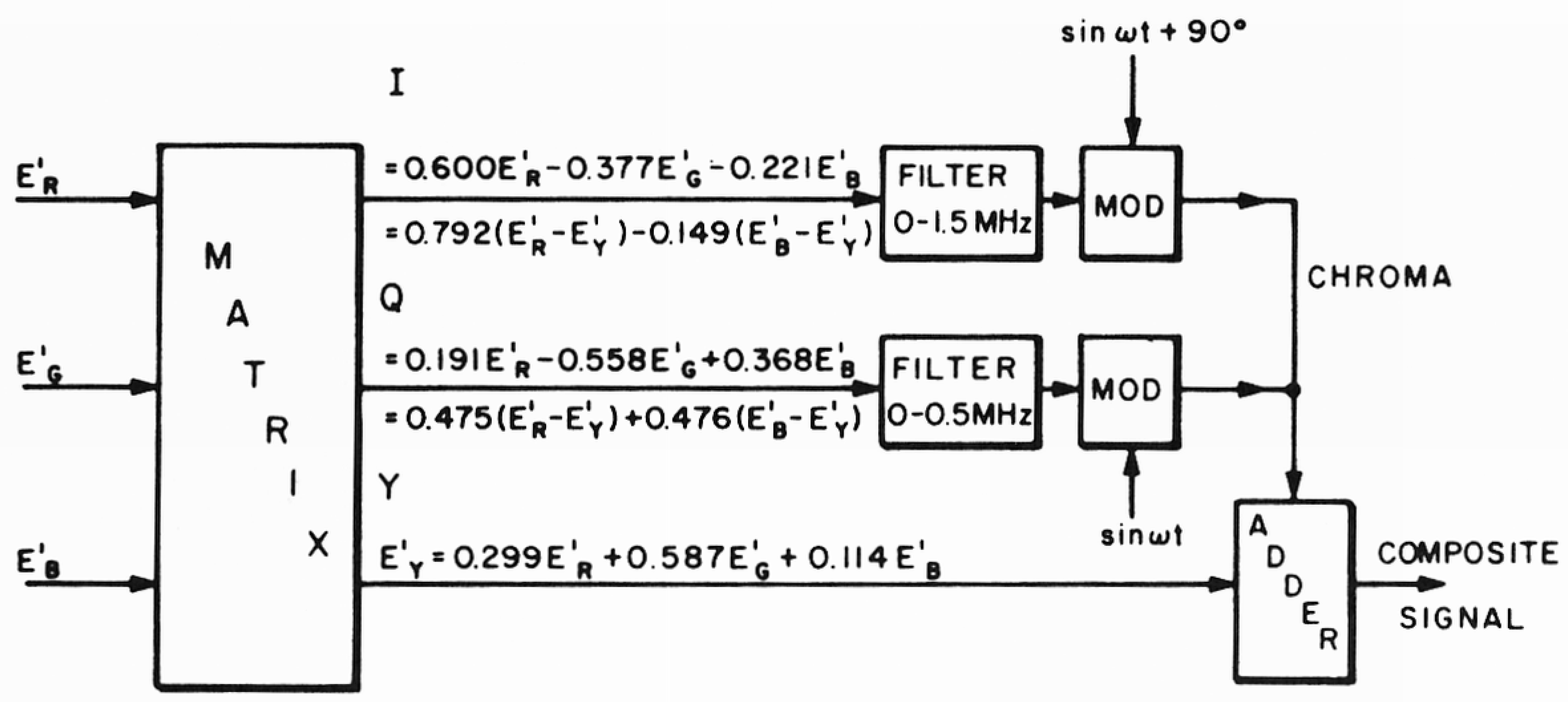

Fig. 18
NTSC encoder functions and signal make-up designations.

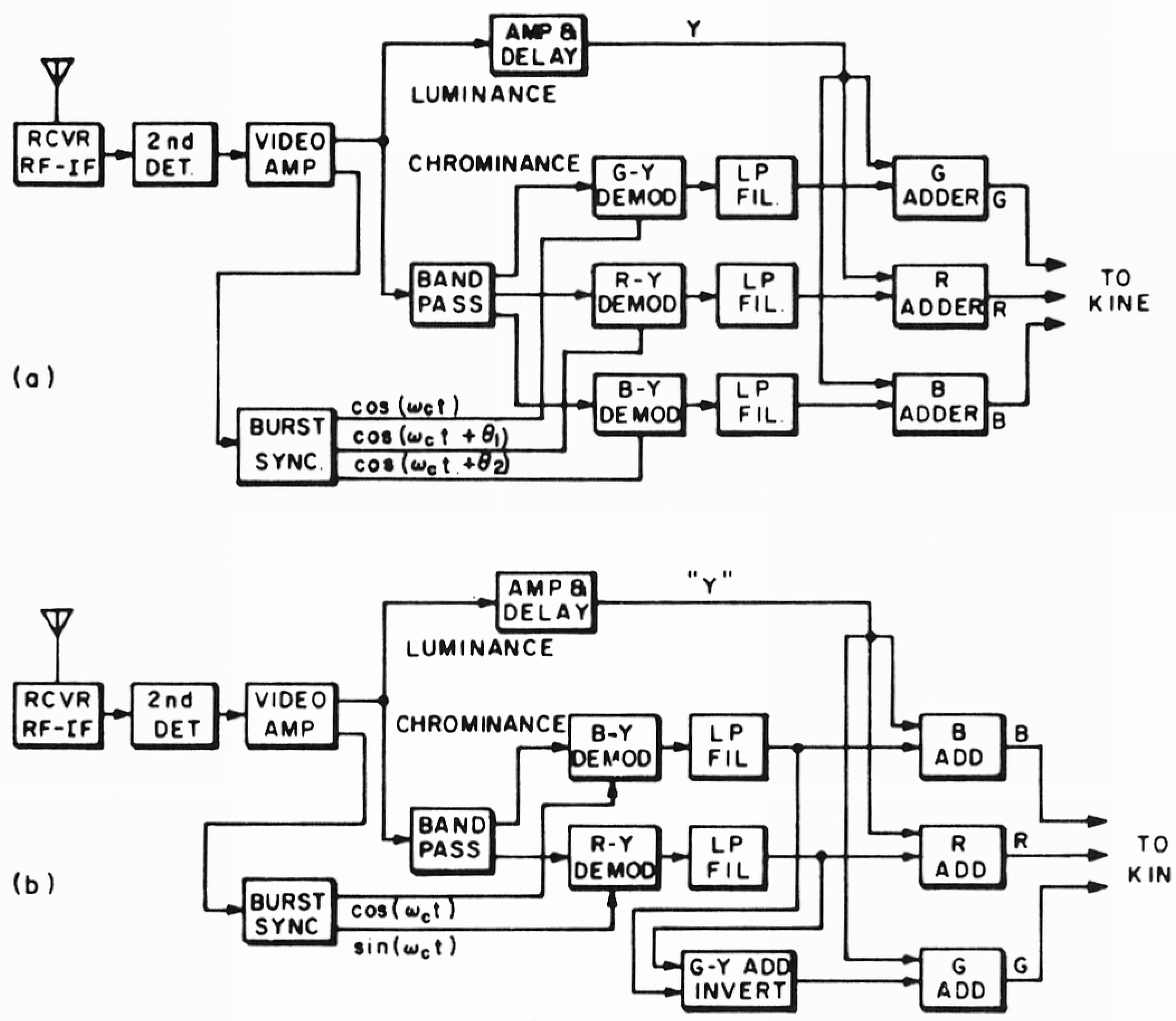

Fig. 19
NTSC receiver decoder functions. Drawing (a) shows the fundamental operation of recovering all three color-difference signals; (b) is a simplification that requires only two decoders with a matrix to form the other (G-Y) color difference signal.

tion. To reproduce the preferred orange-cyan colors, the angles representing I and Q are in phase quadrature, but are rotated 33° from the B-Y and R-Y phase designations. The 33° angle was determined experimentally and specified by committee. Fig. 18 summarizes the transmitter encoding functions and signal-makeup designations.

Decoding

At the receiver, the *decoding process* is essentially the inverse of the encoding function. Fig. 19 shows two typical receiver functional diagrams. The luminance signal, in the video domain, is fed to all three of the reproducing kinescope guns at the appropriate levels to produce a monochrome picture having a D6500 color temperature. The chrominance signal is separated by a bandpass filter and impressed upon the inputs of the synchronous demodulators. These demodulators extract the appropriate color-difference signals at the desired phase angle, as determined by a locally generated subcarrier reference signal locked to the incoming "burst" signal.

The receiver designer is free to determine the particular decoding process. For example, the I, Q signals available, followed by the appropriate matrix, can be used to form the necessary R-Y, B-Y, and G-Y signals. On the other hand, R-Y and B-Y signals with equal bandwidth (0-to-0.5 MHz) may be decoded directly with a simple matrix to form G-Y. In either case, the detected color-difference signals are individually added to the luminance signal in proper proportions to re-create the specific red, green, and blue signals that actuate the kinescope display device.

The overall gain of the chrominance channel determines the reproduced color saturation (ratio of chrominance to luminance), and the overall phase adjustment of the decoding reference signal provides a control of the average hue of the reproduced scene.

Luminance—chrominance

Another reason for the choice of signal values in the NTSC system is that the eye is more responsive to spatial and temporal variations in luminance than it is to the same variations in chrominance. Therefore, the relative chrominance gain and angle values are proportioned to take advantage of this characteristic in order to reduce the visibility of random noise and interference effects introduced into the transmission path between the transmitter and the receiver. Thus, the principle of *constant luminance* is exploited to an extent that the combined brightness of random-noise variations in the red, green, and blue channels appears constant in relation to the luminosity response of the average human eye. In an idealized linear system, the improvement in *visual* signal-to-noise ratio is in the 8-to-10-dB range. However, even though the system is inherently nonlinear, the brightness-cancellation process is effective at relatively low-level chromaticity signals, and the average improvement is in the order of 4 to 5 dB.

The problem remains of arranging the chrominance and luminance signals within a common channel without excessive mutual interference. Recognition that the scanning process, being equivalent to sampling, produces signal components concentrated in uniformly spaced groups across the channel width introduced the principle of *horizontal frequency interlaced* (dot interlace) operation. The color subcarrier frequency was chosen to be an odd multiple of one-half horizontal line frequency at a value of 3.579545 MHz. Thus, in an interlaced system, the phase of the subcarrier alternates in succeeding lines by 180° and four fields are required for picture completion. In addition, the chrominance subcarrier, by definition, becomes zero when no color exists and only shades of gray are to be reproduced via the luminance channel.

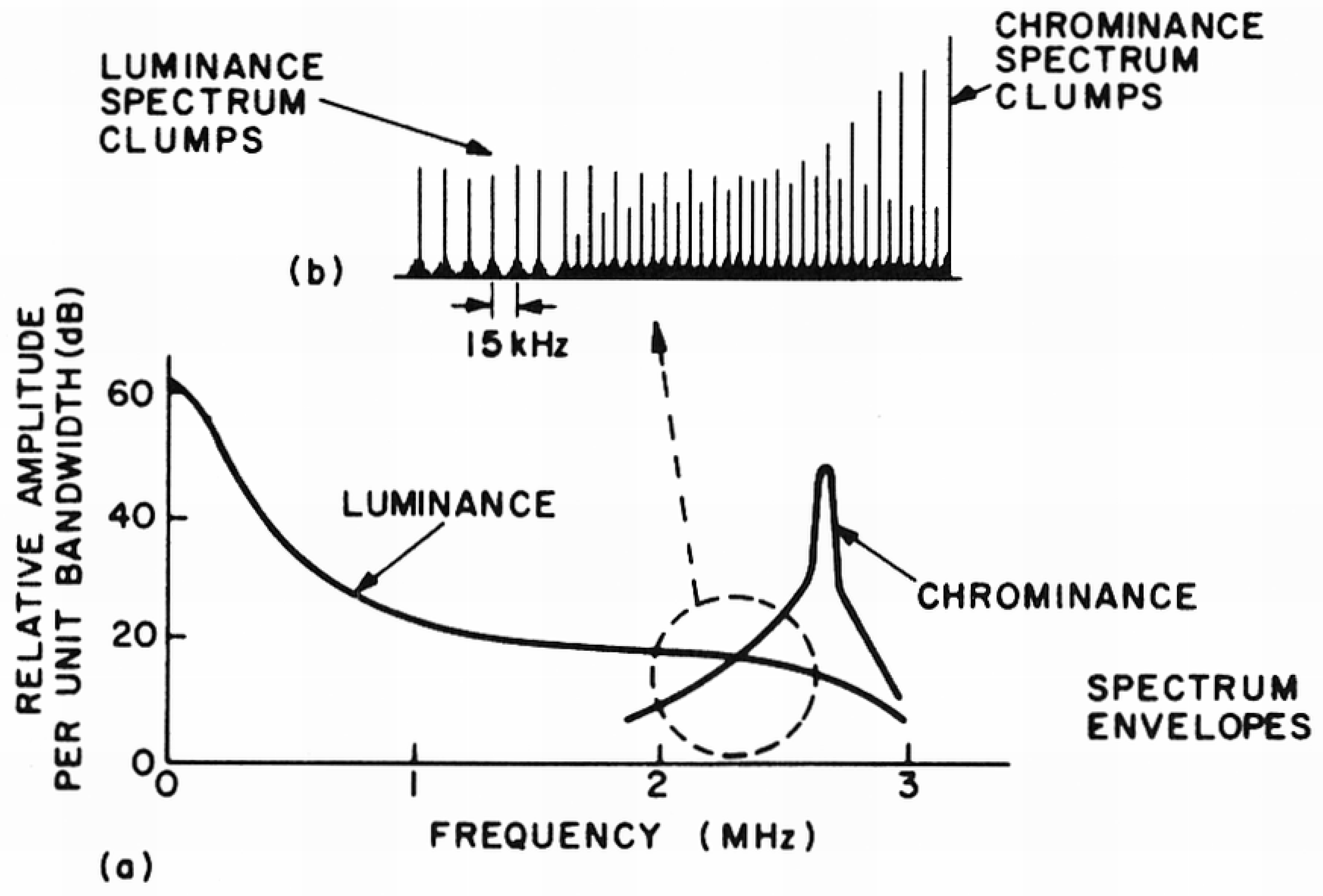

Fig. 20
Frequency-interlaced relationship of chrominance luminance.

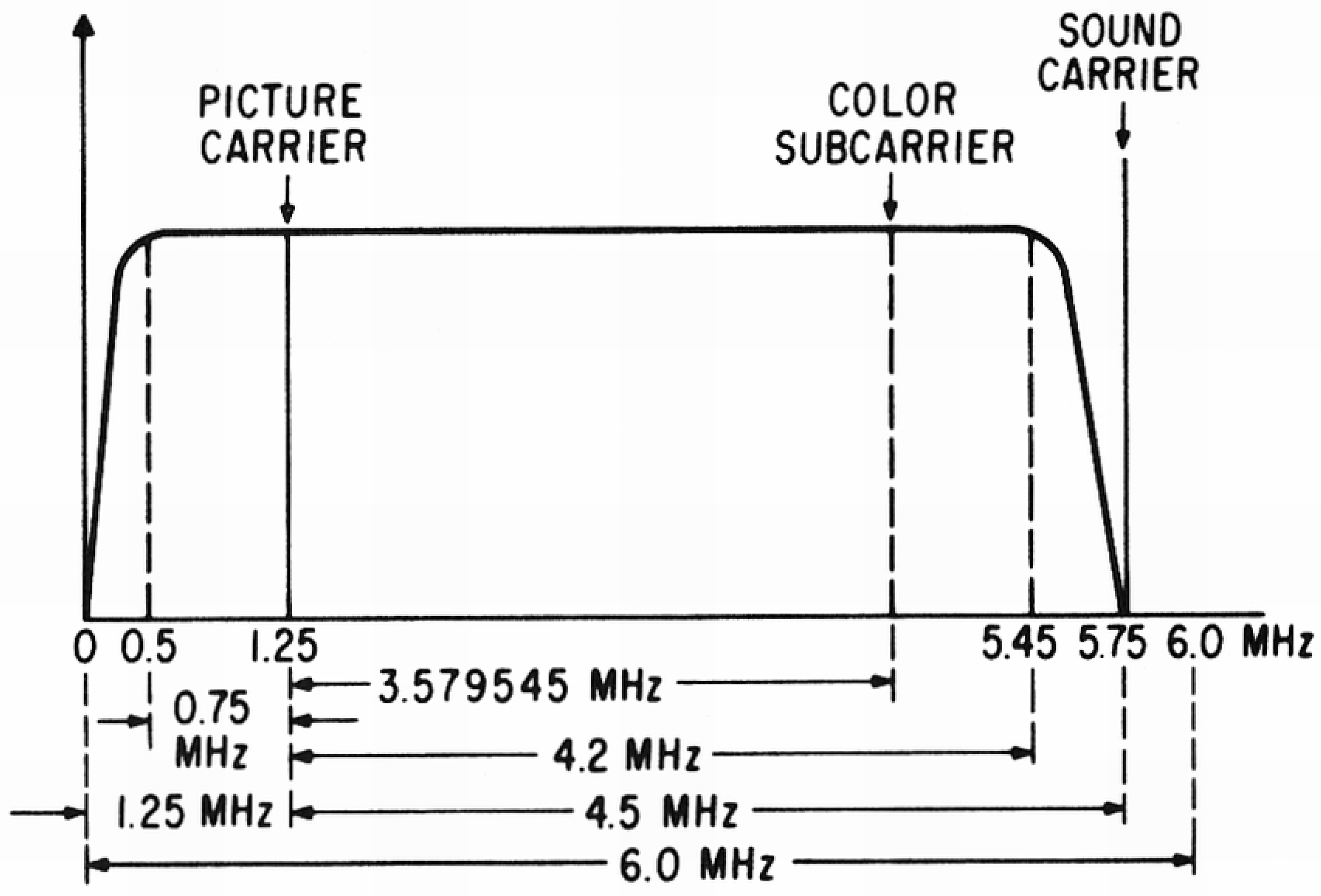

Fig. 21
Transmission channel for the NTSC color system.

By the interleaved nature of the subcarrier frequency relative to the timing of the horizontal scan rate, the visibility of the subcarrier signal is reduced, and if the system were linear, would exactly cancel on alternate lines. This interleaving process, indicated in Fig. 20, makes it possible to transmit the chromaticity information in the form of a phase- and amplitude-modulated subcarrier within the same channel width as that previously occupied by the monochrome transmission alone.

Since the picture-signal-energy-distribution versus frequency is grouped into intervals having 15.734-kHz spacings (horizontal scan rate), various prime numbers can be chosen to produce odd multiples of one-half line rate. The particular choice in the vicinity of 3.6 MHz was made for two reasons. First, the high frequency resulted in a fine interference pattern having low visibility because of small spatial dimensions. Second, this value allows about 0.5 MHz of double-sideband frequency range for the color-signal sideband components allowing for the sound carrier located at 4.5 MHz. The choice of the exact frequencies is

$$f_{LINE} = \frac{4.5 \times 10^6}{286} \text{ Hz}$$

$$= 15{,}734.26 \text{ Hz}$$

$$f_{FIELD} = \frac{f_{LINE}}{525/2} \text{ Hz}$$

$$= 59.94 \text{ Hz}$$

$$f_{SC} = \frac{13 \times 7 \times 5}{2} \times f_{LINE}$$

$$= 3.579545 \text{ MHz}$$

This choice allows the approximate average beat of 920 kHz between the color subcarrier and the sound carrier to also be interlaced to reduce its average visibility. The sound carrier, for reasons of compatibility, remained at 4.5 MHz, and the total number of scanning lines remained at 525 lines in a two-to-one vertical interlaced system. Thus, the color subcarrier, f_{sc}, became 3.579545 MHz with the horizontal scanning rate $f_{LINE} = 15.734$ kHz, and the vertical rate $f_{FIELD} = 59.94$ Hz. These rates, although slightly different from the black-and-white standards, fell within the previous tolerance ranges and therefore were acceptable.

The assigned communications-channel frequency relationships are shown in Fig. 21. The picture signal is handled in a vestigial-sideband manner with appropriate amplitude and phase compensation exactly as previously employed in the monochrome system with the sound signal spaced 4.5 MHz from the picture carrier. The color information is carried on a subcarrier located at 3.579545 MHz from the picture carrier. A specific color-signal phase-compensation filter introduced at the transmitter compensates for the typical characteristics of a receiver i.f. response to maintain phase and amplitude symmetry around the color subcarrier at 3.58 MHz.

Thus, the NTSC color standards provide a compatible signal with respect to the previous monochrome standards, and it follows that the numerical values describing the color signal are more precisely specified and therefore fall within previously existing tolerances. The color signal values for the complete system are regulated at ±20% amplitude and ±10° phase. However, the standards of good practice recommend ±10% amplitude and ±5° phase. The relative time delay match between the chrominance and luminance signal components is ±50 ns. The accuracy of the 3.579545 MHz is ±0.0003% (approximately ±10 cycles tolerance) with a rate of drift not to exceed one-tenth of a cycle per second. The horizontal and vertical scanning signals are, of course, derived from the color subcarrier in order to insure the interleaving relationship.

Conclusion

In the early development period of color television, some critics quipped that NTSC might represent, "Never The Same Color." But this ingenious system of standards—an imaginative combination of psychophysical and electronics characteristics—has prevailed for over twenty years and represents one of the more complex yet highly successful technological information display systems ever devised.

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