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June 6, 1993

Digital Broadband Descrambling Technology - A Compatible Access Control Solution To The Ever-Growing Consumer Electronics Interface Problem

Ron D Katznelson

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DIGITAL BROADBAND DESCRAMBLING TECHNOLOGY - A COMPATIBLE ACCESS CONTROL SOLUTION TO THE EVER-GROWING CONSUMER ELECTRONICS INTERFACE PROBLEM.

Ron D. Katznelson, Ph.D.
Multichannel Communication Sciences, Inc.
San Diego CA.

ABSTRACT

Digital Broadband Descrambling ("DBD") is a newly developed digital technology for simultaneous on-channel processing of a large number of TV signals. It utilizes advanced Digital Signal Processing ("DSP") methods for effecting low cost broadband access control signal security compatible with most addressable converters in use today and thus will provide economically viable option for cable system operators to provide their subscribers with a truly "subscriber friendly" cable service while distributing scrambled video signals on the cable plant and avoiding the need for set-top descramblers.

Unlike existing "single-channel-at-a-time" descrambling technologies, the DBD technology simultaneously descrambles and provides all authorized channels in the clear by broadband selective coherent injection at RF and thus enables subscribers to enjoy all the features of their cable ready TVs and VCRs in a whole-house service, including built-in VCR programming functions, remote controls, watching and recording from different scrambled channels simultaneously or consecutively, and viewing multiple channels at once (picture-in-picture). Furthermore, the DBD devices will pass into the home all other unprocessed channels including digital compression signals, thereby allowing compatibility with future digital transmission.

INTRODUCTION

In the evolving competitive multichannel video distribution environments, Cable operators who adopt broadband access control methods relying on the intrinsic broadband capability of simultaneous multichannel VSB AM television signals are likely to reap powerful strategic benefits in offering tiered cable service: This technical advantage to Cable may remain the only *sustainable* differentiating feature over service provided by other multichannel video providers, such as a DBS operator, who unlike Cable, will have no choice but to employ set-top decoders. These competitors will thus require the use of multiple decoders for VCRs and additional outlets, while offering no relief to the ever-growing consumer electronics interface problem.

Unlike set-top descramblers currently in use, the DBD system does not employ single channel filtering or video demodulation-remodulation circuitry and thus introduces no measurable frequency response distortions or artifacts in either the video or audio signals of the descrambled or non-blocked channels. Therefore, video and audio quality at the subscriber's TV terminal is virtually that which is provided at the subscriber drop, facilitating compliance with recent FCC technical standards.

The following sections describe in relative detail the digital signal processing technology developed by Multichannel Communication Sciences, Inc. ("MCSI") for Broadband Descrambling applications. The descriptions herein describe but a few implementation versions and further cost reduced implementations are likely. The advent of lower cost digital signal processing VLSI used in digital cellular telephony and in the personal computer industry opens a new era for implementing low cost broadband systems that can be added to the cable operators' arsenal for dealing with the consumer electronics interface problem.

BROADBAND DESCRAMBLER PRINCIPLES

Multichannel Processing by Coherent RF Injection

Since the object of a broadband access control system is to provide all authorized channels to the subscribers in a clear form, and only certain channels must be descrambled, and hence modified, the approach herein seeks to avoid any single channel filtering or tuning techniques but rather focus on techniques that involve broadband signal addition in such a manner as to modify (descramble or further scramble and deny) only selected channels. From the outset, it is instructive to observe that many of the baseband and RF sync suppression scrambling formats constitute a linear modifying process in the radio frequency domain. In many cases this linear process is active only during the blanking intervals in which sync suppression occurs. This means that for each of these scrambling process, there exists an additive RF signal pulse of the appropriate duration, onset time, amplitude, frequency and phase, such that when it is added to the scrambled RF signal, it results in an RF television signal with normal synchronizing signals, and hence one that is unscrambled.

Figure 1(a) depicts the signal during the Horizontal Blanking Interval ("HBI") in a baseband sync suppression system. As can be seen, the normal sync signal is suppressed at the scrambler by adding a baseband offset signal of a predetermined magnitude (typically 70 IRE) during the HBI which results in the suppressed sync signal shown by the broken line. In this example, the active video signal is unmodified. Thus, in the inverted modulation scale of the RF domain, the HBI gated offset level at baseband is equivalent to the subtraction of the RF pulse shown in Figure 1(b) from an otherwise non-scrambled RF television signal. The frequency and phase of this RF pulse is equal to those of the picture carrier of the television signal. Hence, in order to restore this baseband sync suppression signal to it's unscrambled mode, one can add a coherent RF pulse train with the horizontal synchronizing repetition rate, coinciding in time with the HBI as shown in Figure 1(b), with the appropriate amplitude and in phase with the picture carrier so as to obtain an unscrambled signal. During the active video time, there is no RF signal injected.

Such addition at RF, hereinafter termed "Coherent RF Injection", must be effected with sufficient precision in amplitude, phase and timing so as to obtain essentially an unscrambled signal. For example, a baseband suppression of 70 IRE units using the standard television modulation scale, means that the in-phase coherent RF injection level required to effect descrambling must have an amplitude corresponding to 44.75% of the peak RF level of the non-scrambled portion of the signal. Moderate errors in the level of such injected RF pulse may not affect the proper synchronizing of the television receiver for satisfactory viewing of unscrambled programs, but may cause minor errors in the black reference level of the television set. This is because most sets establish their black video reference level by sampling the 0 IRE level during the color burst period. However, generally accepted video specifications allow for fixed errors of up to $\pm$ 3 IRE in black level, well below the 7.5 IRE setup level. These fixed error levels are permissible and are undetectable for all practical purposes. Based on this permissible amplitude error, it can be shown that the required accuracy of coherently injected RF signals for descrambling can be characterized by an ideal errorless injection signal accompanied by an injection RF phasor error of magnitude not exceeding -27 dB as compared to the desired injected RF signal. Similarly, a phasor error limited to -27 dB in the injection phase of the RF pulse results in maximum deviation of the combined picture carrier phase of less than $\pm 1.3°$ during

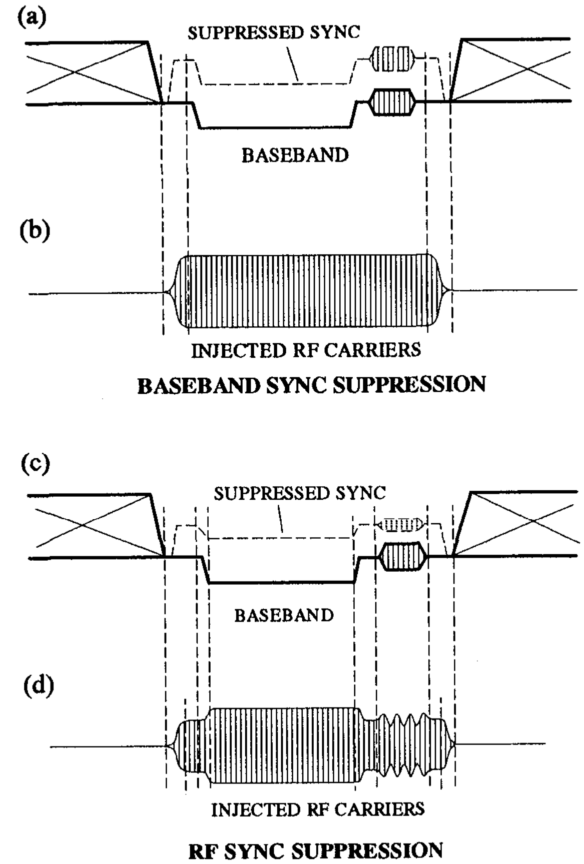

Figure 1. Descrambling by Coherent RF Injection. Signals during the HBI.

the HBI. This is well within the requirement limiting the phase error to $\pm 3°$ due to Incidental Phase Modulation ("ICPM") so as not to cause perceptible intercarrier audio buzz or MTS stereo distortion[1]. As will be subsequently appreciated, this -27 dB permissible error level facilitates a robust and low cost embodiment of a broadband generator for simultaneous injection for a plurality of channels.

The baseband video sync suppression transitions at the scrambler as shown in Figure 1 take place over a time duration not exceeding two hundred nanoseconds, consistent with a standard television video bandwidth of 4.2 MHz. Upon descrambling of such signals, it is preferable to match these transition times when the sync offset level is removed at the descrambler by coherent injection of an RF pulse shown in Figure 1(b). Here, the onset and termination periods of the injected RF pulse would have durations that would preferably each be no longer than two hundred nanoseconds. However, if the pulse shape of the injected RF envelope of Figure 1(b) is attempted by means of an amplitude pulse modulator with video bandwidth, the fast rise-times and fall times would generate double sideband spectral broadening of up to 4.2 MHz above and below the picture carrier frequency. The upper sideband content of this injected signal will be contained within the desired normal television bandwidth as transmitted in Vestigial Sideband ("VSB") Modulation. However, since the injected signal is assumed to be combined with the received signal in a broadband combiner, the lower sideband of the injected signal may interfere with a lower adjacent television channel and in particular with it's audio subcarrier located only 1.5 MHz below the picture carrier of the descrambled channel.

If, instead, longer transition times are assigned for the injected RF pulse so as to limit the spectral broadening of the amplitude modulated pulse to less than 1.5 MHz, the descrambled video signal will contain front and back porch transients with durations lasting several microseconds. These slow transients may invade the leading edge of the horizontal synchronizing signal or the active video time of the descrambled signal, thereby delivering a degraded video signal to the subscriber, which may cause false horizontal sync or unstable video clamping action by the television set.

The above-mentioned conflicting requirements in the frequency domain and in the time domain, can be resolved by turning to the very method which allow fast video transitions in television transmission without undue lower sideband spectral expansion, namely, the use of VSB modulation techniques for the transitions of Figure 1 prior to the RF combining with the scrambled signal. This will allow the television receiver to process the upper sideband containing up to 4.2 MHz wide spectrum associated with fast baseband transitions while limiting the lower sideband expansion to well below 1.5 MHz and thus prevent the associated interference to the lower adjacent channel. An elaboration on the digital RF circuit embodiments which facilitate such VSB spectral shaping of the injected signal will be discussed in the sections below.

The coherent gated RF injection described above can be useful for purposes other than descrambling. Provisions can be equally made for implementing signal denial techniques on a channel by channel basis for non authorized subscribers. In contrast to the descrambling case, in an example signal denial case, the coherent gated RF injection of Figure 1(b) can be effected in opposite phase to that of the picture carrier of the television signal, thereby further suppressing or nulling the synchronizing signals and optionally, with sufficient injection level, even reversing the resultant RF phase of the received television signal during the HBI. This method results in enhanced security for unauthorized subscribers since it denies "pirate" decoders the ability to reconstruct the sync signals and further causes phase discontinuity in the intercarrier audio detector of the television set, thereby introducing disturbing audio buzz and further audio noise masking in some television sets. It should be understood that coherent RF injection for sync denial of the type described above must also be gated during the HBI using VSB transition modulation so as to prevent interference to the lower adjacent channel that may otherwise be clear or authorized for descrambling.

Thus far, processing of the television signals at RF by coherent injection was discussed in a context of a single channel. Clearly, the main reason to use RF injection techniques is to offer simultaneous processing of this novel type for a plurality of channels. This means that coherent injection should take place at each frequency for which either descrambling or further scrambling denial is required.

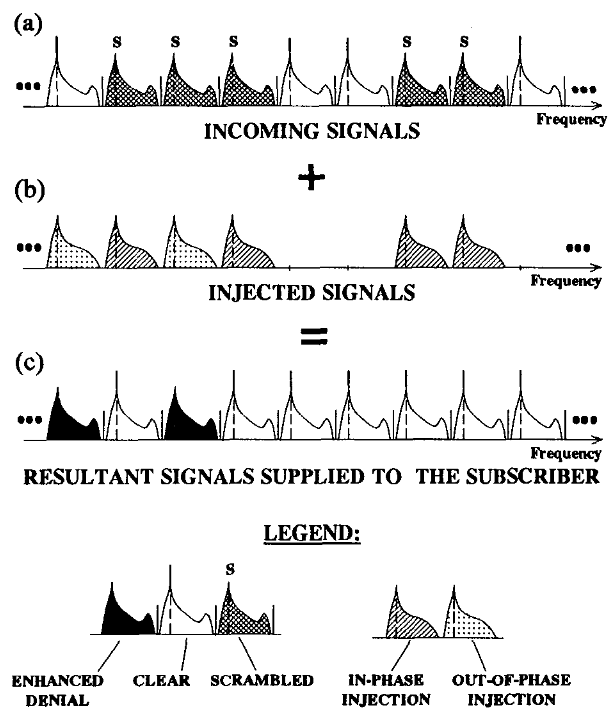

Figure 2. Descrambling and Enhanced Denial by Coherent RF Injection of VSB Shaped Signals.

Figure 2(a) depicts a portion of the broadband spectrum of the incoming signal carried on the CATV system entering the multichannel broadband descrambler. The channel spacing is 6 MHz. As can be seen, the spectra of each television signal appears asymmetric about its picture carrier frequency, as it is upper sideband VSB modulated. In Figure 2(a) one can observe two types of channels being transmitted down the CATV distribution plant. The first type, designated by clear patterns, represent all the non-scrambled channels for which the majority of subscribers are authorized and thus require no further processing at most subscriber locations. The second type of channels carried is the sync suppressed scrambled channels, designated with the letter S and a cross-hatched pattern. In the example of Figure 2 the assumption is made that the subscriber has purchased subscriptions for the premium scrambled channels corresponding to all scrambled channels except the third channel from the left, and has not obtained a subscription for the first channel from the left, transmitted in the clear. Consequently, the required RF injection spectrum corresponding to this subscription configuration is depicted schematically in Figure 2(b). Each signal in Figure 2(b) is assumed to be generated simultaneously within the multichannel descrambler installed at the subscriber's drop point of entry and combined in phase lock with its respective transmitted counterpart picture carrier of the same frequency in Figure 2(a). The broadband composite signal of Figure 2(b) is coherently injected and thus linearly combined with the broadband incoming signal of Figure 2(a) to form the composite broadband signal depicted in Figure 2(c). This resultant signal is subsequently provided to the subscriber for his/her viewing pleasure. The injected signals of Figure 2(b) consist of VSB injection signals with time domain profiles of the type depicted in Figure 1(b) or Figure 1(d). The injected RF signals for the second, forth, seventh and eighth channels from the left are all injected in-phase with respect to their corresponding incoming scrambled signals, thereby effecting simultaneous descrambling and resulting in clear channels in Figure 2(c), the signal provided to the subscriber. In contrast, the injected RF signals for the first and third channels from the left are injected out of phase, thereby causing sync null or other signal denial effects such as sync phase reversal. These are the television signals depicted in solid black on Figure 2(c), which are not viewable or otherwise useful to the unauthorized subscriber. However, because of the broadband characteristics of this combining system, they are fed in their further scrambled mode to the subscriber along with all other clear signals. Since the fifth, sixth and ninth channels are originally transmitted in the clear, and the subscriber is authorized to receive them, these channels require no further processing and therefore no signals are injected in the corresponding channel slots.

Because the injected signals of Figure 2(b) all have identical temporal profile as that of Figure 1(b), their simultaneous generation as a group can be made much simpler if they are all required at the same time, that is if the HBI of all television signals in the channel group of Figure 2(a) coincides in time repeatedly. This relative timing coincidence condition among this group of video channels means they must be "frame synchronous". This condition can be accomplished at the CATV headend for each channel in the group by means of video frame synchronizers providing video outputs genlocked to a master video synchronizing source.

It will become apparent in following discussions regarding embodiments of the multichannel injection signal generator that another appreciable simplification in the subscriber injection generator can be realized if channel groups intended for such processing are grouped in coherent relationships as in IRC or HRC systems, at least within that portion of the band constituting the groups of channels that are being processed by a Broadband Descrambler. This simplification is related to the fact that under such conditions, the composite RF signal of Figure 2(b) can be mostly derived from periodic signals with fundamental periodicity equal to the Incremental frequency separating any two nearest channels within the group (6 MHz). This RF coherence condition can be effected at the CATV headend by phase locking all modulators in the channel group to an appropriate coherent group comb signal.

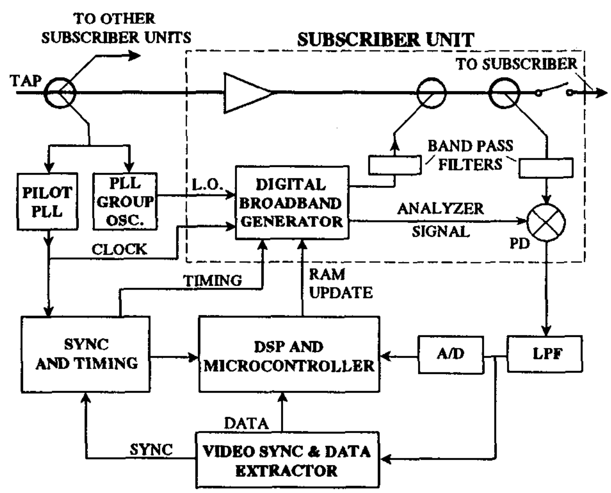

Figure 3. Simplified block diagram of a broadband descrambler.

As indicated above, each channel RF injected pulse must have correct amplitude and phase that matches the level and phase of the corresponding incoming signal. To that end, the broadband descrambling system of Figure 3 is constructed to accomplish such result in a digital feedback scheme as explained below. The assumption is made that the headend video frame synchronization and group coherent carrier phase locking is effected as discussed above. The broadband incoming signal containing all transmitted channels arrives at the input tap. A portion of the broadband signal power is coupled to a broadband amplifier whose output signal corresponds to Figure 2(a). It is then combined with the injected signals correspond to Figure 2(b), that are generated by the Digital Broadband Generator ("DBG"). Each of these injected signals has a temporal profile in video synchrony with the HBI. This coherent combination results in the composite signal of Figure 2(c) at the subscriber port.

The Digital Broadband Generator is a low cost RF generator capable of generating a plurality of incrementally related VSB or CW signals situated on an arbitrary subset of a 6 MHz frequency grid centered about a center local oscillator frequency, the signal of which is feeding the DBG via the L.O. line. The PLL Group Oscillator is locked to the picture carrier of the center channel of the group while the clock frequency may be obtained by using a pilot PLL locked to a low level CW pilot carrier transmitted from the headend at a frequency such as 72 MHz. The clock frequency required by the DBG is an integral multiple of the incremental channel separation frequency such as 144 MHz or 72 MHz.

A special case that can be controlled in the generation capability of the DBG is the generation of a single CW signal in phase coherence with any of the channels within the group, wherein a precise phase control is possible. This signal is used to provide the Analyzer signal shown in Figure 3, feeding a synchronous detector (PD). The DBG is used during the VBI to sequentially generate two quadrature analyzer signals on each channel being processed (Analyzer I and Q). The phasor analysis results from the Integrate & Dump LPF are sampled at field rate by the A/D and then fed to the Digital Signal Processor ("DSP") as sample inputs to the digital phasor tracking algorithm implemented by the DSP. The results enable the update of the RAM content in the DBG, so that the composite waveform generated by the DBG matches the phase and amplitude requirements for each processed channel. In a similar manner, the Analyzer signal can be set for coherent detection of video sync and data during the VBI of any channel within the group. The Sync & Data extractor is used to establish video frame synchronization of the system, so as to synchronize the coherent injection processing as well as VBI data reception of any designated channel within the group.

The Digital Broadband Generator

In general, the generation of a pulsed VSB signal at any given frequency can be accomplished either by passing a double sideband AM pulse through a vestigial sideband filter or by an equivalent phase and amplitude modulation of a sinusoidal carrier signal. The latter method[2] employs the Hilbert Transform of a high pass baseband component of a pulse. Accordingly, it can be mathematically shown that two envelope signals used for quadrature modulation of a carrier yielding a desired VSB pulse shaping are given by *C(t)* and *S(t)* shown in relation to the pulse width during an HBI in Figure 4. The signal *C(t)* is the modulating function of the in-phase component of the carrier and *S(t)* is that of its quadrature component.

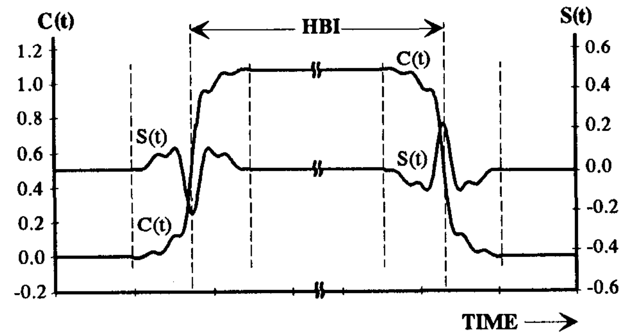

Figure 4. Quadrature modulation components required for VSB generation of the signal in Figure 1(b).

Hence, given a carrier frequency ω, a VSB shaped pulse about that frequency can be represented by a signal $f(t)$ given by

$$f(t) = C(t)\cos\omega t + S(t)\sin\omega t \quad (1)$$

In order to see how a plurality of incrementally related VSB signals can be *simultaneously* generated with a low cost digital structure, we turn to Figure 5. Figure 5(c) shows a block diagram of a Digital Broadband Generator comprised of two sets of RAM, D/A converter ("DAC") and low pass filter ("LPF") feeding a broadband quadrature modulator. The baseband signals feeding the two quadrature inputs are functions of time designated hereinafter as $B_1(t)$ and $B_2(t)$ and are digitally generated by the corresponding DACs, based on the contents of their respective RAMs. The low pass filters provide antialiasing filtering, clock signal components rejection and out-of-band harmonic rejection. The clock signal driving the DACs and the RAMs also advances the RAM address generator, causing the appropriate RAM data contents to be loaded sequentially into both DACs respectively. The clock frequency is set so that it is a sufficiently large integral multiple of the fundamental frequency increment between two adjacent channels. For example, in a 6 MHz channel spacing system, one might

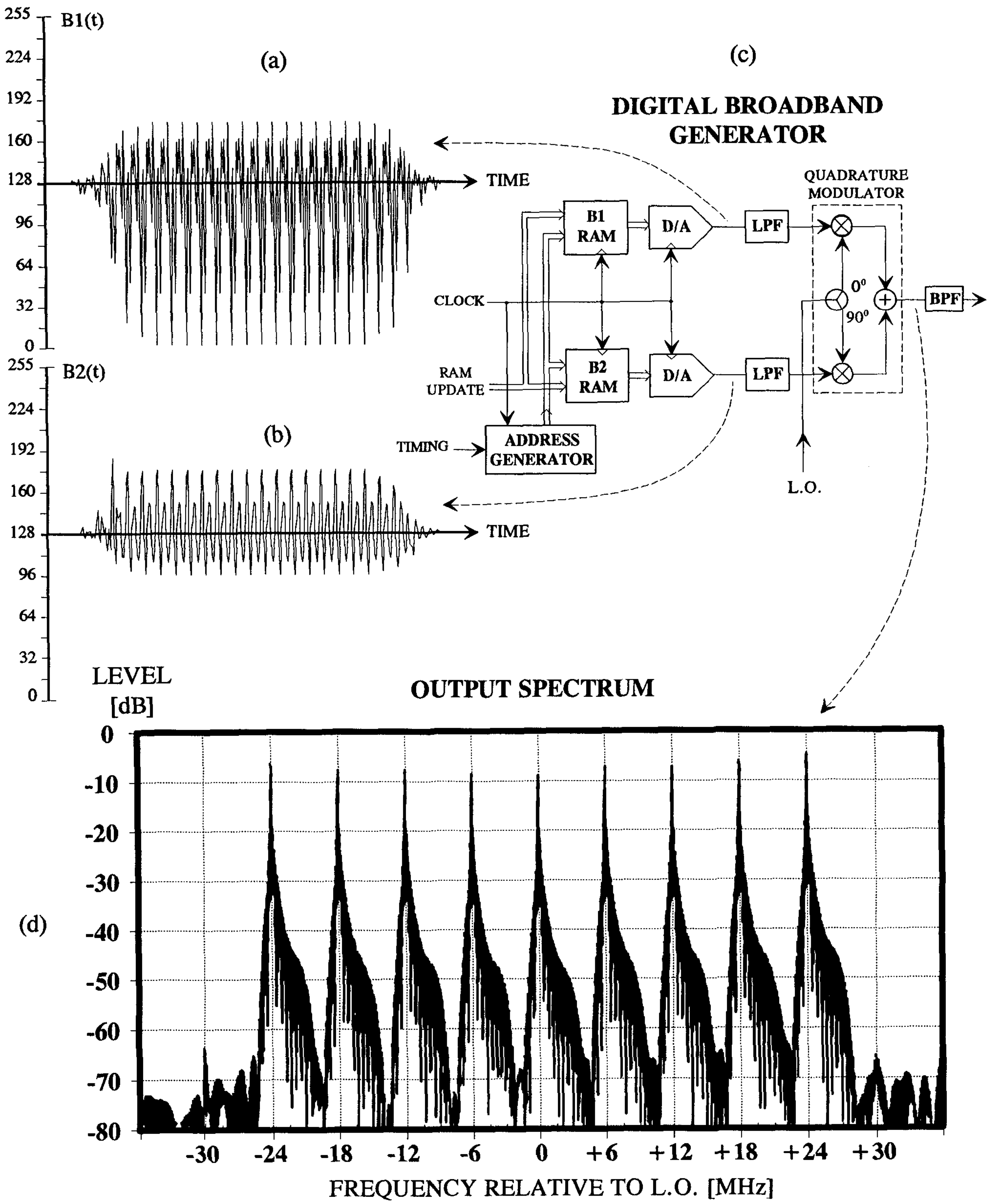

Figure 5. Example of a Digital Broadband Generator operation.

select a 72 MHz clock frequency, thereby allowing digital generation in each quadrature path, baseband signals with frequencies approaching the Nyquist rate of 36 MHz, while a 144 MHz clock will allow a baseband frequency approaching 72 MHz. Because the spectrum generated by the quadrature modulator contains both an upper sideband and a lower sideband, and because practical low pass filter designs limits the useful baseband frequency to less than the Nyquist rate, one can easily generate injection signals for a 9 channel group (for a 72 MHz clock) or 19 Channels (for a 144 MHz clock). Because high speed triple video DACs with clock rates exceeding 150 MHz are employed in a growing number of personal computer displays, their rapidly declining costs allow modular implementation of several Digital Broadband Generators. For example 4 such D/A packages provide 6 Digital Broadband Generators with processing capability for up to 114 channels.

Initially, note that for the generation of incrementally related CW output signals at RF, the required signals $B_1(t)$ and $B_2(t)$ in the DBG must be each a linear combination of sinusoids with frequencies that are integral multiples of 6 MHz. In this CW case, these signals are generally given by:

$$(2) \quad \begin{aligned} B_1(t) &= \sum_{k=0}^{k=N} x_k \cos(2\pi k\frac{t}{M}) + y_k \sin(2\pi k\frac{t}{M}) \\ B_2(t) &= \sum_{k=0}^{k=N} u_k \cos(2\pi k\frac{t}{M}) + v_k \sin(2\pi k\frac{t}{M}) \end{aligned}$$

where the Fourier coefficients x_k, y_k, u_k, and v_k determine the desired amplitudes and phases of the RF CW carriers. This is due to the linearity and superposition principle of the quadrature modulation process. Hence, during period of times within which a steady amplitude and phase is generated, $B_1(t)$ and $B_2(t)$ are periodic waveforms with a 6 MHz periodicity as shown in the center portions of the time waveforms in Figure 5(a) and (b). This allows for a discrete time representation of these periodic signal with M samples (wherein $M = f_{clock}/6$ MHz). Therefore, the RAM address generator need only scan repetitively through M RAM addresses denoted by a discrete time index t in order to generate an arbitrary CW frequency grid at the DBG's output.

At the RF domain, each generated CW carrier at the output can be resolved into two quadrature components I and Q. The index k shall be used here to designate the baseband order of the 6 MHz harmonic corresponding to the separation of the specific carrier in question from the L.O. center frequency carrier on which the group local oscillator is locked. Thus, for any given baseband frequency index k (up to a value of N), there are two RF sideband components (phasors) that can be generated, corresponding to two distinct channels. The situation is illustrated schematically in a phasor diagram of Figure 6.

With an arbitrary RF phase reference coordinate system in Figure 6, I_k^+ and Q_k^+ correspond respectively to the in-phase and quadrature components of the upper sideband RF injection signals of frequency index k, while I_k^- and Q_k^- correspond to those of the lower sideband of frequency index k. Accordingly, for each baseband frequency index k, the baseband Fourier coefficients of Equation (2) are related to the RF phasor components by:

$$(3) \quad \begin{bmatrix} x_k \\ y_k \\ u_k \\ v_k \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 1 \\ 1 & 0 & -1 & 0 \\ 1 & 0 & 1 & 0 \\ 0 & -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_k^- \\ Q_k^- \\ I_k^+ \\ Q_k^+ \end{bmatrix}$$

In this manner, an arbitrary set of RF phasors can be generated by the DBG with only M samples in each RAM. As will be shown below, the generation of arbitrary set of VSB modulated phasors will require a slightly larger memory array: It is based on employing the method of Equation (1) for each phasor and combining it with Equations (2) and (3). That is, given the phasors' desired quadrature components I_k^+, Q_k^+, I_k^- and Q_k^- represented by a 4 entry column vector, and given the desired VSB shaping for each carrier characterized by the envelope components $C(t)$ and $S(t)$, the baseband signals $B_1(t)$ and $B_2(t)$ represented by a 2 entry column vector for each sample time t is given by vector Equation (4).

The I_k^+, Q_k^+, I_k^- and Q_k^- phasor values' representation within the DSP for the computation of Equation (4) will be set in accordance with the desired processing action on each channel, based on the subscriber's subscription status, as addressed to the subscriber device and received in the data stream of the VBI. In the case $k=0$ both sidebands degenerate into two halves of a single center carrier, for which Equation (4) reduces to an equation for 2 entry vectors and a 2x2 matrix. The parameter t is the discrete time variable assuming integer values corresponding to a sequential RAM address value having three sectors in the RAMs: Two non-periodic sectors corresponding to the VSB "rise" and "fall" transition waveforms for all generated carriers, and a pair of M sample sectors holding only one cycle of the periodic CW portion of the generated carriers. In the example of Figure 5(a) and (b), the transition intervals

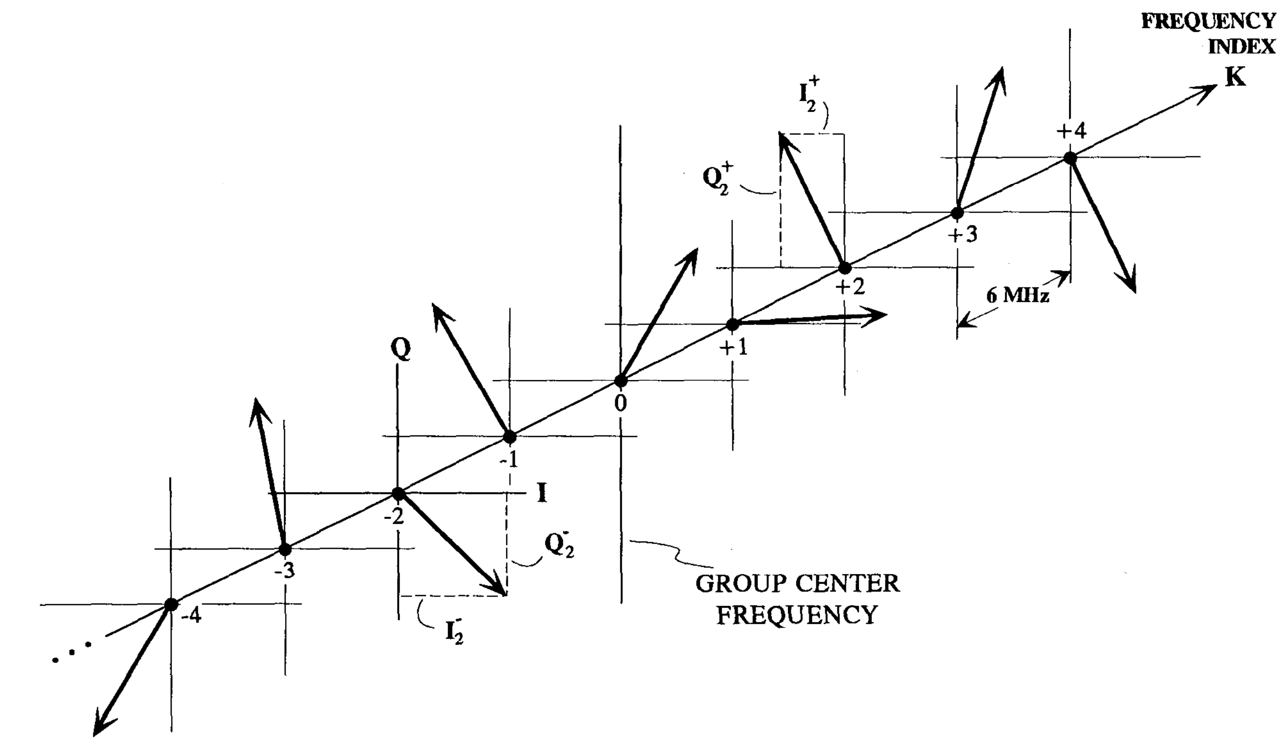

Figure 6. Multichannel RF Phasor Diagram

from 0 to the CW steady state each correspond to a record length of 60 sample bytes assuming 72 MHz sampling rate, while the steady state periodic sector contains only 12 samples bytes. Figure 5(d) depicts the resulting frequency power spectrum at the output of the DBG if all 9 VSB channels are generated. As can be seen, one can achieve an acceptable VSB spectral shaping about the picture carrier with this relatively short sample sequence. Of course, any other selection of a subset of these nine signals can be made and inserted in the DSP calculation in accordance with Equation (4).

$$\begin{bmatrix}B_1(t)\\B_2(t)\end{bmatrix} = \sum_{k=0}^{k=N} \begin{bmatrix} \cos(2\pi k \frac{t}{M}) & \sin(2\pi k\frac{t}{M}) & 0 & 0 \\ 0 & 0 & \cos(2\pi k \frac{t}{M}) & \sin(2\pi k \frac{t}{M})\end{bmatrix} \begin{bmatrix}0&1&0&1\\1&0&-1&0\\1&0&1&0\\0&-1&0&1\end{bmatrix}\begin{bmatrix}C(t)&S(t)&0&0\\-S(t)&C(t)&0&0\\0&0&C(t)&S(t)\\0&0&-S(t)&C(t)\end{bmatrix}\begin{bmatrix}I_k^-\\Q_k^-\\I_k^+\\Q_k^+\end{bmatrix} \quad (4)$$

Another feature provided by the digital signal processing capability is the ability to select the functions *C(t)* and *S(t)* based on a precise computation of spectral nulls provided around the audio subcarrier frequencies, thereby ensuring that the broadband injected VSB signals do not interfere with the audio portion of the signals. In general, these stringent attenuation specifications are not required on frequencies which only affect the *video portion* of adjacent channels. Here, much more relaxed attenuation specifications are needed since the resultant adjacent channel crosstalk effects are video frame synchronous for a contiguous group of channels and thus introduce only small coherent and synchronous transient modifications at the edges of the HBI. These HBI edge "mini-transients" are far more benign in comparison to the artifacts introduced by any set-top descramblers' sync restoration circuit. Special mathematical design tools were developed at MCSI to optimize the functions *C(t)* and *S(t)* so that a proper balance exists between the base requirement of fast baseband equivalent video transition on the desired channel, and adequate adjacent channel spectral overlap rejection, while maintaining the shortest possible memory array for the VSB transitions, so as to minimize the number of DSP calculation cycles per frame.

By proper calculations of phasor increments, essentially in accordance with Equation (4), and based on the required generated values of I_k^+, Q_k^+, I_k^- and Q_k^-, the Digital Signal Processor shown in Figure 3 evaluates the required samples $B_1(t)$ and $B_2(t)$, and stores them in the DBG RAMs via the RAM Update data bus. The numerical values of the trigonometric functions and the predesigned envelopes $C(t)$ and $S(t)$ are stored in a ROM inside the DSP, wherein the usual ROM space savings are realized by taking advantage of the symmetry and sample degeneracy features of these functions. The calculation and phasor tracking of Equation (4) is performed for all processed channels at video frame rate. Thus, the system maintains its injection and analysis waveforms in a fixed phase and amplitude relationship to the incoming signals by closing a phasor control loop for each processed channel. This is done by successive analysis and corrections, thereby tracking any slow relative phase or amplitude drifts in the CATV distribution system or any of the components in the subscriber unit such as power splitter, directional coupler, the broadband amplifier or any of the components within the broadband generator which may affect the relative injected phasors as compared to the incoming channel phasors. This feedback method lends particular robustness to the Broadband Descrambler device which may be subject to extreme environmental conditions.

As explained above, the phasor tracking process is performed by use of the Analyzer signal generated by the DBG for phasor measurement, whereby the injection and Analyzer functions are time-shared in accordance with a predetermined video timing schedule. It is possible to time-share and perform measurements during time periods in which no descrambling or RF injection is required. These measurement or phasor analysis periods would preferably be within the VBI, or during time intervals in which no active video information is present, therefore providing a fixed received reference for the picture carrier amplitude and phase.

Figure 7 shows the RAM address timing for the DBG during an HBI injection pulse and during a portion of the VBI, wherein two quadrature Analyzer signals are generated. One of these RAM records for the Analyzer may also be used for synchronous detection of data in the VBI. The RAM contents required in order to receive a selected channel is the same as that which is required to generate a single carrier, coherent with that channel's received carrier.

In order to perform the injection and analysis in coordination with the group video timing, a vertical frame reference data provides for vertical frame synchronization by the use of a sync/data detector, resetting the timing chain circuitry via the sync detect line. The address

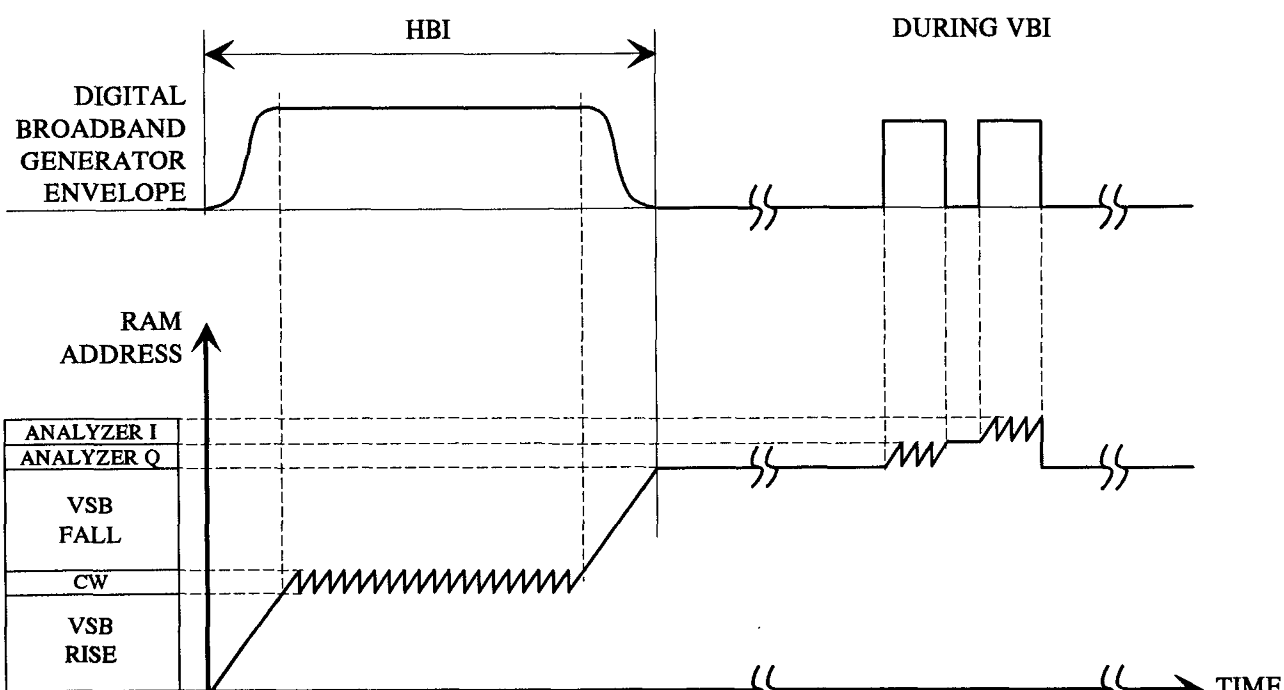

Figure 7. Digital Broadband Generator RAM Schedule

generator is provided with the proper reset and preload signals from the timing chain circuit so as to scan the proper RAM memory locations containing the appropriate data records for the synthesis of the injection signals and the analysis signals as required.

Enhanced Scrambling By Video Folding

It is worth noting that sync suppression descrambling only requires injection during the HBI. Therefore, the DBG can be used during the active video line to generate other fixed injection signals of levels randomly varying from frame to frame during the active video time so as to provide an additional security based on random "video folding". This new scrambling method can be implemented by effecting gated coherent injection at the headend using some fixed set of injection values governed by a cryptographic keystream control for individual channels. At the descrambler, opposite coherent injection signals governed by keystream control are injected simultaneously on authorized channels, thereby descrambling these channels based on precise phasor adjustment similar to that used for sync recovery. Because the injected signal at the headend can be in opposite phase, video inversion on only a sector of the screen may take place (Video Folding), further frustrating any existing "pirate" descramblers. Figure 8 shows the method of scrambling, wherein one of four predetermined levels in Figure 8(b) are randomly selected on a frame by frame basis. As can be seen in Figure 8(d) an unaided TV set will receive a baseband signal that is partly inverted in luminance and in chrominance, and RF phase reversals are likely to frustrate the intercarrier audio detection. Video inversion constitutes a special case of Video Folding, as it corresponds to a folding axis of 0 IRE.

It can be appreciated that while a Broadband Descrambling system can be rolled out over an extended period because of its compatibility with existing sync suppression systems, the Video Folding scrambling mode can only be used on channels for which all authorized subscribers have a Broadband Descrambler installed. However, it is possible to use Video Folding as means of local denial of otherwise clear signals. Since the random injection is confined only to the active video period, the method is highly secure because it is virtually impossible for the pirate to obtain an estimate or a guess absent the knowledge of the particular injection level being used in for each frame, since it is impossible to separate between changes in folding point and changes due to program material.

In this Video Folding operation mode, the DBG RAM records must be configured to provide VSB

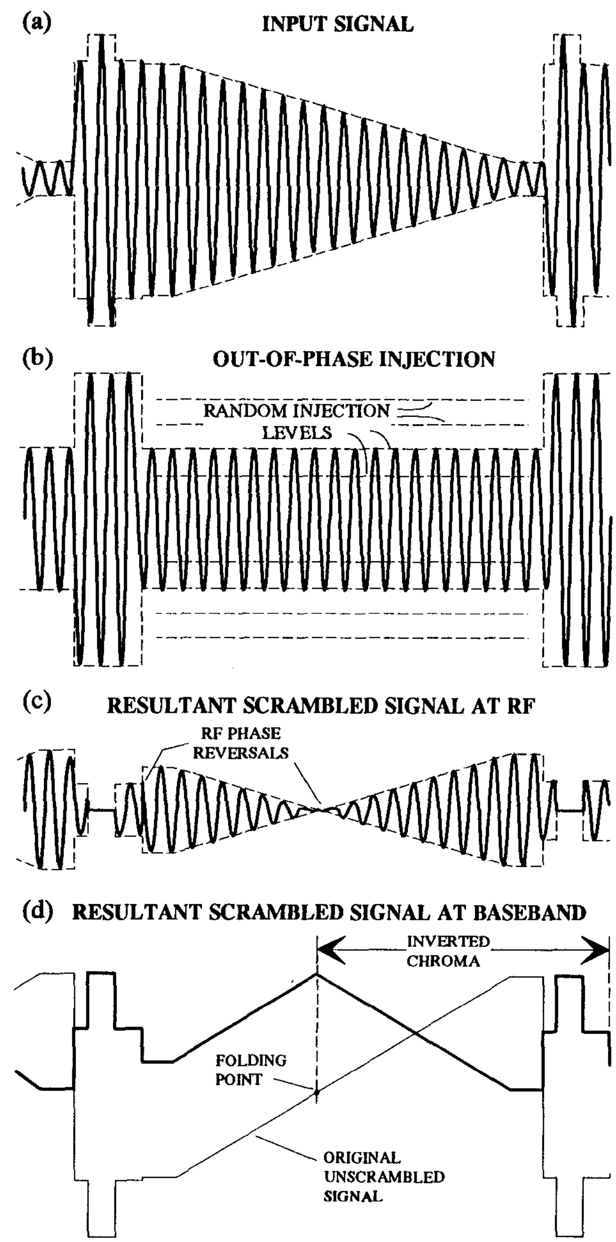

Figure 8. Random Video Folding or Inversion Scrambling

transitions from an HBI injection phasors to active video CW injection phasors on certain channels with different levels of injection. These transitions from one set of phasors to the next is effected by storing RAM samples corresponding to a superposition of values derived from an equation similar to Equation (4).

Descrambling of Dynamic RF Sync Suppression

Figure 1(c) shows a baseband representation of an RF sync suppression HBI. Figure 1(d) depicts the required coherent injection signal for descrambling. Due to the scrambler attenuation at RF, all signal components are in need of injection including a portion of the color burst. As can be seen, six RAM records are required for generation of the picture carrier portion of the injection signal as opposed to three in the baseband sync suppression case. Although it may be possible to generate the missing burst signal by VSB generation about the picture carrier, this approach is expensive in memory because of the poor congruence between the color subcarrier frequency and 6 MHz.

An alternative solution is based on the fact that all upper sideband color subcarriers in a frame synchronized video sources are also incrementally related at RF with 6 MHz spacing. Hence they can be generated and injected separately using a DBG local oscillator gate-locked on the RF component of the color burst of the center carrier channel. In a manner similar to the picture carrier tracking, all injected color burst phasors required are measured and tracked preferably during the VBI. Since all RAM records are recalculated by the DSP every video frame, injection matching the 6 - 10 dB suppression dynamics can be provided on a channel by channel basis. An additional group keystream informing the broadband descrambler at the beginning of each frame the suppression level for each channel must be added to an addressable control stream. Such control stream can be made secure through encryption.

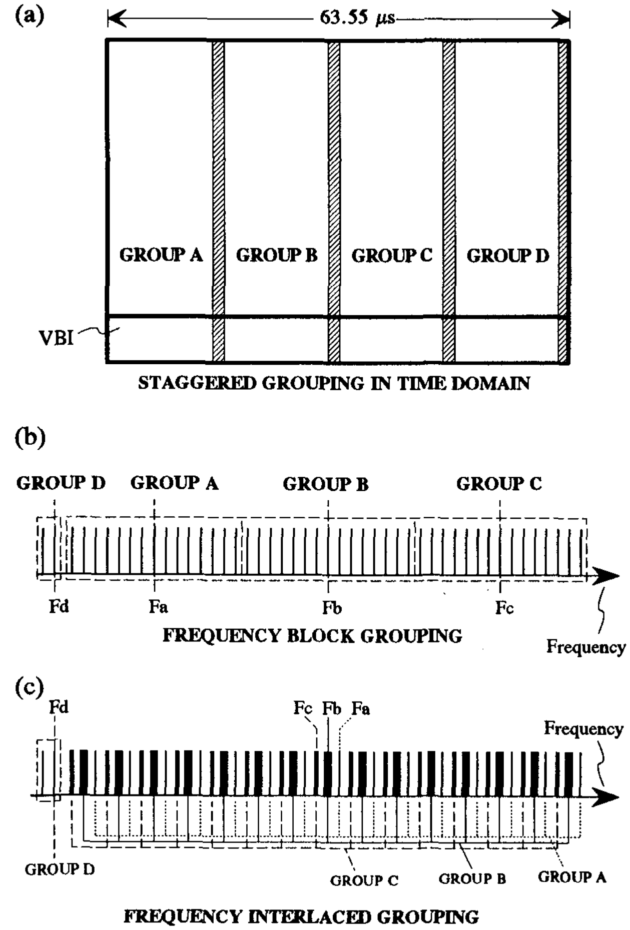

Figure 9. Video Frame Staggering for Time-Shared Utilization of a Digital Broadband Descrambler.

Use of Time-Shared DBG

In applications in which no processing is required in the active video period (sync suppression), it is desirable to be able to use the Broadband Generator in a time-sharing mode, whereupon several channel groups may be processed sequentially, thereby increasing the total number of channels processed by a single DBG by switching the frequency of the local oscillators feeding the DBG to the center frequency channels of each group. This operation mode is generally possible in this video application since the required processing (and injection) time per line is limited to the HBI, which duration is less than one forth of the total horizontal line time. Thus, at the headend, groups of channels are video synchronized in a staggered manner so that their HBI's do not overlap. This is shown schematically in Figure 9(a). Time intervals shown in gray provide a guard interval, during which no injection is required, for switching the center carrier local oscillators among the four channel groups A through D.

Two possible frequency arrangements for channel assignments for each group are shown in Figure 9(b) and (c) respectively. The first utilizes the frequency block grouping, requiring lower DAC speeds for the same number of channels per group. However, at the expense of faster DACs and RAMs, the frequency interlaced grouping of Figure 9(c) offers potential savings in filtering and frequency swing of a VCO which might be used for the switched local oscillator. In both configurations, the same Digital Broadband Generator performs the required processing for each channel in the four groups by coherent injection during the HBI of every channel. This operating mode requires 4 times more memory containing the required records for each group based on subscription.

IMPLEMENTATION AND OPERATIONAL ISSUES

Hardware Configurations

For the purpose of clarity, Figure 3 shows a single DBG operating on a fixed center frequency. In practice, however, it may be desirable to allow the flexibility for remotely configuring the center frequency of the DBG and perhaps provide several DBG's for processing a larger number of channels. Low cost application of "High Side" 900 MHz center frequency DBG's generating signal groups that can be down-converted to any contiguous channel groups in the CATV band are possible by the use of a "high-side" L band variable frequency synthesizer. Furthermore, using this "high-Side" conversion scheme, a single agile "high-side" Local Oscillator (VCO) can be used with a single time-shared DBG, resulting in spectral processing coverage for up to 4 groups in a manner described in Figure 9(b). Finally, future implementations of DBGs with large channel groups of as many as 60 channels per group can be anticipated with recent commercial availability of GaAs 14 bit D/A converters with sampling rate capability of up to 1 GHz.

Particularly noteworthy is the potential for low cost implementation of Broadband Descrambling in a Multiple Dwelling Unit (MDU) devices incorporating 4 or 8 subscriber ports. In this case, many subsystems such as power supplies, enclosure, DSP, VCO's and data reception can be shared among subscriber units resulting in a cost per subscriber that is significantly lower than that of using addressable set-top converters.

Typical Applications in Tiered and Pay Services

As explained above, the same subscriber processing platform including the DBG can simultaneously descramble some channels, while locally denying others by further scrambling using Sync Null or Random Video Folding as described above. A typical example might illustrate the economic and operational benefit of this approach:

Assume, for example, that today a cable system with 50,000 basic subscribers carries 30 basic channels in the clear and 10 scrambled channels for which addressable descramblers are required. Assume further, that there are 20,000 addressable subscribers in the system and the operator wishes to unbundle the 30 channel tier and offer a Statutory Basic tier of 13 clear channels and the other 17 satellite cable programming channels are to be configured as Expanded Basic. Assume further that only 1000 subscribers (2%) opt for the Statutory Basic without the Expanded Basic. If the operator elects to retier by scrambling all 17 satellite delivered channels, he must purchase addressable converters for 29,000 subscribers (roughly 38,000 set-tops including AO's) and convince his current non-addressable subscribers to accept set-top installations *before* the transition to scrambling. Alternatively, the operator may opt to supply the 1000 Statutory Basic subscribers with band reject traps. This solution suffers from truck roll costs, inflexibility and even outright impossibility of handling the broadcast (Must Carry) channels within the Statutory Basic tier while still effectively trapping all other 17 channels without excessive trap cascades and the resultant signal degradations.

In contrast, compatible Broadband Descramblers can be supplied to the 1000 subscribers of the Statutory Basic tier and they can be addressed for denial of all 17 Expanded Basic channels, while providing these subscribers with full access to scrambled channels on an addressable basis. This can be done without Buy-Through requirements and without the need for addressable set-top devices. As the system employs such Broadband Descramblers, set-top descramblers can be replaced by Broadband Descramblers over time, and an economically graceful migration to full Broadband Descrambling for analog signals can be effected with allowance for digital services pass-through to the home. Hence, the use of Broadband Descrambling can provide the lowest cost and most subscriber friendly solution for dealing with the post Cable re-regulation tiered access control environment.

Installation and Powering

The DBD can be installed at any point, from the pole or pedestal to the side of the house or any other point of entry to the subscriber premises. Also possible, are indoor locations such as the basement, garage, attic or even internal "set-back" devices behind the TV set. The power requirement of Broadband Descramblers may be in the range of 3-5 Watts per subscriber, and therefore a subscriber premises wall mount power supply can feed the device via the coax line. In more external installations, CATV plant powering may also prove to be an attractive powering mode.

Security

Although during the phasing-in period of a compatible migration into cable systems employing sync suppression scrambling the operator will be precluded from employing the new enhanced DBD security features as described above, immediately upon deployment of DBD, other security measures will be available. These measures are local denial on otherwise scrambled channels for subscribers in known pockets of piracy. This will ensure that pirate boxes that are able to illegally descramble existing formats are rendered useless due to the enhanced denial processing that further scrambles the channels to which that subscriber port is not entitled.

Some in the cable industry have expressed concern about the reduction of security in cases where groups of channels are made frame synchronous. Their concern is that the availability of sync timing for one channel supplies the pirate with sync information for other channels. Implicit in this concern, is the assumption that pirate decoders could be constructed to tune to one channel and supply a sync recovery signal for another. This folklore concept may be held by those who are apparently unaware of programmer's operation practices due to which many channels on every cable system are already frame synchronized, and have been so genlocked *for years on every cable system.* The satellite uplink facilities in Hauppauge, New York transmit over a dozen of the most valuable cable channels in video frame synchrony due to "House Genlock" Sync. For example, the following Viacom channels are all frame synchronized to one sync source: *Showtime, Showtime 2, The Movie Channel, Flix, Viewer's Choice 1, Viewer's Choice 2, MTV, VH-1* and *Nickelodeon.* Similarly, the Time-Warner uplink in Hauppauge transmits the following signals in frame synchrony: *HBO, HBO-2, HBO-3, Cinemax, Cinemax 2, Comedy Central* and *USA Network.* Every cable system carrying these channels is doing so in frame synchrony for many years. Yet, after all that time, no dual receiver pirate decoders obtaining sync from one channel to illegally descramble another have been discovered. The fact is that none of these hypothetical pirate decoders are likely to ever materialize, presently or upon the introduction of DBD, because it is much easier for the pirates to employ simple means for illegally modifying existing addressable descramblers to permanently enable them to descramble every premium channel available on the cable system.

CONCLUSION

The specific ability of low cost digital generation of simultaneous multichannel VSB signals with essentially arbitrary amplitude and phase in video synchrony and RF coherence with incoming signals, allows one to provide simultaneous processing of a large group of television channels in a Broadband Descrambler for the purposes of access control. Because the Broadband Descrambler employs an additive broadband processing, it will pass into the home all other unprocessed channels including digital compression signals, thereby allowing compatibility with future digital transmission decoders that are not deployed at the subscriber premises' point of entry.

A Broadband Descrambler can be made compatible with most existing sync suppression scrambling formats and therefore can be installed in a gradual and economically graceful manner. Because Broadband Descramblers can simultaneously descramble incoming scrambled channels while at the same time denying other clear channels, it will constitute the lowest cost method to provide tiering without Buy-Through requirements while providing full compatibility between cable systems and subscriber consumer electronics equipment.

ACKNOWLEDGMENT

The author is indebted to Max Ashkenasi, whose assistance and critical review made the preparation of this manuscript possible.

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