Encoding of Telemetry Data in a Standard Video Channel

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Summary. Various methods for compressing of a television image to fit a channel of reduced bandwidth are available; most are difficult and/or expensive to use, and many degrade the resulting picture appreciably. This paper describes an alternative method of placing the signals which accompany the picture within the passband of a picture, and separating them again at the receiving end with minimum crosstalk and picture degradation.

A standard television picture occupies a passband of about 4.2 MHz, and requires a signal-to-noise ratio of about 40-50 dB for quality transmission. While wider in bandwidth than a normal telemetry signal, the television signal can nevertheless be handled with commercially available equipment made for this purpose. However, a second transmitter is often required to handle the telemetry data which accompanies the picture, thus increasing the size and power drain of the system appreciably. Since a television transmitter is of necessity a less efficient user of spectrum space, various methods have been used to compress the picture bandwidth while still providing an acceptable (although possibly degraded) picture. This requires either a decoder at the receiving end to permit the picture to be displayed on a standard monitor, or a nonstandard monitor. Such signals also present problems in recording, due mainly to the encoded signal's critical requirements for phase coherence, and will not (unless decoded) satisfactorily record on standard videotape recorders. If telemetry signals are added as subcarriers above the video signal, the frequencies used greatly increase the high-frequency content of the signal to be transmitted, requiring that the injection of the video signal be reduced to accomodate the subcarriers. The resulting subcarriers when recovered at the ground station must be downconverted to frequencies low enough to record on standard IRIG instrumentation recorders, or discriminated as they are received. Combining the compressed video with subcarriers of lower frequency helps, but generally not much—the subcarriers are still of too high frequency to conveniently record directly. However, since there are frequencies within the video passband where energy is unlikely to occur, and since the absence of these frequencies does little to the picture, it is possible to actually add data signals without increasing the bandwidth of the video signal. The resulting composite signal can then be handled as a video signal for recording and distribution.

A television picture does not use the spectrum it occupies very well. Since each television "frame" is much like the one transmitted before or after it, and since each individual line in a picture looks a lot like the one above or below, and abrupt changes in brightness seldom occur in either space or time dimensions, a great deal of redundancy is obviously present. Even when objects in a scene move, the time-sampling process that produces what the eye perceives as continuous motion produces enough pictures that the frame-to-frame changes are minor.

Part of this redundancy causes the frequencies present in the spectrum of the picture to not be evenly distributed in the range of DC to 4.2 MHz, but rather to be grouped in the vicinity of harmonics of the vertical and horizontal sweep rates. The vertical sweep rate in a standard black-and-white picture is 60 Hz, so those harmonics are too close together to put much between them, but the horizontal rate is 15,750 Hz, far enough apart to consider if the distribution about each harmonic is narrow.

The 15,750 Hz harmonics are due to the line-to-line similarity of the information content of the picture. Since no two lines are identical except on the most trivial pictures, not all the energy is contained at exactly these harmonics, but because of vertical and time redundancies, most of the energy will be at or near harmonics of $15{,}750 \pm 30N$, where N is an integer. Total frequency content of an average picture falls off exponentially; energy about each harmonic of the horizontal frequency is distributed at harmonics of the field frequency in a Gaussian envelope; and distribution about each harmonic of the field frequency is also Gaussian. These characteristics are shown in Figures One and Two. On most pictures, the even multiples of 30 Hz predominate due to the interlaced nature of adjacent vertical sweeps.

If a bandstop filter were inserted in the video line between a source and a monitor, tuned to one of the spaces between horizontal harmonics, the resulting picture degradation would be slight if observable at all. Even passing the picture through a comb filter which removes the energy between each harmonic would not have a significant effect other than to remove half the random noise—in fact, that is the nature of devices which are used to enhance existing signals. The actual degradation that such filtering introduces is a blurring of diagonal lines and of moving objects, both of which are not objectionable to the viewer since moving objects and diagonal lines appear less distinct than stationary objects and vertical or horizontal lines due to the nature of the processing in the brain. From this we conclude that removing those spectral components in the areas in which we wish to place subcarriers will not degrade the picture substantially. Such filtering might be required to prevent random components of the picture from occupying the same spectral position as the injected subcarrier.

If an unmodulated signal of frequency N + 1/2 times the horizontal rate is added to an existing picture and displayed, the effect on the picture will be considerably less than that which would be caused by injection of a carrier of random frequency. This is because the added carrier is rejected spatially and temporally by the eye, especially if the original picture contains significant amounts of detail. In any single vertical sweep of the picture, any point on the screen made lighter by the presence of the carrier will be surrounded by areas made darker. The next time any line is scanned where some point was made lighter, that point will be made darker.

Tolerance of the eye to the injected carrier drops rapidly when modulation is added to the carrier. The carrier becomes most obvious when sidebands of the signal fall on the harmonics of the horizontal frequency. This places an upper limit on the frequencies that may be used, but experiments have shown that 5 KHz bandwidth (using AM or DSB) was not unreasonable,

By prefiltering the video data, and filtering the carrier from the video prior to display, essentially complete (greater than 40 dB) separation can be obtained between the video and data carriers.

Color television signals introduce some additional problems, The color signal is a double-sideband subcarrier with center frequency between the 227th and 228th harmonics of the horizontal frequency. Since the color difference is in itself a standard television picture in terms of repetition rate, all the harmonics of the color signal fall between harmonics of the black-and-white signal. The color signal, when transmitted with full bandwidth, extends upwards from 2 MHz on the composite signal, although a normal color monitor detects only that portion of the color signal in the area above 3 MHz due to the limited bandwidth of the receiver's color decoding circuits. If the area occupied by the color signal is not used for data subcarriers, the area between 1.5 and 2 MHz is still available—enough space for 31 carriers, if all were used.

In cases where a maximum system is not required—that is, a little picture degradation can be accepted, and slight picture interference with the data isn't critical, a system can be produced without, prefiltering of the picture and/or without filtering the carrier from the displayed picture. Experiments conducted at NWC with black-and-white and with color signals have demonstrated the practicality of using carriers with levels 20 dB below peak-to-peak picture level producing usable tone-encoded data and using data consisting of on-off functions. The carrier is least apparent when the signal modulating it contains multiple or random frequencies and when the picture contains most detail, but the picture was not unviewable even in the worst cases. Videotape recordings of the combined signal had introduced on them a dropout at a 60 Hz rate, due to the short period of time in which the head does not contact the tape; severity and duration of the dropout depends on the type of machine used, and certain machines do not produce this effect at all. The tape recorder used (an IVC one-inch helical-scanning machine) had the capability of stopping on a single field. When the stopframe mode was activated, the frequencies shifted slightly, but the carrier could still be recovered by retuning of the detector. No carrier shift occurred when a disc recorder was used. Carrier in all tests was detected by a Hallicrafters S-38E shortwave radio receiver with 5 KHz output bandwidth, but a phase-lock oscillator controlled by the horizontal frequency of the video can be used which can follow frequency drift and be set to the desired frequency by digital control. Phase-locking for generation of the carriers was an absolute necessity to prevent the pattern on the monitor from becoming objectionable as the carrier and/or horizontal frequency drifted.

Conclusions. In many instances, where a standard television picture and telemetry data were sent by separate transmitters or by data subcarriers above the frequency range of the television picture on a single transmitter, considerable savings in cost, size, and power demand can be made by using redundancies in the television picture to accomodate subcarriers within the video passband itself. Such a system also streamlines the ground station procedures somewhat and requires less equipment and provides inherent synchronization between data and video on playback. The system is compatible with color television systems and with most videotape recorders, as well as with video distribution systems.

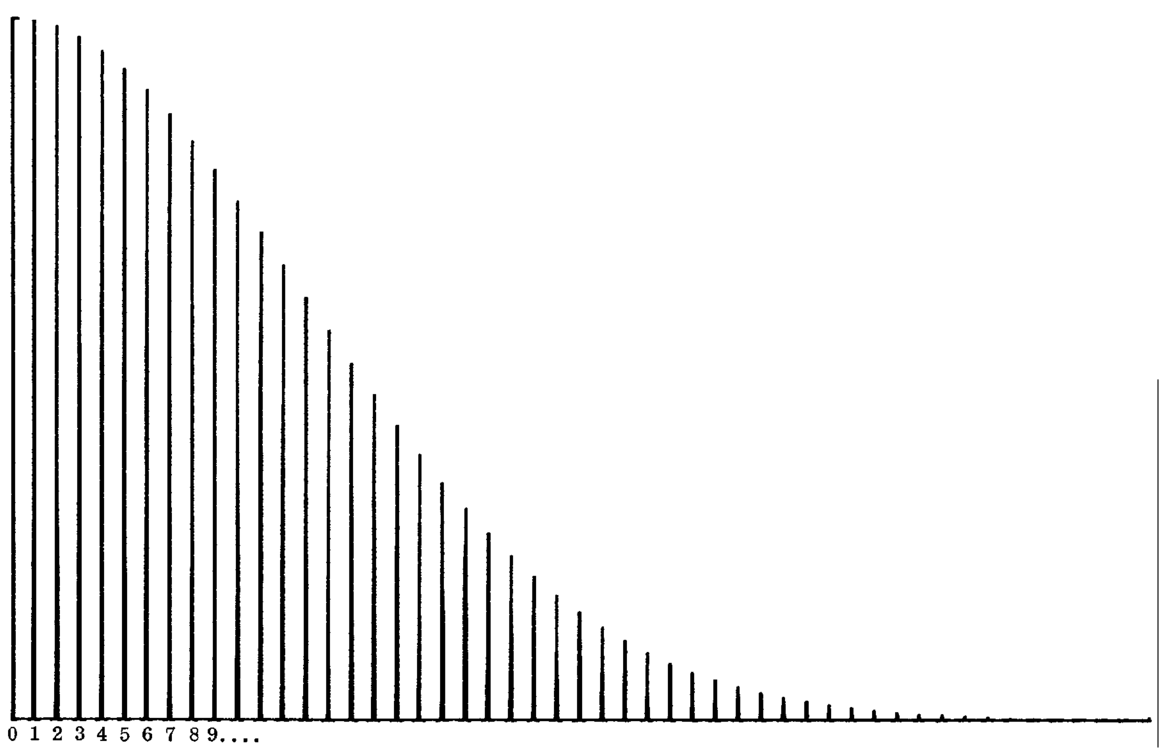

Figure One: Generalized distribution of energy—Gaussians about harmonics of the horizontal rate, falling off as a Gaussian.

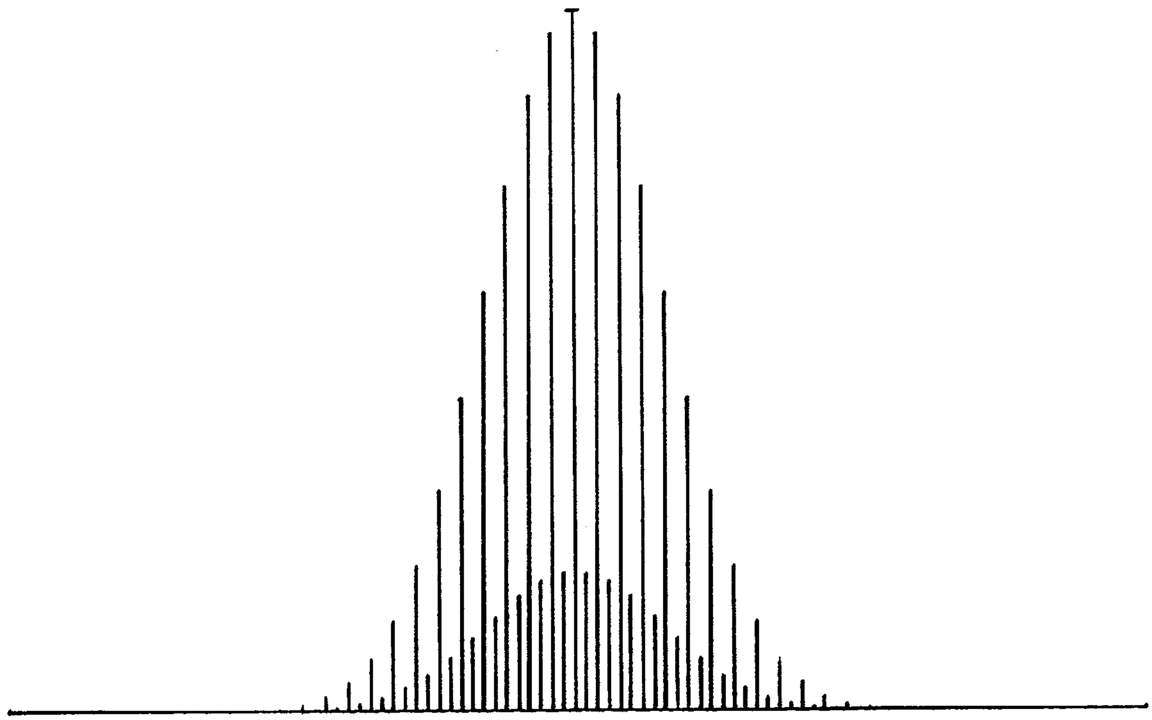

Figure Two: Generalized distribution of energy about a single harmonic of the horizontal frequency: small Gaussians at 30 Hz intervals, contained in an overall Gaussian envelope.