ABSTRACT

Central to "multimedia" image processing is the need to encode computer graphics data into a television signal, complete with line, field, and color subcarrier synchronizing information. The incompatibilities between television and computer display standards render this operation far less trivial than it sounds to anyone who hasn't worked with both types of signals.1

To simplify the task of encoding computer graphics into standard NTSC or PAL television format for display, broadcast, or recording, Raytheon Semiconductor has introduced two multimedia integrated circuits, the TMC22090 and TMC22190 digital video encoders.2

1. STATEMENT OF PROBLEM

Beyond the obvious commonality of the three-color cathode ray tube, computer and video display technologies developed somewhat independently. As a result, the standards for the two differ considerably, in sample rate, spatial resolution, and in method of encoding chroma data. In particular, when the U.S. formulated the NTSC television standard in the late 1940s and early 1950s, the Federal Communications Commission (FCC) mandated that the new color broadcast signals be compatible with existing monochrome television sets. Thus, today's NTSC broadcast signal comprises a standard luminance (monochrome brightness) waveform, on which an amplitude-modulated chrominance (color difference) signal is superimposed.

Each Raytheon video encoder (Figures 1 and 2) accepts computer graphics data in red-green-blue (RGB), color-index Video Graphics Adaptor (VGA), or luma - chroma (YUV or YCrCb) format and passes it through a user-programmable lookup table (Section 2.1) before converting it into luma - color difference (Y, R-Y, B-Y) format (Section 2.2). At this point, the chip generates the color subcarrier and modulates it using the color difference signals (Section 2.3), which it band-limits in Gaussian low-pass filters to prevent "cross luminance" distortion, or color leakage into the final luma output signal. At the same time, the chip superimposes controlled-slope vertical and horizontal video synchronizing pulses onto the luma signal, generating a standard baseband monochrome television signal (Section 2.4). Finally, the chip interpolates the luma and chroma signals to twice the pixel rate, combines them into a composite signal which can be multiplexed with a separate incoming digital television composite signal, and sends the resulting digital signals to the on-chip digital to analog converters (DACs) (Section 2.5). Three DACs are provided, one for keyed composite video and two for "S-video," the "semiprofessional" television and VCR format in which the chroma and luma signals are kept separate. As in an audio compact disk player, the 2x oversampling of the output DACs considerably simplifies the design of the external analog reconstruction filters.

2. INSIDE THE VIDEO ENCODER CHIP

2.1 Color lookup table (CLUT)

To enhance their versatility, both parts include triple 256x8 color lookup table (CLUT) RAMs. These provide fully programmable offset, gain and color correction in the RGB and YCrCb input
format modes. They also provide a full 24-bit color lookup function in the 8-bit VGA input mode and can be loaded in the same manner, with the same data, as a standard VGA RAMDAC.

Four of the many uses for the CLUTs are: 1) mapping of the 8-bit VGA color index values into any \(2^8 = 256\) of the \(2^{24} = 16,777,216\) possible colors; 2) "gamma" correction of RGB signals to compensate for camera and CRT nonlinearities; 3) gain correction for digital component video signals which comply with the CCIR-601 standard; and 4) (in the TMC22190) overlaying (foregrounding/backgrounding) of various captions and picture components (Section 4, below).

A computer with a VGA monitor has a 256-word x 24-bit CLUT, which it programs to define a 256-color subset of the "universe" of 16,777,216 possible colors. If the same values are loaded into this CLUT and into that of the video encoder, then the computer will display the same colors on its monitor and the encoder-driven television screen.

A typical NTSC gamma curve is shown in Figure 3. For gamma correction, each of the three sections of the CLUT (red, green, and blue) will typically receive the same set of values.

2.2 Input formatter

This portion of the chip converts the CLUT-remapped graphics data into luma-color difference \((Y, R-Y, \text{and } B-Y)\) format, as the next step toward video encoding. Based on empirical studies of the sensitivity of the human eye as a function of frequency, luma (overall brightness) is computed from the \(R\), \(G\), and \(B\) components as follows:

\[
Y = 0.30 R + 0.59 G + 0.11 B
\]

(This signal, if encoded by itself without any color difference signals, will produce a monochrome image on a television monitor.) Having computed \(Y\), this circuit then trivially generates the \(R-Y\) and \(B-Y\) color difference signals, multiplying each by an appropriate gain normalization term for modulation, yielding:

\[
V = 0.877(R-Y) \text{ and } U = 0.493(B-Y).
\]

2.3 Chroma modulator

The color difference components emerging from the input formatter are low-pass filtered to prevent interference with the luma information, since the computer graphics system can support a greater chroma bandwidth than can the video stream. As shown in Figure 4, the chips' built-in chroma filters comply with the CCIR Report 624 specification for chroma rolloff over the full range of design pixel rates. Although these filters will tend to soften spatial transitions between colors, without them plaids and other intricate color patterns would generate objectionable stripes and other brightness artifacts on the television screen.

The encoder chip locally synthesizes its own chroma subcarrier, using either information programmed by the host system ("master" and "slave" modes) or data continuously provided by a companion genlock circuit ("genlock" mode). In genlock mode, the encoder's chroma subcarrier will conform in phase and frequency to that of an incoming video reference signal (see video keying discussion in Section 2.5 below). With its 32-bit phase accumulator, the encoder chip can accurately generate either an NTSC (3.58 MHz) or a PAL (4.43 MHz) subcarrier to millihertz precision.

The subcarrier is then modulated by the chroma difference signals, according to the formula:

\[
\text{CHROMA} = V \cos(p) + U \sin(p),
\]

where \(p\) is the instantaneous phase of the chroma subcarrier. In both NTSC and PAL, hue information is carried in the modulated subcarrier's phase, whereas saturation is represented by its amplitude.

2.4 Luma conditioner

While the chroma modulator generates the subcarrier and modulates it using the chroma data, this portion of the chip generates NTSC or PAL standard rate-controlled horizontal and vertical synchronizing pulses and combines them with the luma \((Y)\) data.

The digitally generated leading and trailing edges of all sync pulses comply with NTSC and
PAL risetime specifications, to guard against "ringing" in downstream filters and circuits. In generating these edges, the chip can use any of three different timing sources: 1) its internal user-programmable sequencer ("master mode"); 2) the host computer or display system's horizontal and vertical sync signals ("slave mode"); or 3) a companion genlock circuit's sync signals, extracted from an external "reference" video signal ("genlock mode").

In master mode, the encoder chip determines all horizontal and vertical timing for the display system and generates digital sync signals for the host computer in addition to those embedded into the video output stream. Because the horizontal timing parameters are fully programmable, the user can fit any desired clock and pixel rate to the PAL or NTSC standard horizontal line rate of 15.625 or 15.734 Hz, respectively.

In slave mode, the encoder starts each new line or field when told to do so by the host computer. In this case, the host computer controls the horizontal and vertical synchronization of the video display, via the encoder chip.

In genlock mode, the encoder starts each new line or field when told to do so by a companion genlock circuit, such as the upcoming TMC22070 genlocking video digitizer integrated circuit from Raytheon. In turn, the genlock circuit has extracted its synchronizing information from an incoming analog or digital video signal. Via the encoder chip, the genlock establishes horizontal and vertical sync for both the host computer and the video display, thereby locking the computer graphics display to the incoming video signal. This mode is essential to applications which entail overlaying computer-generated text and graphics over a video signal, for captioning, highlighting, and special effects.

2.5 Output interpolators and adder/keyer

This block's two functions are: 1) to double the digital video sampling rate; and 2) to implement switching (keying) between an incoming digital composite video signal and the computer-generated graphics and text.

Following the lead of the digital compact disk player manufacturers, the video encoder chips employ 2x oversampling at their outputs, i.e., they drive their output DACs at twice the internal digital sampling rate. The spectral images created by this upsampling are removed by an on-chip digital filter (Figure 6). The oversampling and associated low-pass digital filter greatly simplify the design of the external analog low-pass reconstruction filter by relaxing the rate of rolloff it must provide.

This block also contains an adder, which combines the emerging oversampled luma and chroma graphics signals into a composite graphics signal in digital video format. The keying multiplexer then routes either this graphics signal or an incoming composite digital video signal (from the companion genlock) to the composite DAC. By switching between the output of the graphics adder and the incoming composite video signal, this block implements the video keying function, effecting overlays of text and graphics onto a video background, or the overlay of video inserts over a graphics background.

For enhanced versatility, the encoder chips provide both data-driven and hardware-driven keying. In data-driven keying, whenever a specific user-selected color appears in the computer graphics data stream, the chip selects the incoming video signal instead. One can regard this special control color as "transparent," i.e., the computer graphics is always in the foreground, hiding the Adeo, but the video shows through this particular "color." Using a pin on the chip, the host system can also time the transitions between video and graphics, to create picture-in-picture and similar effects.

3. VIDEO ENCODER PERFORMANCE

In designing the TMC2290, Raytheon scrupulously observed the NTSC and PAL video signal specifications, which cover everything from rise and fall times to the amplitudes of the color reference and video signals themselves. To minimize the generation of color artifacts, highly linear, low-glitch 10-bit DACs were used on chip.

In any digital video system, the visual quality of the color image is limited by the linealities of its analog to digital converters and DACs. The encoders' DACs feature (worst-case maximum)
0.2 percent integral and 0.1 percent differential linearity error. Their differential phase error of 0.5 degrees and differential gain error of 0.9 percent are well within industry standards. Differential phase errors appear as chromatic aberrations on the television screen, whereas differential gain errors cause undesired variations in saturation (chroma channel) and/or brightness (composite channel).

4. SUMMARY AND CONCLUSIONS

The TMC22090 and TMC22190 video encoder integrated circuits cost effectively bring new levels of performance to computer based video image generation. Systems and personal computer application boards built around these chips and the upcoming companion TMC22070 genlocking video digitizer will endow the professional and consumer computer user with exciting new multimedia and video processing capabilities, such as text and graphics overlay, picture-in-picture, and special effects generation.

5. REFERENCES


Figure 3. Typical gamma curve for NTSC

Figure 5. Horizontal video line timing
Figure 2. Functional block diagram, TMC22090 (TMC22190 similar)

Figure 4. Color-difference low-pass filter response

Figure 6. Digital oversampling filter response