NTSC or PAL television systems, which frequency multiplex the colour information on a subcarrier at the relatively high frequencies of 3.58 MHz and 4.43 MHz respectively.

When the colour is demodulated down to baseband for display, the high amplitude noise which was present on the high frequency subcarrier is converted to low frequency noise and becomes much more visible (Fig.4).

DIGITAL SATELLITE TRANSMISSION

A number of methods have been explored to improve satellite transmission including the development of all-digital transmission systems. These have been seen to yield excellent quality at the receiving point, in some cases providing quality essentially equivalent to that transmitted. Due to the extremely high data rates required for video, all-digital transmission requires complex and expensive equipment at the receiver. Even with state-of-the-art large-scale integration, it is doubtful that all-digital transmission could be cost effective for use in the home in the 1980's or, possibly, well into the 1990's.

MULTIPLEXED ANALOG COMPONENTS

A hybrid system has therefore been selected which uses digital transmission techniques for the audio and data, combined with analog component video. This system known as Multiplexed Analog Components (MAC) was originally developed for satellite transmission by the Independent Broadcasting Authority (IBA) in the U.K. The chrominance and luminance are transmitted in a line by line, time multiplexed, rather than frequency multiplexed mode (Fig.5). Numerous technical papers have been published detailing the merits of sequential chroma/luminance transmission.

AUDIO/VIDEO FORMAT OPTIONS

For the past year and one-half there has been a great deal of discussion on the C-MAC format, but there are three other basic options open for the combining of data with video. These are described by the matrix of frequency multiplex or time multiplex at either baseband or RF (Fig.6).

A-MAC

A-MAC provides a baseband frequency multiplex of the audio and data on a subcarrier at approximately 7 Mhz (Fig. 7 and 8). This provides the advantage of an extremely rugged data channel, however, it has limitations on its potential for threshold extension, and bandwidth constraints on video for extended definition.

D-MAC

D-MAC employs frequency multiplexed data at RF. With video centred at 70 Mhz, for example, the data might be on a separate carrier at 85 Mhz. Audio and video can be uplinked from separate locations and exceptionally high data rates are possible, but two receivers are required and interference problems are raised.

C-MAC

C-MAC time multiplexes the data at RF (Fig.9) providing in excess of 20 megabits per second during the 9 microseconds that would otherwise be devoted to the horizontal blanking period. One advantage is the efficiency of direct demodulation from RF to digital data providing for high data rates for up to 8 audio channels. Separate demodulation of this data is costly and, in terms of baseband bandwidth (Fig.10), a transmission channel in excess of 10 Mhz is necessary for applications such as cable or SMATV.

B-MAC

B-MAC time multiplexes the audio and data at baseband using a multilevel code during the 9 microsecond "horizontal blanking" period (Fig.11). The video is essentially identical to C-MAC but the bandwidth of the system is held to just over 6 Mhz by utilizing the wide dynamic range of the transmitted "video" signal for multilevel data (Fig.12). This provides a satellite signal that can also be used for cable, SMATV, terrestrial microwave or UHF broadcast without the need for decoding at an intermediate distribution point.

In Satellite Master Antenna Television (SMATV) applications, for example, the B-MAC signal can be received from the satellite and passed directly through a cable system within the building for subscriber access control at each individual television set. This also provides the potential for high quality red, green and blue signals for the television display combined with digital stereo audio directly to each viewer.

Compared with C-MAC, B-MAC has the somewhat lower data rate of 1.8 megabits per second but it has many advantages over C-MAC including its compatability with conventional video tape recorders and demodulation with one conventional low cost satellite receiver. It also retains compatability with future extended definition systems using wider bandwidths (Fig.13).

DIGITAL SYNC

Sync is extremely rugged, yet it requires .2% of the total time as opposed to over 20% required for NTSC or PAL (Fig.14). Sync is carried on one line in the vertical interval as a highly redundant digital word and provides for receiver lockup at 0 dB carrier to noise. This will assist the amateur in dish set-up and satellite signal acquisition, and provide picture continuity under the most adverse reception conditions.

Through elimination of the traditional sync pulses and both the colour and audio subcarriers, FM deviation in the channel, IF filters, and the pre-emphasis/de-emphasis networks can all be optimized to yield excellent results. Smaller satellite receiving dishes or improved performance is achieved. B-MAC is also uneffected by most non-linearities in the transmission channel.

Further significant reductions in dish size can be achieved by reducing the video bandwidths and data rates for applications, for example, where "video cassette quality" pictures and 2-channel stereo sound are considered viable.

Standard NTSC or PAL satellite receiving equipment including dishes, low noise converters, receivers, and television sets can be used with the B-MAC system. Certain portions of this chain will be lower cost and have improved performance when their design is optimized for B-MAC. Of the systems studied, B-MAC yields the lowest cost satellite distribution system (Fig.15).

B-MAC ADVANTAGES

In summary, the principal advantages of the B-MAC system are:

a) a component system eliminating cross luminance and cross colour effects;
b) colour noise is reduced;
c) colour bandwidth increased;
d) red, green, blue signals are available for improved television display;
e) rugged, truly digital sync;
f) improved threshold extension techniques can be applied when all subcarriers are eliminated;
g) dish size is reduced.

VIDEO SCRAMBLING

Scrambling of the analog video signal can be done in two basic ways. The amplitude of the signal can be varied or the video can be re-arranged in relation to time.

The most elementary scrambling system is sync suppression (or sync denial) which has been used for many years in the cable television industry in North America. Even in a controlled distribution cable environment, piracy of signals with many of the sync suppression systems runs high. With minor modification, some of the more sophisticated new television sets are capable of providing a locked picture in the absence of traditional sync pulses thereby automatically defeating such systems.

Sync suppression and sync denial are considered to be inadequate for satellite distribution if any level of controlled access is to be maintained even for the short term.

The more sophisticated scrambling methods include video inversion, line reversal, line segmentation or line rotation, line shuffling using a field store, and line translation.

Video Inversion

Video inversion is an amplitude system providing a relatively low order of security. It is particularly subject to non-linearities in the channel. Should there be black stretch and white compression in the channel when the transmitted video is inverted, this becomes black compression and white stretch yielding an amplitude flicker at the rate of the change from inverted to non-inverted video (Fig.16).

In general, all systems varying amplitude have provided relatively low security and, in some cases, low quality.

Line Shuffle

Use of a field store at both the transmit and receive points to re-organize the line sequence during transmission can provide highly obscured pictures. Effectively perfect reconstruction of the picture can be achieved in the descrambler through knowlege of the correct line sequence. This is potentially a high-quality scrambling system, but its cost will remain relatively high, particularly in light of the requirement for a random access memory in the decoder. Integrated circuits for field store use being developed today generally provide sequential access only.

Line Segmentation

Line segmentation or "line rotation" scrambling is essentially a technique where each line is divided into two segments which are interchanged in position for transmission (Fig.17). Portions of the line are repeated to mask the effects of the "splice". Using digital sampling, the lines are reconstructed in the descrambler with the repeated portion of the line around the splice discarded. This system, and variations of it, place excessive demands on specifications such as linearity, line tilt, and frequency response in the various equipment in the transmission chain.

Line tilt in the order of 3% to 5% is usually not visible to the human eye because of the gradual change across the picture (Fig.18). When even 1% tilt is added to a segmented line signal during transmission, the reconstructed pictures are visibly unacceptable (Fig. 19 and 20). When descrambled, the tilt becomes a dc level shift in the picture which changes from line to line as the scrambling patterns change, and manifests itself as highly visible low frequency noise (Fig.21). A total system line tilt specification of .3% is required to provide acceptable video. This defines a very basic rule about video: the clamp-to-video timing relationship must be held constant.

Should a segmented line picture be distributed via a vestigial sideband (VSB) cable system, another impairment problem is encountered. Any mistuning at the receiver causes a boost or attentuation of the low frequency component of the signal (Fig.22) thereby effecting the step response of the channel (Fig.23). A low frequency transition that is artificially created by line segmentation scrambling yields a long overshoot or undershoot recovery period which is visible in the descrambled video and has no relation to actual picture transitions (Fig.24).

Line Translation

Line translation scrambling uses a horizontal time-shift technique. The blanking time is varied on a line-to-line basis from a minimum of zero to a maximum of two times the normal blanking. The clamp period is tied to the video with that relationship held constant (Fig.25). This line translation, or "time base" scrambling system redistributes the picture information in time (Fig.26), yielding a scrambled picture that is totally obscure, yet can be reconstructed in the descrambler to a high-quality picture with no visible or measurable degradation or artifacts relating to the scrambling technique.

The scrambling is dynamic in that the patterns are changed every frame. A benefit, apart from controlling viewer access, is the decorrelation of transmission channel interference patterns when the pictures are descrambled. The only thing asked of the transmission channel is that it be relatively time invariant for approximately 100 microseconds, a specification easily met by every normal channel today.

B-MAC format decoding, line translation descrambling, or both together, require a maximum of three TV lines of storage. While providing both high security and high quality, the cost is low and it is compatible with CCD technology (Fig.27). The video descramble key is encrypted using the data encryption standard (DES) algorithm and is interleaved with other information in the digital data channel.

Data Channel

The digital data channel includes audio, addresses, the data decryption key, video descramble key, personal message data, and full field data as an option. The system supplies hi-fidelity digital stereo sound which can be connected to the viewers' standard hi-fi sound system.

Four-Channel Digital Audio

B-MAC has been designed with a four-channel digital audio system with 31.4 Khz or 31.2 KHz (two times the TV line frequency) digital sampling. A new enhanced delta modulation technique yields a dynamic range at the descrambler greater than 84 dB and very gentle failure under low carrier to noise ratio reception conditions. The audio is encrypted to the data encryption standard (DES). This encryption algorithm is applied on a bit-by-bit basis with the decryption keys and codes changing at irregular intervals. This provides dynamic DES encryption for the highest security commercially available.

A data channel with 94 K bits per second is standard. Any audio channel can be assigned to data transmission and reception, each channel providing 320K bits per second. Full field data is also available by replacing the picture with digital information. This yields an additional 10.8 million bits per second.

Addressing

The addressing technique provides for up to four billion addresses with redundancy for reliable reception. This high number of addresses provides for effectively infinite tiering. Addressing is at the rate of one million per hour. Effectively instant (1/4 second) access is provided to all authorized programs when the subscriber switches channels. The decoders are generic, and are capable of being addressed by any one or all program distributors using the system, depending on their desire to reach each individual viewer.

Text Services

Teletext is an integral part of the B-MAC system with 200 pages of encrypted or clear text available to all or any specific user with 20 seconds access. Uses include film sub-titles as a user option, sub-titles for the deaf, general and personal messages, program guides, current tiering and parental lock information and individual account status for monthly and pay-per-view billing including presentation of the bill itself.

Summary

The B-MAC transmission, scrambling and encryption system employs a satellite optimized format; highly secure yet low-cost scrambling; a high data channel capacity; virtually unlimited addressing; facilities for pay-per-view programming and infinite tiering; multi-channel digital audio; and hard encryption. Personal messages can be sent to any individial, group, or to all receiving points. Red, green, blue video is available along with baseband NTSC or PAL and RF channel outputs. B-MAC provides excellent potential for use of two channels on one transponder and leaves the door open for extended definition techniques in the future.

The current implementation of the system is designed for professional use at cable headends, tele-conferencing, and other professional applications to the 525 line standard. The technology is also being implemented as a set of custom integrated circuits for both 525 and 625 line standards (Fig.28). These custom ICs and other components will be carried on a printed circuit board approximately 6 inches by 9 inches and will be inserted into certain satellite receivers and become integral to the design of others (Fig.29). Sample quantities of this decoding equipment will be available late this year, with production quantities available in the first half of 1985.

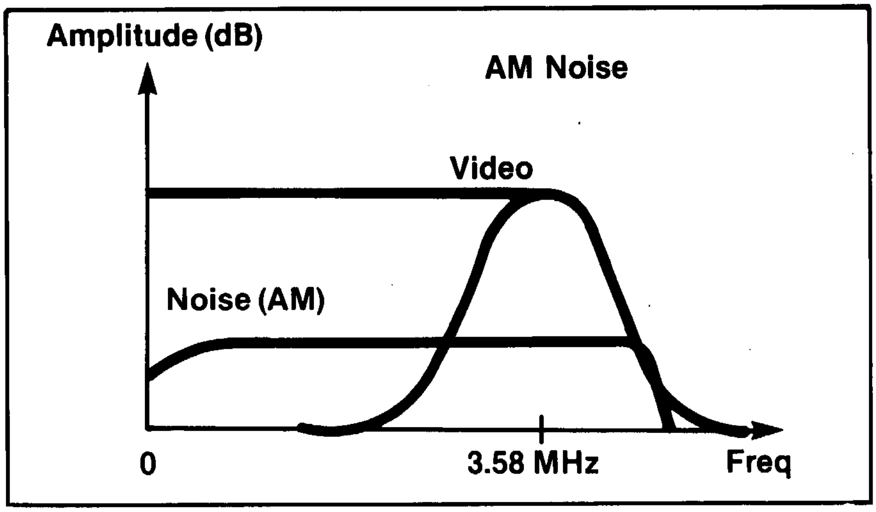


Fig. 1. With AM transmission, noise is relatively flat in relation to frequency.

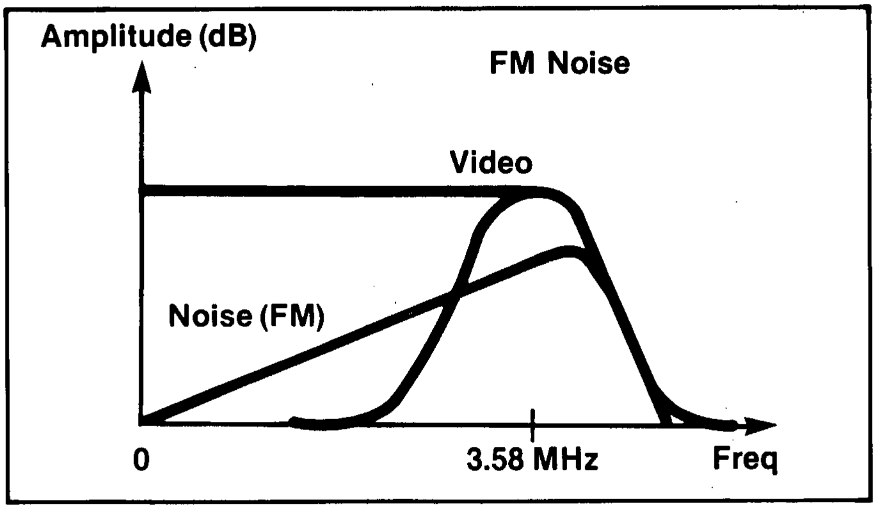


Fig. 2. With FM transmission, noise is triangular, rising with the frequency.

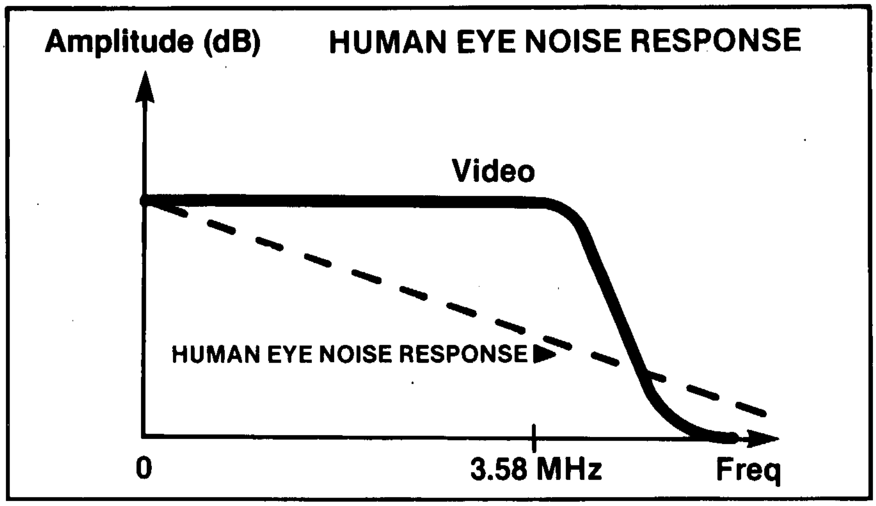


Fig. 3. The human eye perceives a noise characteristic which is essentially triangular decreasing with the frequency.

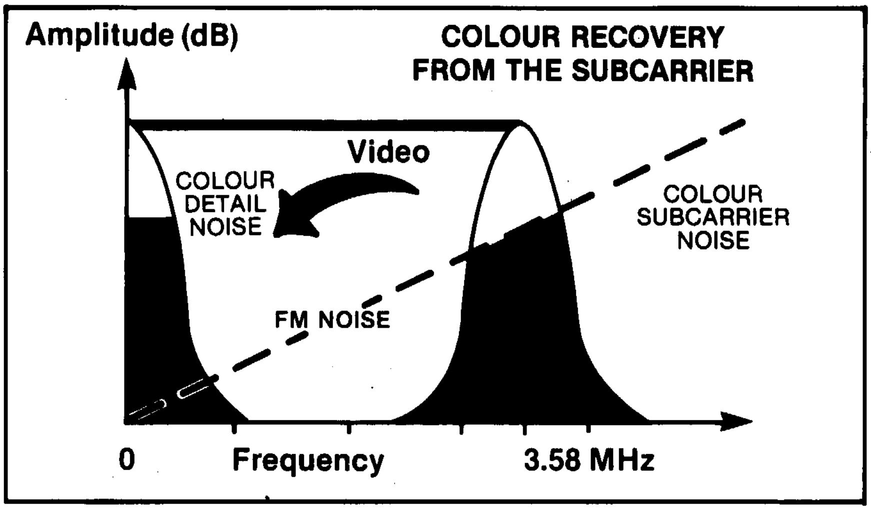


Fig. 4. Chroma demodulation converts high-frequency, high-amplitude noise into more visible low-frequency, high-amplitude noise.

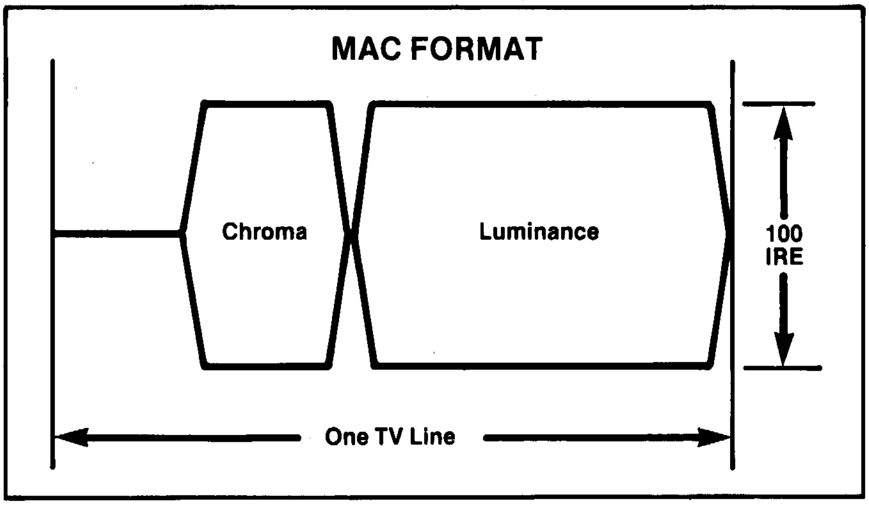


Fig. 5. Chrominance and luminance are time compressed and transmitted in a sequential format on each TV line.

FORMAT OPTIONS FOR DATA COMBINED WITH VIDEO

	Frequency Multiplex	Time Multiplex
Baseband	A	B
RF	D	C

Fig. 6. Matrix of four possible format options.

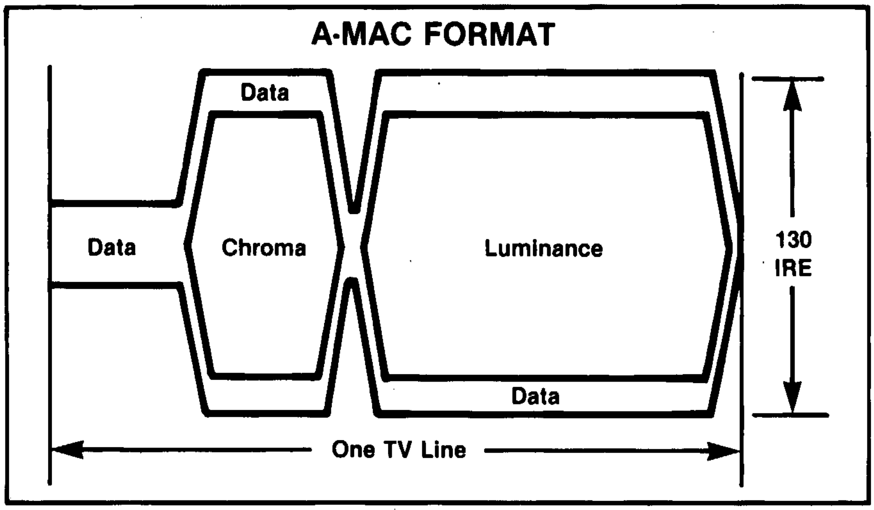


Fig. 7. A-MAC provides a baseband frequency multiplex of the audio and data on a subcarrier.

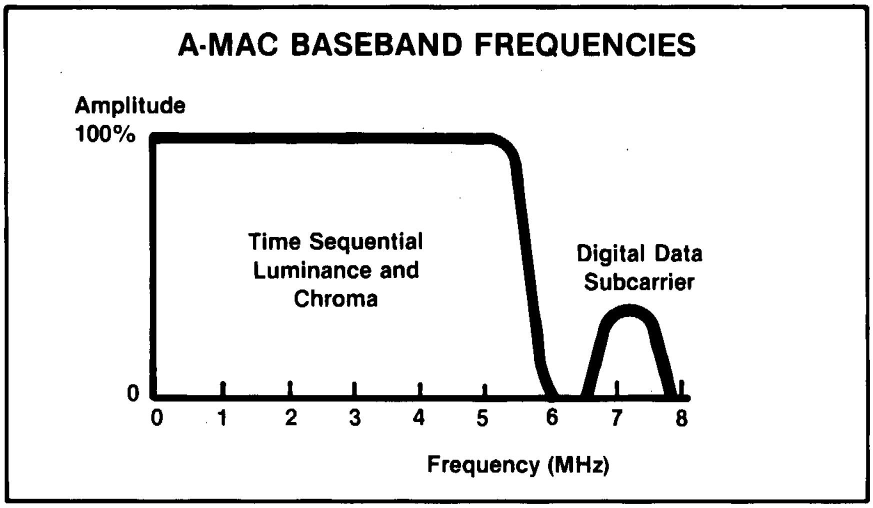


Fig. 8. Luminance and chroma occupy approximately 6 MHz with a digital data subcarrier at 7.16 MHz.

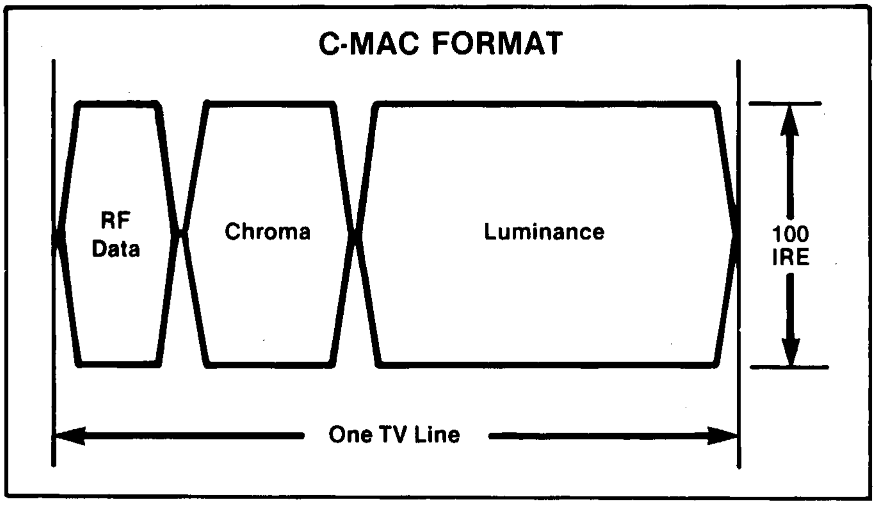


Fig. 9. C-MAC time multiplexes the data at RF with the baseband chroma and luminance on each TV line.

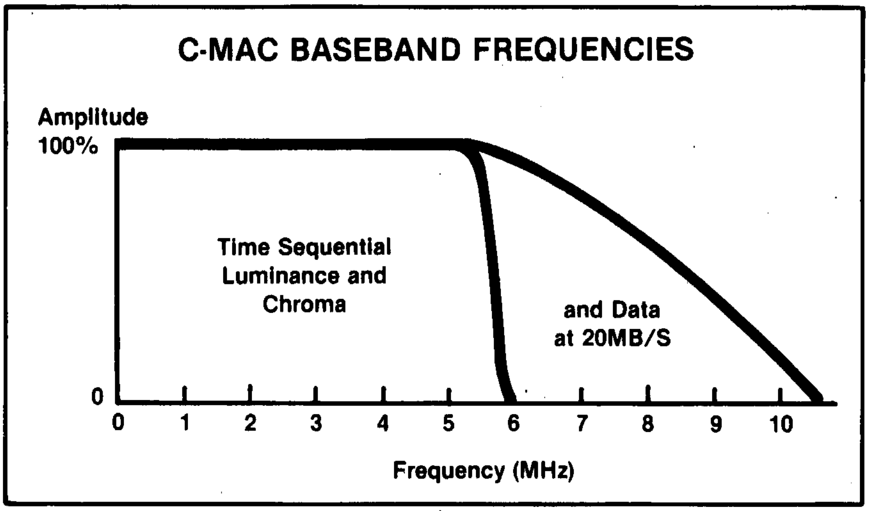


Fig. 10. The C-MAC data burst of over 20 Mbits/sec requires over 10 MHz equivalent baseband bandwidth.

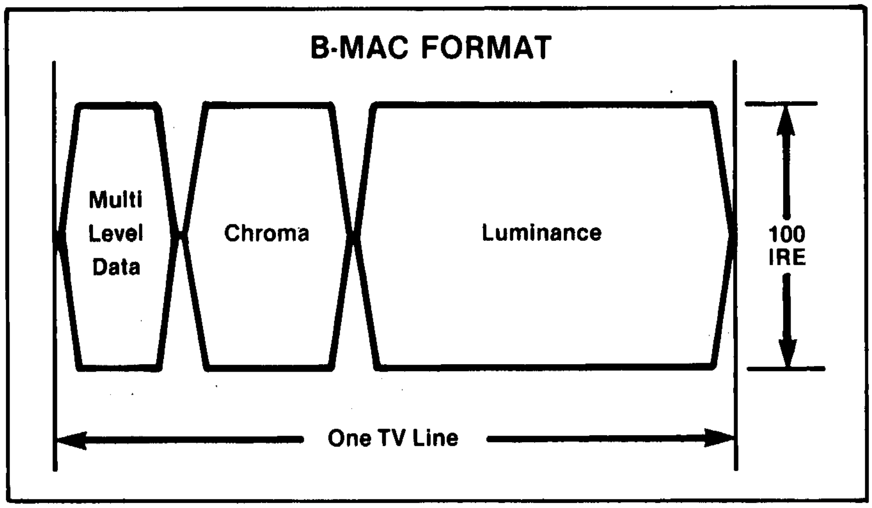


Fig. 11. B-MAC utilizes a multi-level code for data and time multiplexes this baseband signal with chroma and luminance.

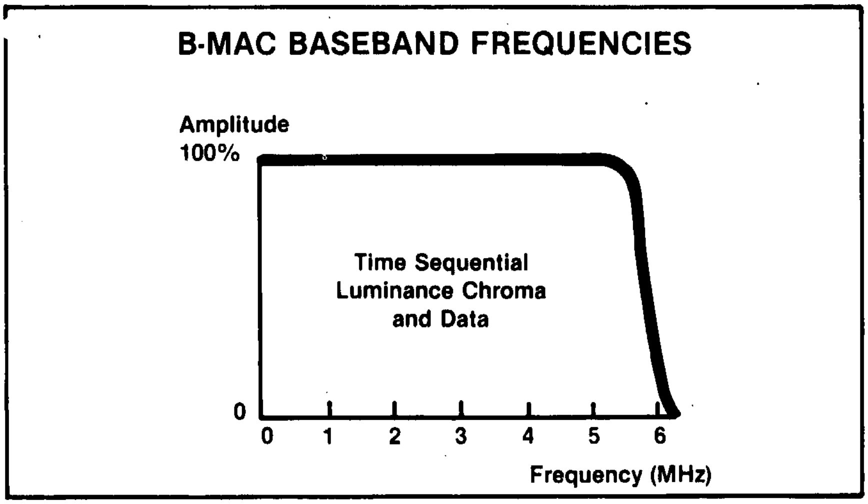


Fig. 12. The baseband bandwidth of B-MAC is held to just over 6 MHz for data, chrominance and luminance yet provides 1.8 Mbits/sec.

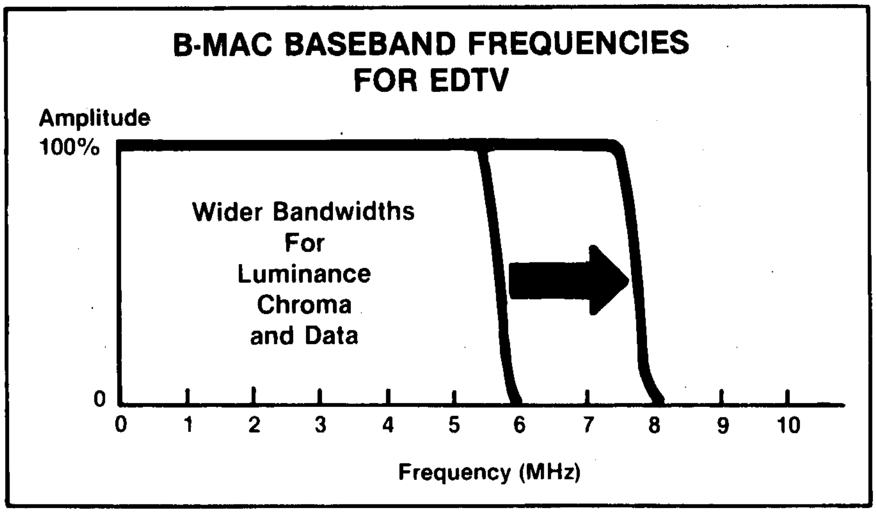


Fig. 13. A broad range of market requirements for the complete television delivery system are met by B-MAC.

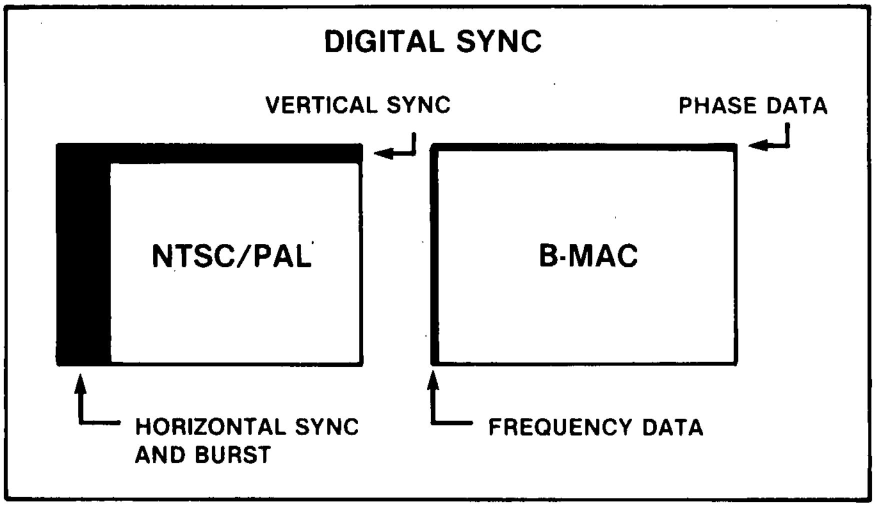


Fig. 14. The absence of subcarriers for chroma, audio or data allows simple expansion of bandwidths for extended definition television systems in the future.

MAC FORMAT OPTIONS

	A-MAC	B-MAC	C-MAC	D-MAC
Data Capacity (approx.)	2 Mb/s	1.8 Mb/s	2.5 Mb/s	3 Mb/s +
Cable Compatible	no	yes	no	no
STV/MDS Compatible	no	yes	no	no
Conventional Satellite Receiver Compatible	yes	yes	no	no
VTR Compatible	no	yes	no	no
Compatible with EDTV Bandwidths	no	yes	yes	yes
Cost	medium	low	medium	high

Fig. 15. Sync is replaced by a digital code on one line in the vertical interval (defining the top left-hand corner of the picture), combined with a burst on each line for phase and frequency to generate all timing requirements.

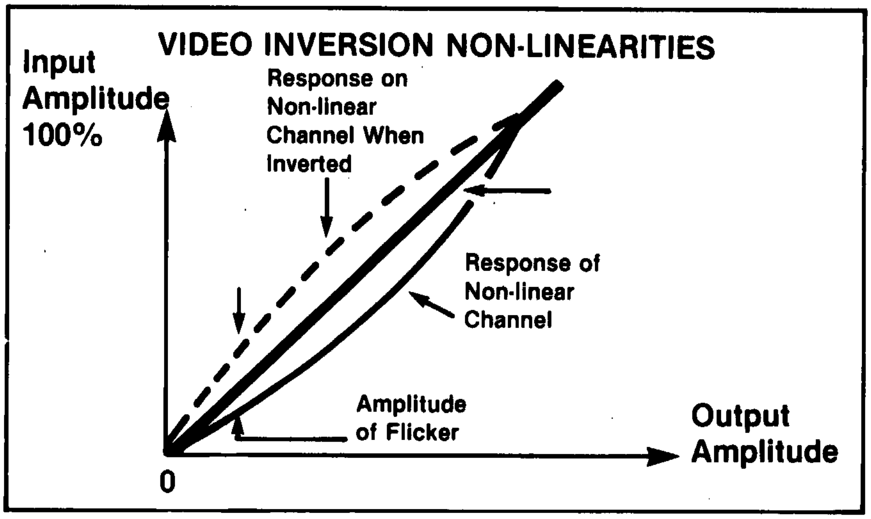


Fig. 16. Scrambling techniques which vary the amplitude or invert the video are subject to picture degradation due to transmission non-linearities.

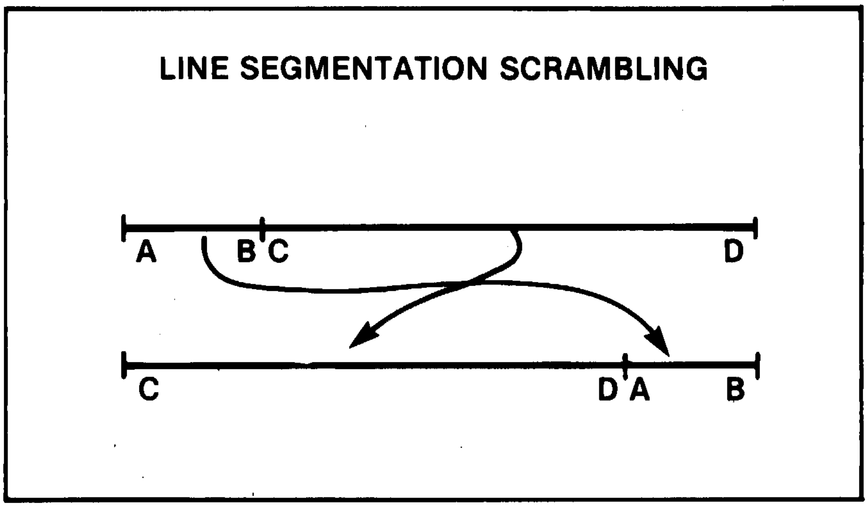


Fig. 17. The line might be cut in any one of, say, 32 different positions with the line AB, CD transmitted as CD, AB.

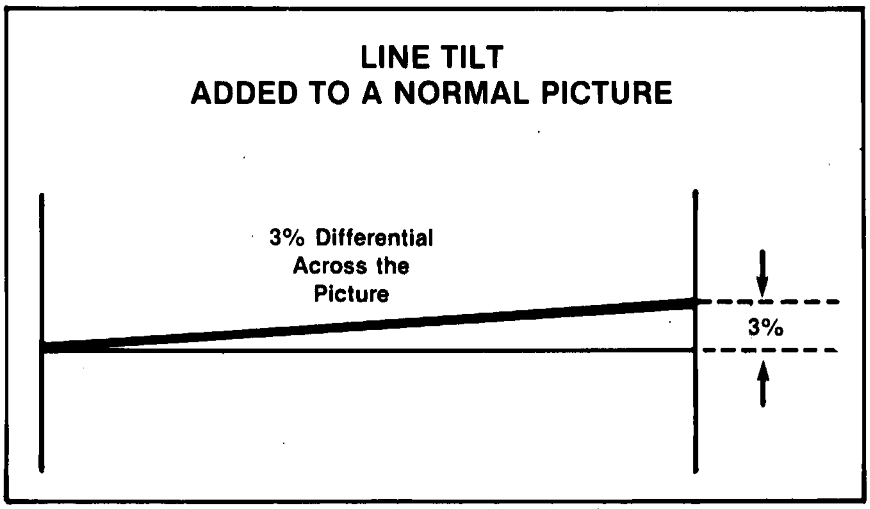


Fig. 18. A constant line tilt of 3% is normally not visible.

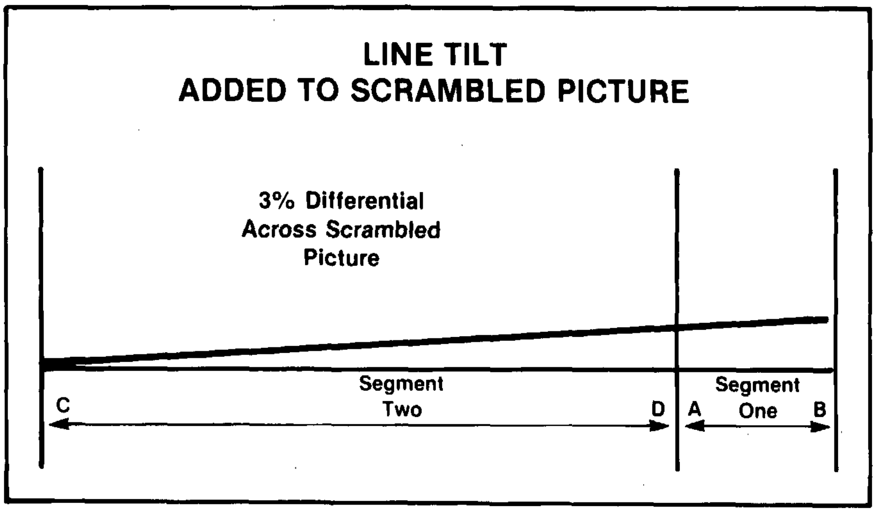


Fig. 19. Tilt is added during transmission to the scrambled line CD, AB.

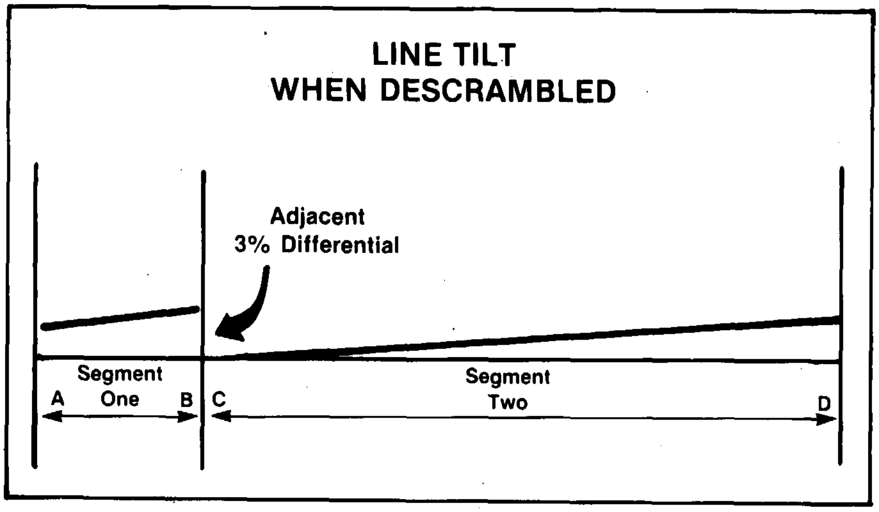


Fig. 20. After descrambling tilt is no longer a picture edge-to-edge gradual function.

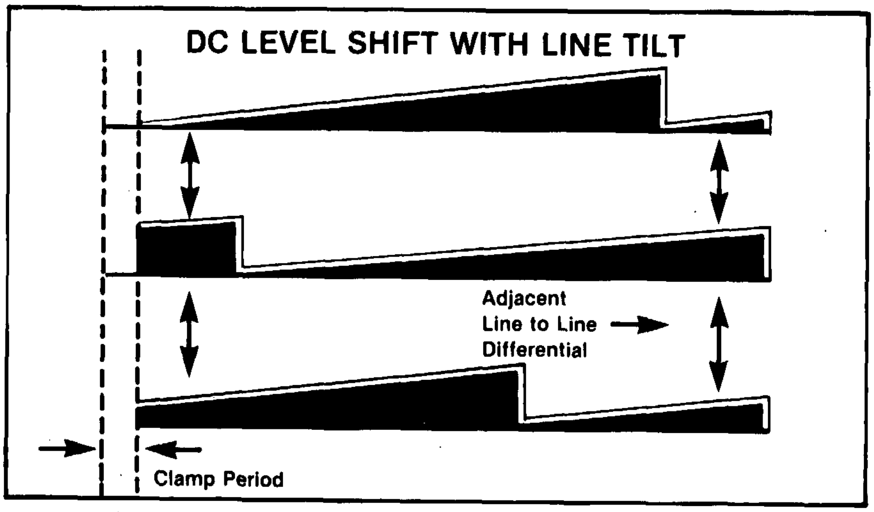


Fig. 21. A visible degradation with line rotation techniques is the DC level shift created by moving the video in relation to the clamp.

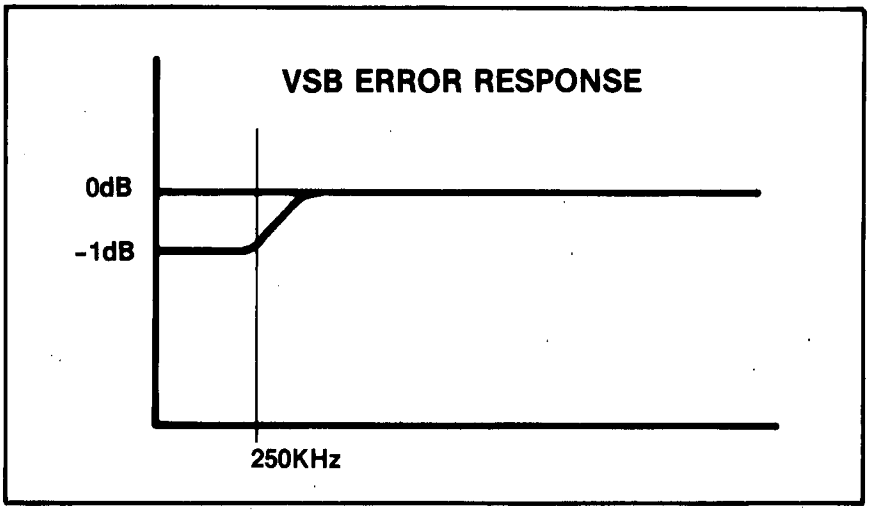


Fig. 22. In a vestigial sideband system such as cable, any mistuning at the receiver causes a boost or attenuation of low-frequency components.

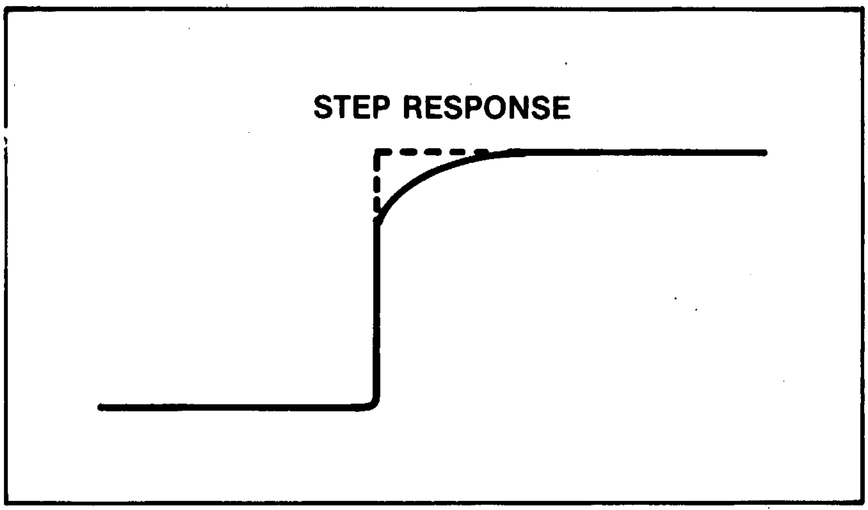


Fig. 23. Step response will vary as a function of vestigial sideband receiver mistuning.

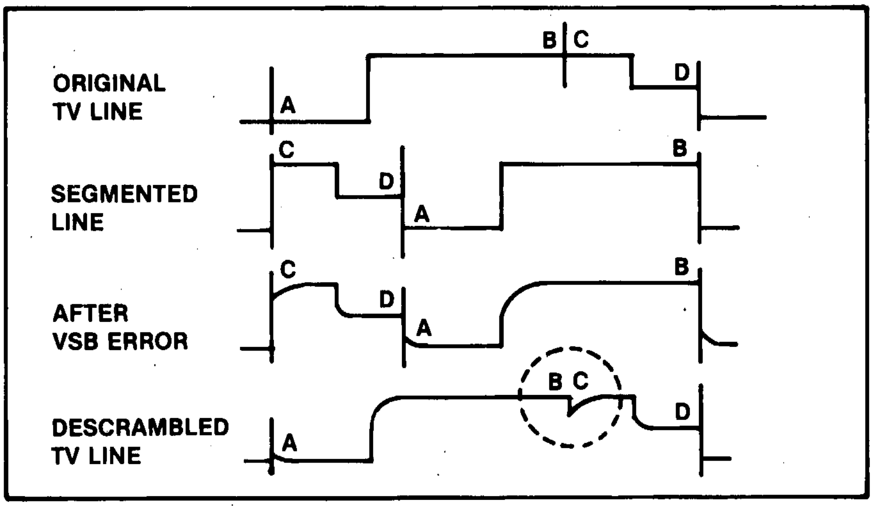


Fig. 24. Low-frequency transitions that are created by line segmentation scrambling yield a long overshoot or undershoot recovery period that has no relation to actual picture transitions.

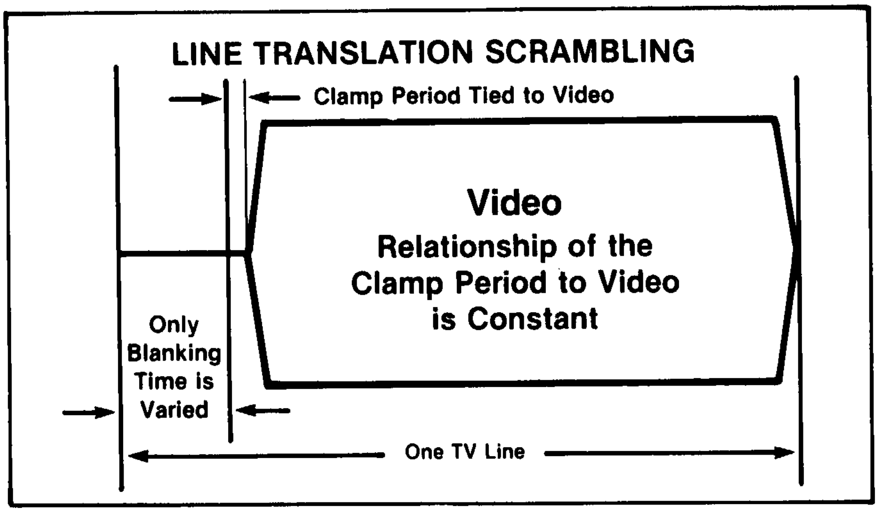


Fig. 25. Line translation or "timebase" scrambling maintains the video line and clamping period intact. Blanking time is varied from a minimum from 0 to a maximum of 2× normal.

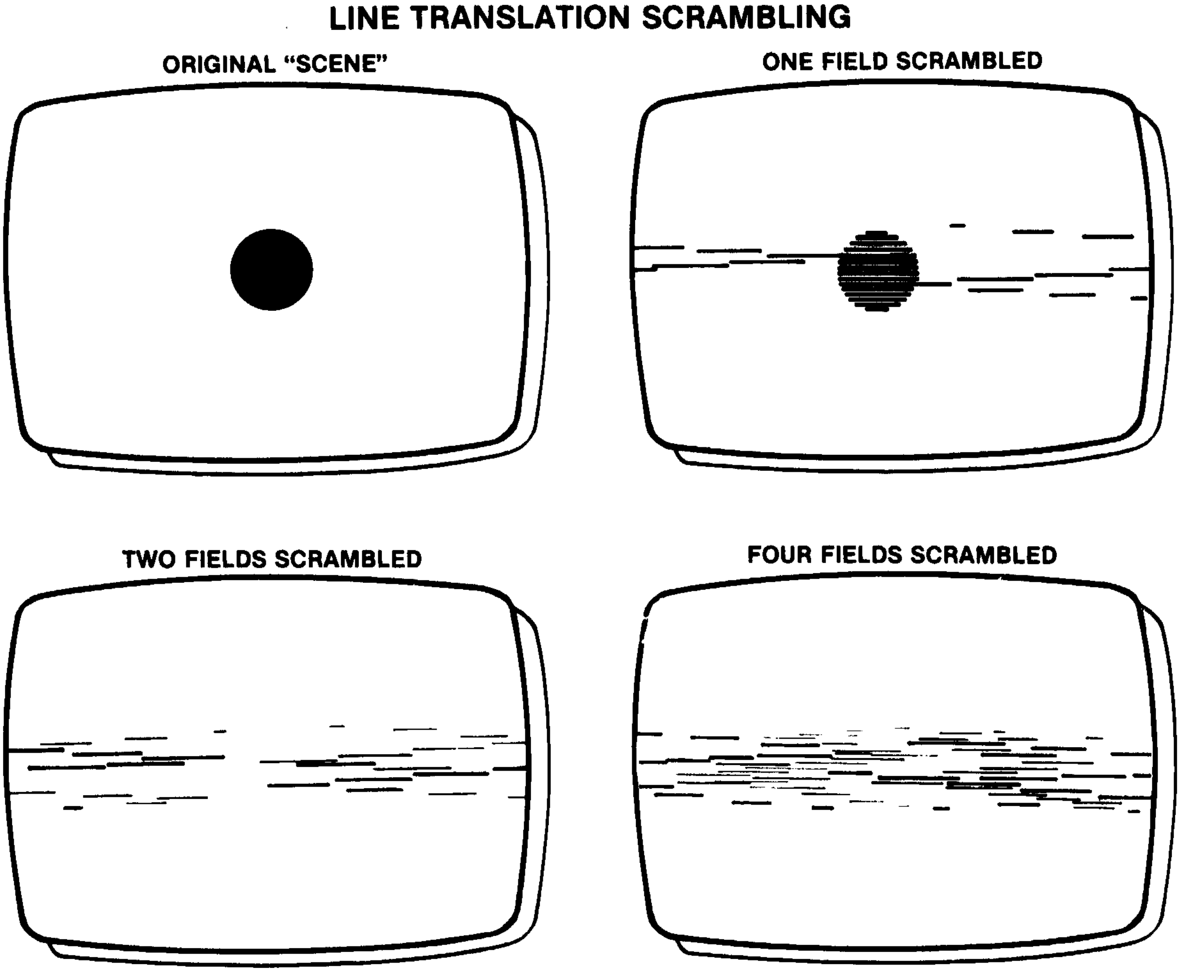


Fig. 26. Picture information is re-distributed in relation to time by the cumulative effect of reducing or expanding the horizontal blanking (data) period. The blanking (data) period is normal when averaged over each field.

VIDEO SCRAMBLING OPTIONS

	Sync Denial	Amplitude Reversal	Line Segmentation	Line Shuffle	Line Translation
Quality	high	low	low?	high	high
Security	low	low	high	high	high
Cost	low	low	high	very high	low
Compatibility with CCD	N/A	N/A	no	no	yes

Fig. 27. Line translation scrambling presents the most viable opportunity for a high quality secure consumer product.

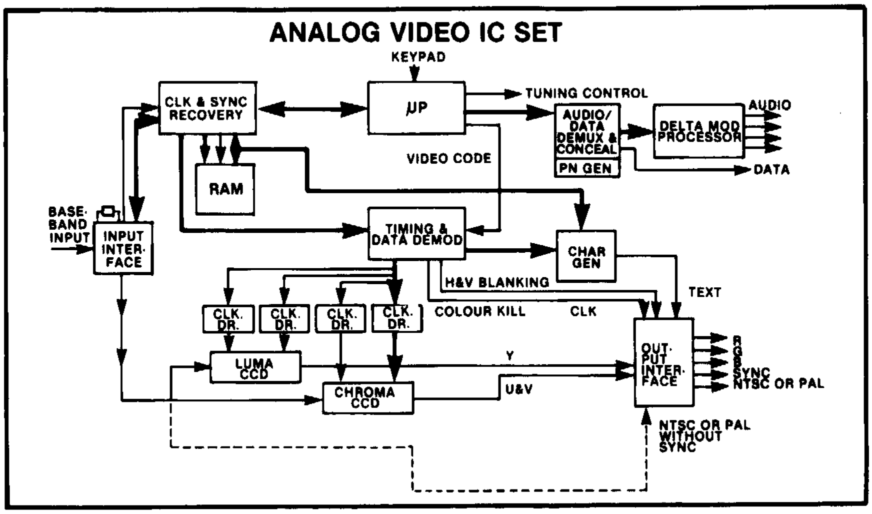


Fig. 28. A block diagram of the CCD implementation of the B-MAC descrambling and decryption receiver. It is compatible with both 525- and 625-line systems.

PROPOSED P.C. BOARD LAYOUT

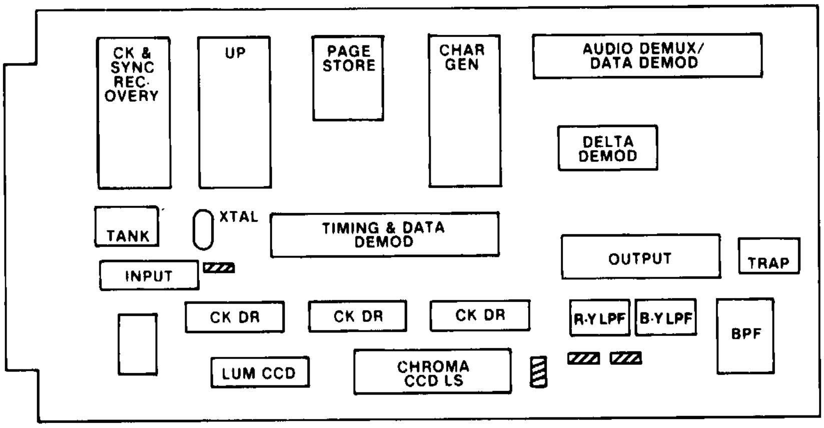
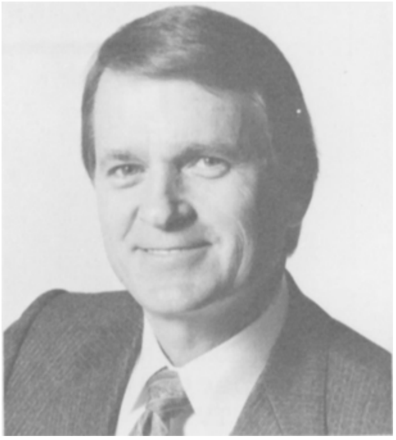


Fig. 29. Printed circuit board layout for the initial consumer implementation of the B-MAC system.



John Lowry started his career in television at the CBC in Toronto in 1952. In 1961, he worked on the development of the first electronic editing system for videotape in cooperation with Ampex Corporation and Advertel Productions. Mr. Lowry spent 6 years in film production and was co-developer of the Wesscam stabilizer for helicopter photography. In 1971, he developed the Image Transform signal processing and videotape-to-film conversion system. In 1976 Mr. Lowry founded Digital Video Systems, where he has pioneered numerous aspects of digital television. Today he is a member of the corporate staff of Scientific-Atlanta and Chairman of Digtal Video Systems.
Mr. Lowry is a Fellow of the SMPTE and has six patents on video noise reduction, image enhancement and film recording systems, with others pending.