W. T. Frost*
C. T. Masters†

A New Technique for Wide-Band Video Recording

Abstract: An efficient means for distributing the information contained in a wide-band analog signal over two limited bandwidth channels is provided by using frequency modulation and "zero-crossing counting." The new technique should accommodate at least twice the bandwidth that can be recorded or transmitted by the usual FM methods. Experimental results with a two-channel magnetic tape system confirm this expectation.

Introduction

In the general effort toward improved image storage and retrieval, video recording is becoming practical for more and more kinds of information. Printed documents, binary-coded data, still photographs, motion pictures—forms heretofore too diverse for common handling—can now be converted and combined within a system for storage, display, and output in other forms. These new possibilities introduce new bandwidth requirements as the level of image detail increases and as systems are designed with many output devices operating simultaneously from a shared pool of information.

In systems featuring television-like devices, for example, a stable and continuous display is essential. To make each display as satisfactory as if it were the only one in operation, a video buffer can be introduced—a loop of magnetic tape or a magnetic disk, for instance, with one closed recording track for each display station to be served. In such a case, the signals for each video frame are recorded using frequency modulation techniques; then the track is read repetitively to supply a steady image at the display unit.

This method can handle limited bandwidths without difficulty but refinements are needed to accommodate higher resolution. A bandwidth of at least 10 MHz is needed if a system is to store or reproduce letter-size typewritten documents, and more detailed images may call for as much as 30 or 40 MHz.

To provide for future needs of this kind, magnetic recording of video signals can be improved in two general ways. The first approach retains the present single-channel recording configuration, and concentrates on improving magnetic head materials, recording media, modulation techniques, and mechanical components. Such improvements are needed to assure reliable operation at the increased velocities between head and recording medium, which can extend the usable bandwidth. If this course is pursued, video bandwidths in excess of 15 MHz may be attainable.

Alternatively, the video bandwidth capability can be increased by partitioning the signal and distributing it over a number of recording channels. Techniques for doing this may be based on conventional sampling and time or frequency partitioning of the signal. The purpose of this paper is to describe a new technique[1] involving the counting and distribution over 2 channels of the zero crossings of a waveform generated by the use of frequency modulation. In this way, the combined bandwidth capability will be very nearly double the single-channel capability.

Zero-crossing counting and distribution

- *Distortion-free transmission*

The expression for a frequency modulated signal is given by[2]

$$f(t) = A_c \sin(\omega_c t + \psi(t)) , \tag{1}$$

where

$$\psi(t) = m_f \int_0^t g(\mathrm{T}) d\mathrm{T} ,$$

A_c is the amplitude of the unmodulated carrier of angular frequency ω_c and m_f is the modulation index of the modulating signal $g(t)$.

From (1), $f(t) = 0$ at times, t satisfying the expression

$$\omega_c t + \psi(t) = n\pi \qquad (n = 0, 1, 2, \cdots) .$$

* Located at the Advanced Systems Development Division laboratory, Los Gatos, California.
† Components Sales, California Inc., Palo Alto, Calif.

If we consider the even zero crossings (of order 0, 2, 4, 6, etc.),

$$\omega_c t + \psi(t) = 2n\pi ,$$

and a waveform establishing these zero crossings can be described by the expression

$$f_1(t) = \sqrt{2A_c} \sin \tfrac{1}{2}(\omega_c t + \psi(t)) . \quad (2)$$

Similarly, the odd zero crossings (of order 1, 3, 5, etc). occur at times given by

$$\omega_c t + \psi(t) = (2n + 1)\pi ,$$

resulting in a describing waveform given by

$$f_2(t) = \sqrt{2A_c} \cos \tfrac{1}{2}(\omega_c t + \psi(t)) . \quad (3)$$

From expressions (1), (2) and (3) it can be seen that

$$f(t) = f_1(t) \times f_2(t) . \quad (4)$$

This means that a frequency modulated signal can be partitioned into two quadrature FM signals and can be restored by obtaining the product of the two signals.

Consider now the case of a sinusoidal modulating signal $g(t) = \cos \omega_m t$, Eq. (1) becomes

$$f(t) = A_c \sin (\omega_c t + \beta \sin \omega_m t) , \quad (5)$$

where

$$\beta = m_f/\omega_m .$$

When

$$\beta \ll 1 ,$$

$$f(t) = A_c(\sin \omega_c t + (\beta/2) \sin (\omega_c + \omega_m)t - (\beta/2) \sin (\omega_c - \omega_m)t) . \quad (6)$$

From (6), the expression for a vestigial-sideband, small deviation ratio FM signal is

$$f(t) = A_c(\sin \omega_c t - (\beta/2) \sin (\omega_c - \omega_m)t) , \quad (7)$$

which represents a carrier and a single lower sideband. This property of FM is used in video recording on magnetic media where higher modulating frequencies (for example, 4 MHz) can frequency modulate a 5 MHz carrier to give a single sideband at 1 MHz.

Equation (6) can be partitioned into

$$f_1(t) = \sqrt{2A_c}\left(\sin \frac{\omega_c t}{2} - \left(\frac{\beta}{4}\right) \sin \left(\frac{\omega_c}{2} - \omega_m\right)t\right), \quad (8)$$

and

$$f_2(t) = \sqrt{2A_c}\left(\cos \frac{\omega_c t}{2} - \left(\frac{\beta}{4}\right) \cos \left(\frac{\omega_c}{2} - \omega_m\right)t\right), \quad (9)$$

when only the lower sidebands are considered.

From (8) and (9), it can be shown that

$$f_1(t) \times f_2(t) = A_c\left(\sin \omega_c t - \left(\frac{\beta}{2}\right) \sin (\omega_c - \omega_m)t + \left(\frac{\beta^2}{16}\right) \sin (\omega_c - 2\omega_m)t\right). \quad (10)$$

Ignoring the $\beta^2/16$ term, which is insignificant, it can be seen from Eqs. (10) and (7) that

$$f(t) = f_1(t) \times f_2(t) .$$

This means that a small-deviation-ratio FM signal can be partitioned into two quadrature vestigial-sideband FM signals and recovered by obtaining the product of the two signals.

As an example, a signal of frequency 10 MHz can frequency modulate a carrier of 12 MHz with $\beta \ll 1$. The 2 vestigial-sideband partitioned signals would have folded sidebands at

$$\frac{1}{2}\pi\left(\frac{\omega_c}{2} - \omega_m\right) = 4 \text{ MHz} .$$

The two signals could be multiplied by a product modulator and the resultant demodulated to regain the 10 MHz signal.

- *Effects of distortion*

In the foregoing simple analysis it has been assumed that the timing of the zero crossings is accurately preserved. Circuit elements such as amplifiers, triggers and limiters in combination with particular demodulator actions can cause errors in the accuracy of the transmitted zero crossings through distortion occuring in the amplitude and phase of the FM signals. These effects, however, are considered of secondary importance compared with the possible distortion arising from differential delays in the recording channels. Each recording channel will have a characteristic delay, which may contain a fixed component and a dynamic component. The former may be due to a fixed delay in the electronic circuits or to poor alignment of the read heads; the latter, to mechanical errors in the recording system. In a tape system, for example, such errors may be caused by tape skew and differential flutter.

If $\phi_1(t)$ and $\phi_2(t)$ are phase-modulating functions resulting from differential delays in the recording channels 1 and 2 respectively, then from Eqs. (2) and (3), the recording channel outputs are

$$f_1(t) = \sin \tfrac{1}{2}(\omega_c t + \psi(t) + \phi_1(t)) \quad (11)$$

and

$$f_2(t) = \cos \tfrac{1}{2}(\omega_c t + \psi(t) + \phi_2(t)) . \quad (12)$$

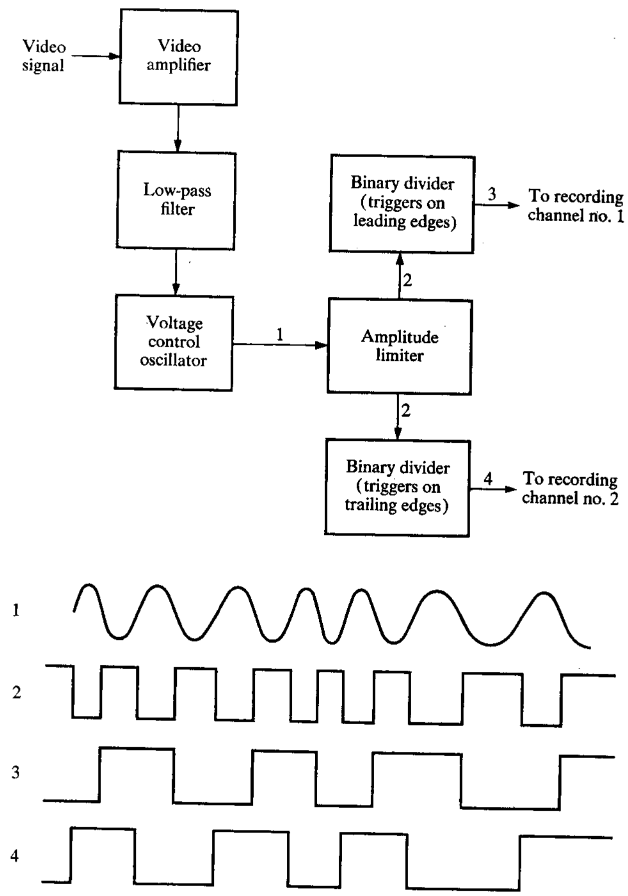


Figure 1 Zero-crossover counting and distribution process.

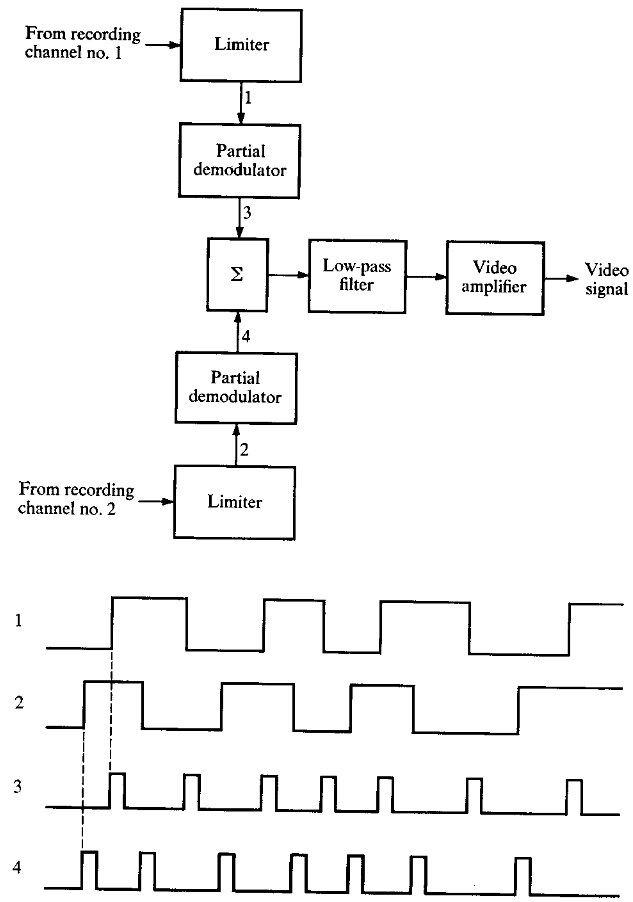


Figure 2 Multiplexing process.

If these signals are multiplied as in a balanced modulator, the output can be shown to be

$$f_1(t) \times f_2(t) = \tfrac{1}{2} \sin\left(\omega_c t + \psi(t) + \frac{\phi_1(t) + \phi_2(t)}{2}\right) + \tfrac{1}{2} \sin\left(\frac{\phi_1(t) - \phi_2(t)}{2}\right).$$

This result shows that if two channels are combined by the use of a product demodulator, the resultant signal (except for the second term) will be the same as that which would have resulted from a single double-bandwidth recording channel with a flutter phase-modulating function equal to $\frac{1}{2}[\phi_1(t) + \phi_2(t)]$. The second term involves the difference between the individual phase modulating functions due to flutter, which is just the differential delay due to flutter. Expressed in terms of the dynamic delay, $\tau_1(t)$ and $\tau_2(t)$ of the two channels, the second term is

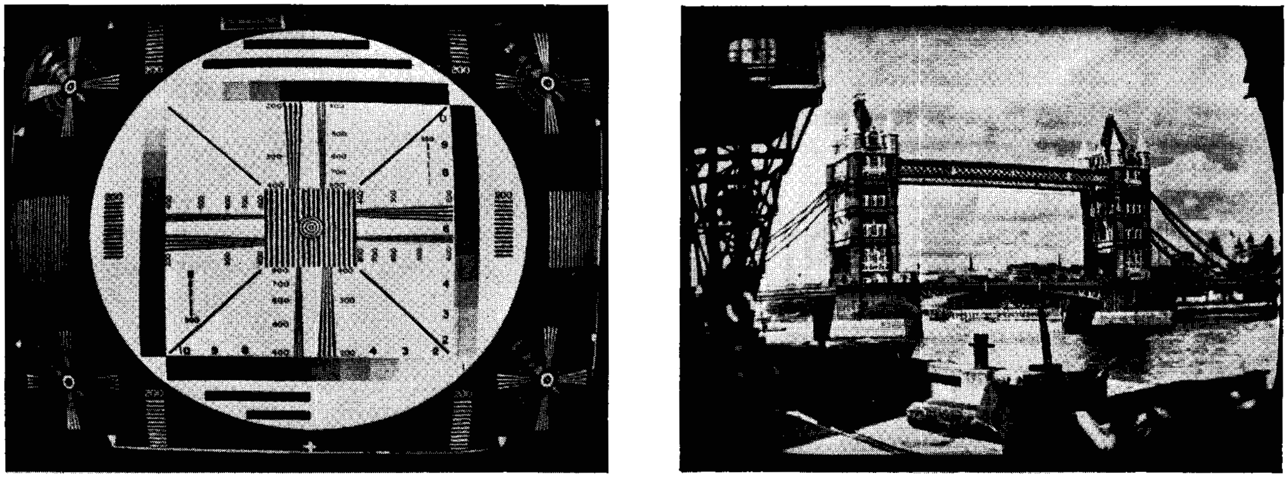
$$\tfrac{1}{2} \sin\left[\omega_c \frac{(\tau_1 - \tau_2)}{2}\right] = \tfrac{1}{2} \sin \frac{\omega_c}{2} \Delta\tau(t) .$$

Since $\Delta\tau(t)$ results from flutter, its spectrum will be limited to frequencies below the first order lower sideband of the FM signal and therefore may be removed by a simple high-pass filter.

Differences in amplitude as a function of frequency between the channels must be minimized so that significant distortion terms do not arise from the product of Eqs. (8) and (9) containing differing carrier and sideband coefficients. Both magnetic recording channels do not respond to dc. From Eqs. (8) and (9) this means that a frequency of 6 MHz modulating a carrier of 12 MHz produces a single sideband occurring at zero frequency which will not be recovered. Hence, when the channel outputs are recombined and demodulated, this effect shows up as a notch centered about a video frequency of 6 MHz. Provided that the notch is narrow (less than 100 KHz is entirely feasible), it will have little effect at a part of the spectrum where the energy content is not high.

Experimental system and results

Figure 1 illustrates zero-crossover counting and distribution into two recording channels. The video signal fre-



(a) (b)

Figure 3 Experimental results. (a) Resolution chart. (b) Specimen photograph.

quency modulates a carrier in the conventional manner. The resultant FM signal is then amplitude-limited in such a way that the output is a series of rectangular pulses whose zero-crossover points correspond in time to those of the FM signal. The amplitude-limited signal is then simultaneously applied to two binary dividers, one designed to change state when a positive transition is detected, the other to change on negative transitions. That is, successive flip-flop output signals carry the information contained in alternate zero-crossover points of the original FM signal. The outputs of the binary divider stages are then applied to recording amplifiers and recorded simultaneously on adjacent tracks of the magnetic recording system.

The two recorded signals are reproduced by separate playback heads, and in order to obtain experimental results expediently, commercially available demodulators are used in the configuration shown in Fig. 2. Such equipment is used in television recorders, where it limits the amplified reproduced signal for partial demodulation. The partial demodulation results in a positive pulse output for each transition (positive or negative) of the limiter output signals. The resultant pulse train is put through a low-pass filter to provide the demodulated signal.

In the multiplexing system shown in Fig. 2, the output signals of the two partial demodulators are first added, then low-pass filtered. The output is amplified to reproduce the original modulating signal.

An experimental model of the system shown in Figs. 1 and 2 has been constructed in the laboratory to confirm its feasibility. The recording system employed a 50-inch loop of one-inch wide tape, moving at a velocity of 1500 inches per second. The video signal, 525-line, interlaced 30 frames per second, had a bandwidth of 10 MHz. Other significant parameters were: source carrier frequency 12 MHz and deviation $\pm$ 0.7 MHz; divided carrier frequency 6 MHz and deviation $\pm$ 0.35 MHz.

In the tests carried out, pictures of standard test charts, typewritten pages, and photographs were recorded and played back. The test charts indicated a horizontal resolution of about 800 lines. A demonstration of the system amplitude and phase response is shown in Fig. 3.

Conclusions

The wide-band recording technique described can increase bandwidth capabilities by means of zero-crossing counting of a frequency modulated waveform and distributing signals over two channels. The technique has been found feasible in a magnetic recording system to buffer and display high-resolution images. The same method can be extended to include long-term storage of video and other information contained in waveform zero crossings.

The process is admirably suited to non-linear magnetic recording channels providing care is taken to maintain sufficient precision in the timing of the waveform zero crossings. This involves matching the two channel responses and minimizing time displacement errors between the two recorded tracks.

A simple but by no means exhaustive analysis has been presented to describe the process and to consider some distorting effects. Experimental results show the feasibility of the process. Further analysis and experimental work is needed to establish quantitatively the amplitude, phase and transient response and tolerable distortion limits using various demodulating techniques. When used with optimized magnetic channels, a video bandwidth exceeding 20 MHz can be expected.

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