

AN INTEGRATED TV VIDEO MODULATION SYSTEM

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INTRODUCTION

New developments in T.V. add-on areas such as V.D.R., games, and data display, have produced a common need for composite video encoding and R.F. modulation circuits to interface with the T.V. receiver. This paper reviews the basic requirements for this area and then presents a new T.V. video modulation system using only one integrated circuit.* The new system includes the sound subcarrier oscillator and chroma subcarrier encoding circuits, in addition to R.F. oscillators and modulators for two low-V.H.F. channels. Channel switching is achieved with a d.c.-operated switch.

A review of the high frequency characteristics of bipolar transistors dictates the design approach. Low impedance level shifting and positive temperature compensation techniques are used to achieve excellent L-C oscillator stability. Basic trade-offs were discovered between stability, harmonic content, and oscillator drive level which apply to all monolithic balanced modulators used at high frequencies.

The sound subcarrier oscillator uses only one pin and two methods of F.M. modulation are available. The chroma section produces encoded subcarrier from R-Y and B-Y color difference inputs. The chroma modulators employ externally adjustable phasing elements and have a floating output level at the R.F. modulator input. The d.c. channel switching approach shares biasing and input circuitry between the two channels to take advantage of the fact that only one channel is on at a time.

The full capabilities of the 1-chip T.V. modulation system can be used in T.V. games that have color and sound. In addition, other applications for the system include composite video encoding and R.F. modulation of standard composite video. Excellent modulator linearity suppresses 920kHz sidebands by better than 60dB, and carrier harmonics can be removed using simple filters. Significant board savings have been achieved over multi-chip approaches.

*LM1889

SYSTEM REQUIREMENTS

The modulation functions required to interface audio and video signals to a T.V. receiver can be broken into two groups: 1. Composite video encoding, and, 2. R.F. modulation on channel carrier. Although the sound subcarrier is normally transmitted separately, it will be assumed to be part of the composite video signal which will modulate the channel carrier. Thus composite video encoding must include generation of both sound and chroma subcarriers and summation with the luma and sync components. Note that the goal is not to create any baseband signals, but rather to encode and modulate them for T.V. reception.

It is desirable to have the capability of modulating the composite video signal onto one of two low - V.H.F. channels selected by the user. This is normally achieved in discrete designs by means of a single oscillator/modulator combination in which the tank and output filters must both be switched. Common disadvantages with this approach are channel tuning interaction and layout problems associated with 2-pole R.F. switching.

Figure 1 shows the system approach used to integrate the desired functions. The frequencies given are for the N.T.S.C. system, but the basic approach also applies to the P.A.L. system. Chroma subcarrier encoding is achieved by modulating chroma oscillator quadrature components by two color difference signals.¹ Modulation along the R-Y and B-Y axes is chosen in Figure 1 because it allows the burst to be easily created with a (-) pulse on the B-Y modulator. In the P.A.L. system an equal burst component is included in the R-Y signal which changes polarity every other line. Summation of the modulator outputs before filtering produces equiband operation, i.e. equal bandwidth of the two subcarrier components.

The sound subcarrier encoding requires only a V.C.O. which may be frequency-modulated by audio. The sound and chroma

DESIGN PROBLEMS

The integrated video modulator is basically just a collection of oscillators and modulators on one chip. Therefore a review of the I.C. designs chosen for those functions is in order, particularly with respect to the problems associated with operation at T.V. channel frequencies.

Oscillators

Economic considerations dictated the use of LC R.F. and sound oscillators. Figure 2 shows the basic differential amplifier approach taken. The cross-coupled collectors produce positive feedback for oscillation at a frequency defined by the parallel tank. The peak-to-peak oscillator level across the tank is determined by the load resistors, which also set the Q. Saturation is devastating to high frequency temperature stability, so zener level shifting is used to the bases.

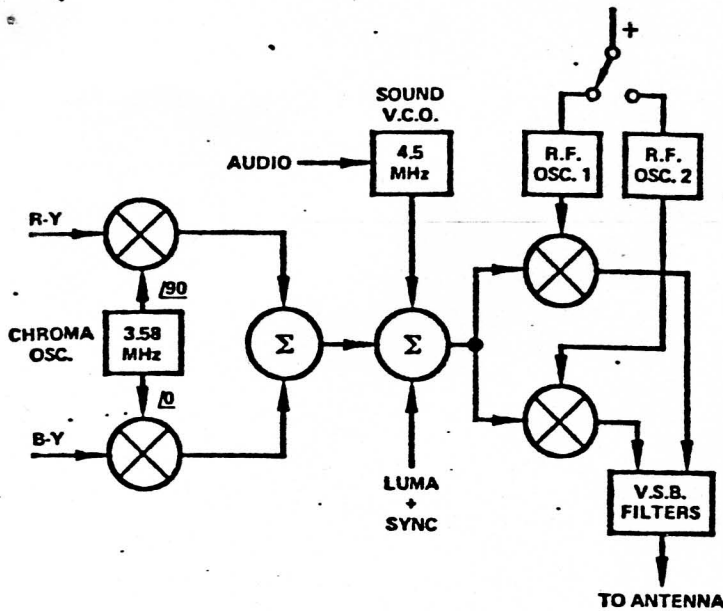


FIGURE 1. System Approach

subcarrier components are then summed in the correct ratios with luma and sync to form composite video (the luma must be delayed if the chroma subcarrier has been band-limited).

The R.F. section shown in Figure 1 takes advantage of the increased complexity possible with integrated circuits to provide separate oscillators and modulators for the two channels. By feeding the modulator inputs in parallel, oscillator switching can be achieved simply by turning on one oscillator or the other. This reduces the switching requirement to a single-pole d.c. switch and greatly eases tuning and layout requirements. After modulation the R.F. signal is passed through a vestigial sideband (V.S.B.) filter for each channel in order to remove the lower chroma and sound sidebands and attenuate carrier harmonics.

The performance requirements for video encoding and R.F. modulation systems are covered in F.C.C. part 15 rules and regulations² and E.I.A. manufacturers guidelines.³ Some of the requirements pertinent to an integrated approach are summarized in Table 1.

TABLE 1
SYSTEM PERFORMANCE REQUIREMENTS

Timing of Chroma to Luma	$-.17\mu\text{Sec} \pm .2\mu\text{Sec}$
Sound Carrier Modulation Deviation	+25kHz
Sound Carrier Relative Amplitude	-13dB to -34dB
Frequency Stability, Initial	
R.F.	$\pm 50\text{kHz}$
Sound	$\pm 5\text{kHz}$
Chroma	$\pm 100\text{Hz}$
R.F. Modulator	
Peak Sync Power, max.	3mV_{rms} into 75Ω
Peak Sync Power, min.	-6dB from above
Out of band signal, at greater than 3MHz from channel edge	-30dB max.
Beat products	-45dB
Modulation as % of voltage	
Peak Sync	100%
Blanking	75%
Ref. White	12.5%

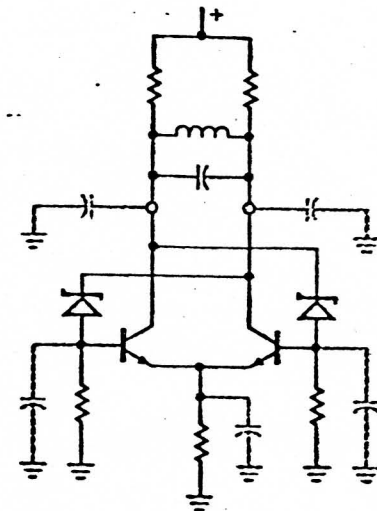


FIGURE 2. LC R.F. Oscillator

The next most important stability consideration is phase shift around the oscillator loop. Figure 3 reviews the phase response of a parallel tank circuit. If ϕ degrees of phase lag is present in the oscillator, then the oscillation frequency will be forced lower to produce a compensating ϕ degrees of lead in the tank. Increasing the tank Q reduces the frequency change; however, a practical upper limit on Q is set by the oscillator level allowed.

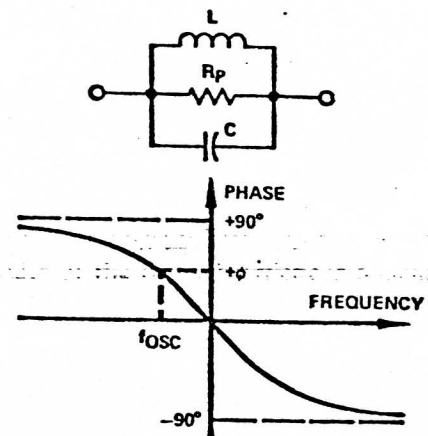


FIGURE 3. Oscillator Tank Characteristics

Where does phase shift in the oscillator come from? The two main sources are from the parasitic capacitances shown in Figure 2 and from the NPN devices themselves. The simplified NPN model of Figure 4 shows the phase lag produced in the base circuit by the level-shift resistance r_{LS} , base resistance r_b' , and emitter junction capacitance C_E . At R.F. carrier frequencies ($\omega \gg \omega\beta$) the phase lag is dominated by C_E :

$$\phi \approx \text{Tan}^{-1} [\omega C_E (r_{LS} + r_b')] \quad (1)$$

Since the resistive terms in equation (1) have a positive temperature coefficient (T.C.) when implemented in an I.C., ϕ increases with temperature causing a negative oscillator frequency drift. To minimize this effect the level-shifting and base resistances are kept as low as possible.

A further temperature dependence in the oscillator is the decrease in open-loop gain caused by the $-0.3\%/^{\circ}\text{C}$ T.C. in g_m of the devices. This can be effectively dealt with by introducing a positive T.C. of the same magnitude in the oscillator current.

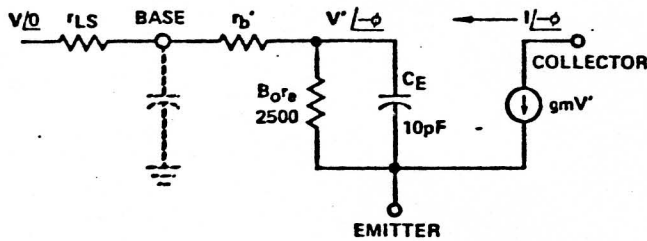


FIGURE 4. NPN Model

Modulators

The monolithic balanced multiplier of Figure 5 is used for both the chroma and R.F. modulators. If an oscillator signal $\cos \omega t$ is applied to the top quad and the lower pair is offset, then V_{out} is given by:⁴

$$V_{out} = AV_{offset} X \cos \omega t \quad (2)$$

where A is the modulator conversion gain. In general V_{offset} can contain a d.c. term K and a modulating function $f_m(t)$. Thus equation (2) becomes:

$$V_{out} = \underbrace{AK \cos \omega t}_{\text{carrier}} + \underbrace{Af_m(t) \cos \omega t}_{\text{sidebands}} \quad (3)$$

Suppressed carrier operation is required for the chroma modulators, so the lower pairs are balanced ($K = 0$). In the R.F.

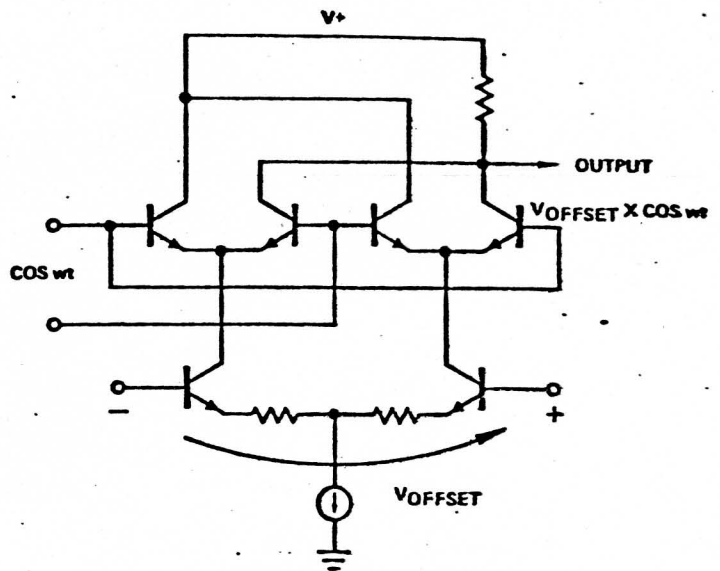


FIGURE 5. Balanced Modulator

Like the differential oscillator, the monolithic multiplier has its own pitfalls at high frequencies. If the top quad is being switched, then the output should be a square-wave which would produce the first out-of-band signal at 3rd harmonic. Unfortunately, the parasitic capacitance at the emitters of the top quad shown in Figure 6 can cause severe frequency doubling as follows: For every transition of the switching signal, one of the two devices connected to the output is turning on. This creates a current spike into a parasitic capacitance once every half cycle. The 2nd harmonic generated in this manner is directly related to oscillator drive level, and can be as high as the fundamental! Thus there are conflicting requirements for the oscillator tank Q - high for good stability, and low to reduce the drive level for modulator harmonic reduction.

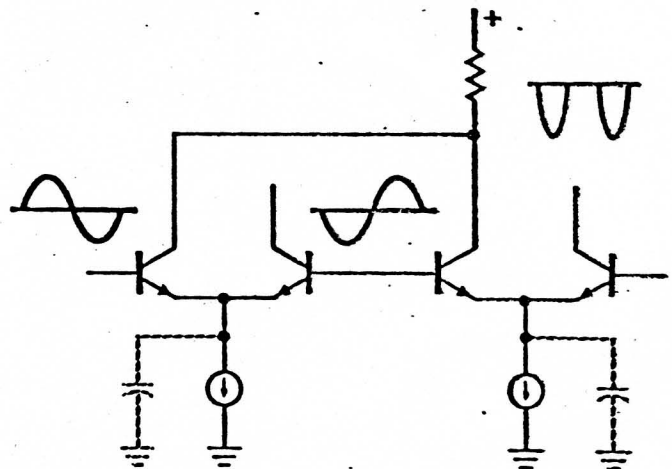


FIGURE 6. 2nd Harmonic Generation

CIRCUIT DESCRIPTION

Sound Oscillator

The sound subcarrier oscillator and two methods of frequency modulation are given in Figure 7. A single-ended output version of the differential oscillator is used to save one package

The conventional F.M. approach is to a.c.-couple the audio into an external d.c.-biased varactor diode to deviate the tank frequency. However, if good sound quality is not required, then the frequency may be deviated simply by switching a capacitor across the tank at an audio rate as shown in Figure 7 in dotted lines. The latter method is very effective in producing single-frequency audio "beeps."

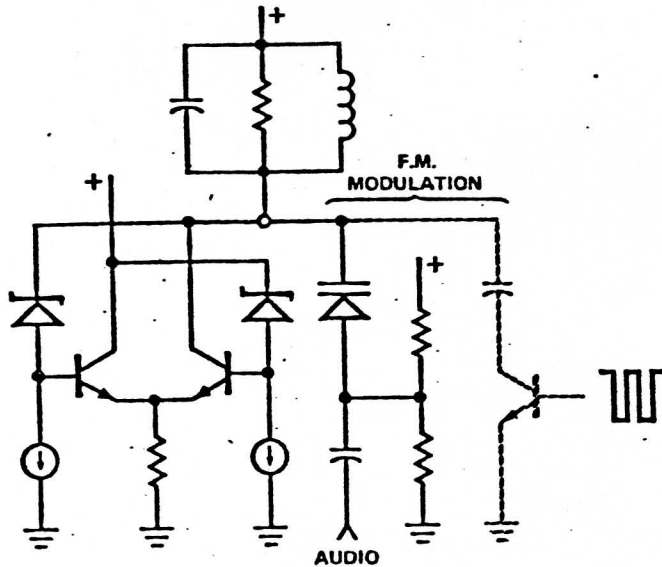
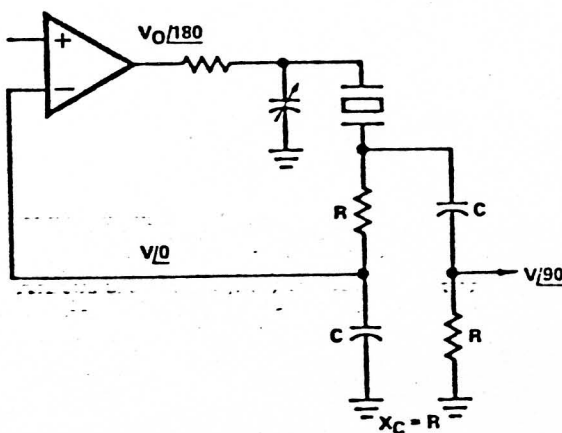


FIGURE 7. Sound Subcarrier Oscillator

Chroma Encoding Section

The accuracy requirements for the chroma frequency dictate the crystal oscillator of Figure 8. The inverting amplifier is equivalent to 180 deg. of phase lag, so an additional 180 deg. is required to complete the 360 deg. required for oscillation. This is furnished by the external R-C and crystal network tuned to the appropriate subcarrier frequency for the P.A.L. or N.T.S.C. systems.

In addition to generating the feedback signal for the oscillator, an R-C lead/lag phase-shift network is used to generate the quadrature reference signals for the chroma modulators. If the phase of the feedback (lag) side is defined as 0, then the phase of the opposite (lead) side is 90. Furthermore, if $X_C = R$, then the two signals will be equal amplitude $|V_{0/0}| = |V_{0/90}|$.



The $V_{0/0}$ signal is coupled to the top quad of the B-Y modulator and $V_{0/90}$ to the top quad of the R-Y modulator in Figure 9. A common d.c. reference is applied to one base of the lower pairs of each modulator, and the color difference input signal B-Y or R-Y to the other (see Fig. 5). When either input is offset (+) with respect to the d.c. reference, an output subcarrier of the corresponding phase is produced with amplitude proportional to the offset. When an input is offset (-), say -(B-Y), then the output phase for that modulator is inverted, in this case to 180 . In this way, the chroma burst can be created by simply applying a (-) pulse to the B-Y input.

The modulator output signals add vectorally in the common load resistor to produce the complete 360 deg. circle of color phases. The PNP/NPN output circuit converts the subcarrier to an a.c. current at the output pin, which also doubles as an input pin for the R.F. modulator. Under quiescent conditions ($V_{B-Y} = V_{R-Y} = V_{REF}$), the currents subtract as shown in Figure 9 and no output current flows. When an a.c. signal is applied to the NPN base, the PNP emitter current is modulated. Since all other currents remain constant, an a.c. current must flow in the load at the output pin. In this way, a chroma subcarrier signal may be developed at the input of the R.F. modulator with an arbitrary quiescent d.c. voltage.

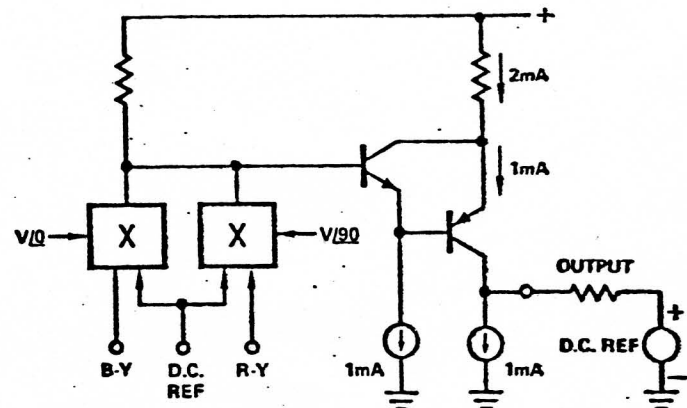


FIGURE 9. Chroma Subcarrier Encoding

R.F. Oscillators and Modulators

Figure 10 shows the R.F. oscillator and modulator interconnection, which is duplicated for the second channel. An oscillator is switched on by connecting the tank resistors to supply. The current flowing in the level-shift zener diodes then combines in a common diode-resistor network to ground which biases the current source for the modulator. In this way turning off an oscillator not only removes the R.F. carrier to the corresponding modulator, but completely kills the output current. The second oscillator shares the temperature-compensated emitter current source so only one may be on at a time.

The basic modulator inputs are again the carrier at the top quad and the modulation at the lower pair (see Fig. 5). The sound subcarrier is a.c.-summed with the luma + sync signal at one base of the lower pair, and the encoded subcarrier is applied to the other base. Since the chroma subcarrier output is

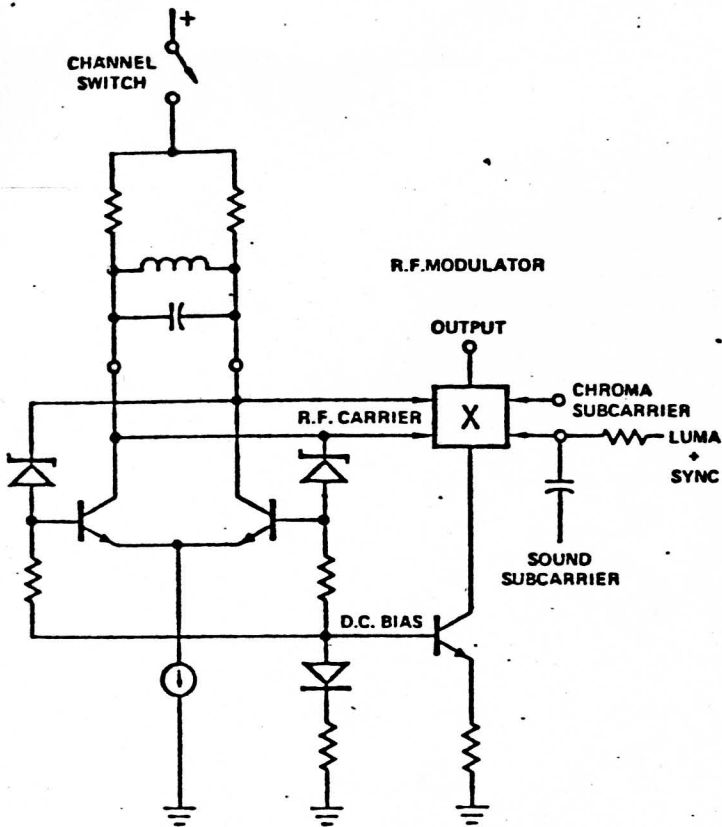


FIGURE 10. D. C. Channel Switching

up the d.c. offset required for either (+) or (-) sync modulation. In order to make the sync correspond to peak carrier, the d.c. level of the subcarrier must be such that the sync creates the maximum offset at the lower pair. Figure 11 shows two cases which meet this requirement, and would have identical R.F. outputs.

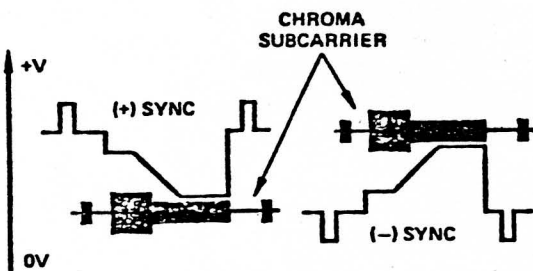


FIGURE 11. R.F. Modulator Inputs

Complete Circuit

A complete circuit diagram for the video modulator integrated circuit is given in Figure 12. The sound subcarrier oscillator devices Q1 - Q6 switch 0.6mA p-p in the sound tank at pin 15 of the I.C. The chroma oscillator consists of the inverting amplifier Q16, Q17 and Darlington emitter follower Q11, Q12. Zener diodes Q13 and Q15 level shift the amplifier bases negative to allow a 5V p-p output swing at pin 17.

The chroma lead-lag signals are applied to pins 1 and 18 respectively and drive the chroma modulator top quads via buf-

devices Q29, Q30, and Q21 - Q24, while the B-Y modulator consists of Q31, Q32, and Q25 - Q28. The output subcarrier is coupled through the balanced amplifier Q35 - Q38 to one input of the R.F. modulators at pin 13. All top quad currents (which sum to a constant 2mA) flow in R18, so the output signal is only developed across R19. This improves linearity by reducing the a.c. to d.c. signal ratio in Q38.

One R.F. channel oscillator consists of devices Q54 - Q57 connected to the tank at pins 6 and 7. The corresponding R.F. modulator consists of multiplier devices Q58, Q59, and Q50 - Q53 connected to output pin 10. The oscillator tank signal is coupled to the multiplier top quad through isolating devices Q48 and Q49. Current flowing through the oscillator level shift zener diodes is turned around in Q60, Q61, and Q62 to source current for the modulator. Zener diodes Q46 and Q47 hold the bases of the top quad approximately 7V below supply with the oscillator turned off.

The devices Q65 - Q79 in the second oscillator/modulator combination are an exact duplicate of the above configuration. Common to both R.F. sections are the pin 12 and 13 modulator input buffers Q45 and Q44, and the oscillator current source Q43. The current source regulator devices Q39 - Q43 generate a 0 T.C., supply independent current in R35. From this current a highly negative T.C. $V_{be}/R34$ current is subtracted, thus creating the required positive T.C. current in Q43.

APPLICATIONS

2-Channel Encoder/Modulator

The video modulator I.C. operates over a supply range of 11V to 19V. The external components required to use the full capability of the device are shown in Figure 13. Using this circuit, composite video with color and sound may be encoded and modulated on one of two low-V.H.F. channel carriers. In all cases, the chroma and R.F. modulator inputs must be d.c.-coupled and operated within their common-mode range (see Fig. 16).

The sound tank is F.M. modulated by one of the methods given in Figure 7 and coupled into the R.F. modulator input pin 12. The series R-C coupling network is set up such that the sound subcarrier is approximately 10% of the peak-to-peak video at pin 12. The 240 ohm R.F. tank resistors produce a 350mV p-p modulator drive level, which gives the best compromise between oscillator stability and output harmonics. The separate R.F. outputs feed vestigial sideband channel filters which could be L-C or surface wave construction.

D.C.-Coupled N.T.S.C. Modulator

In applications starting with previously encoded composite video, the chroma section may be used for other functions. For example, the split-supply circuit shown in Figure 14 uses the chroma oscillator inverter as a X2 d.c. gain stage. The input accepts 1Vp-p ground referenced standard video which is

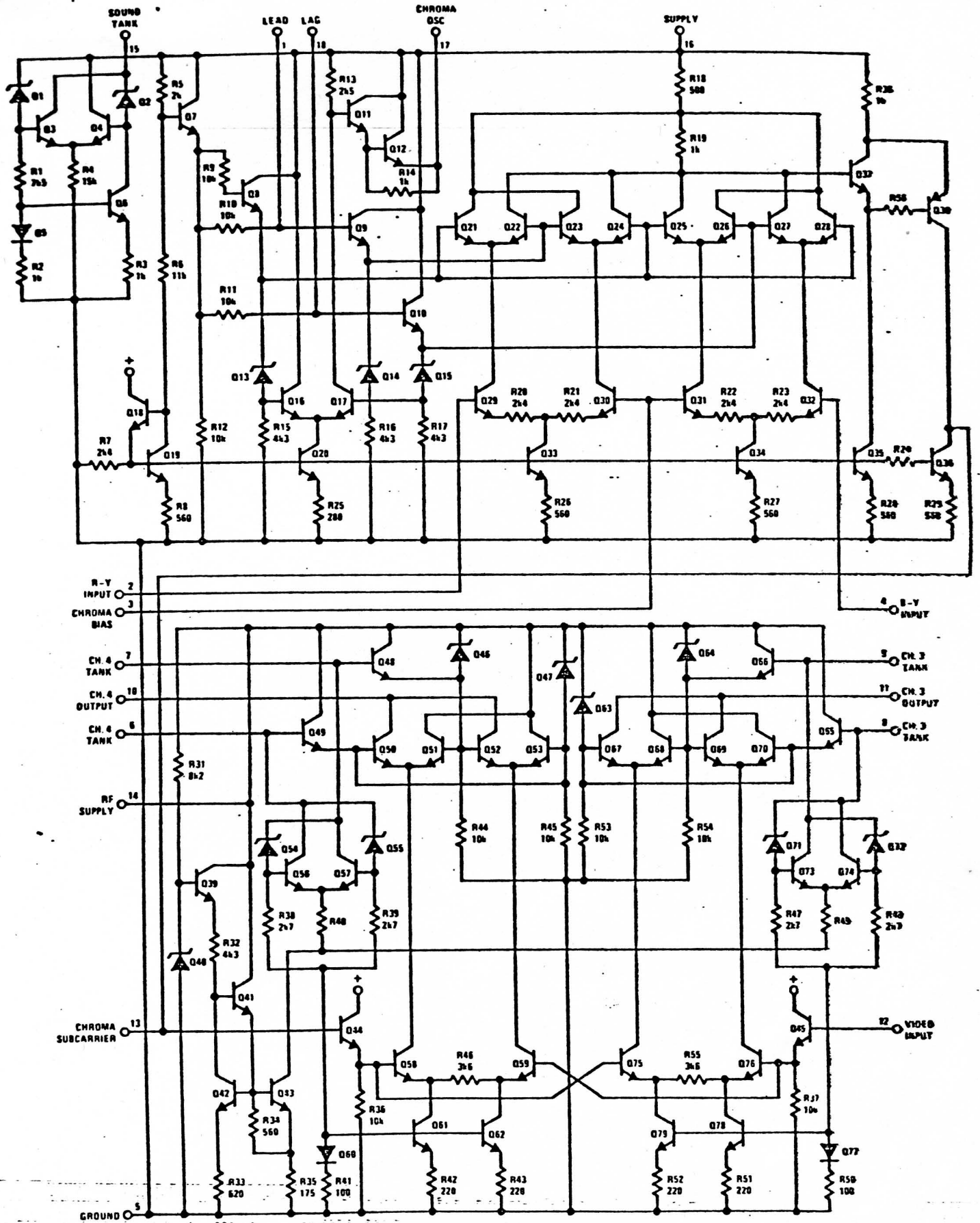


FIGURE 12. Complete Circuit

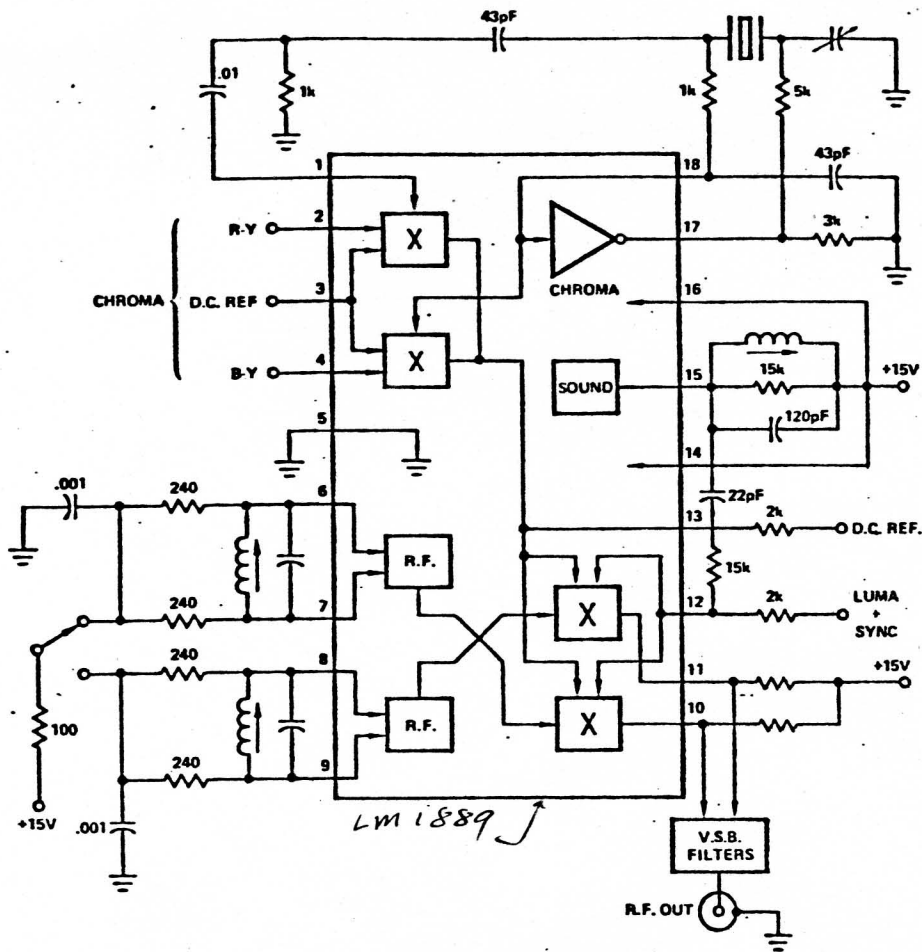
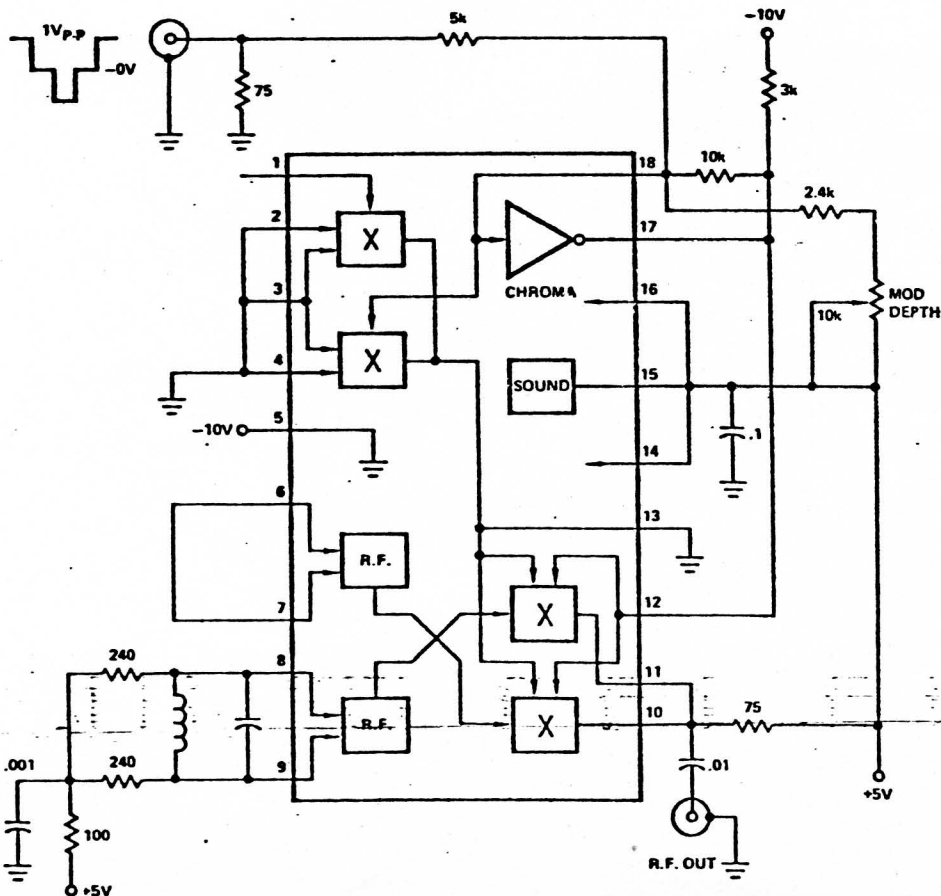


FIGURE 13. 2-Channel Encoder/Modulator



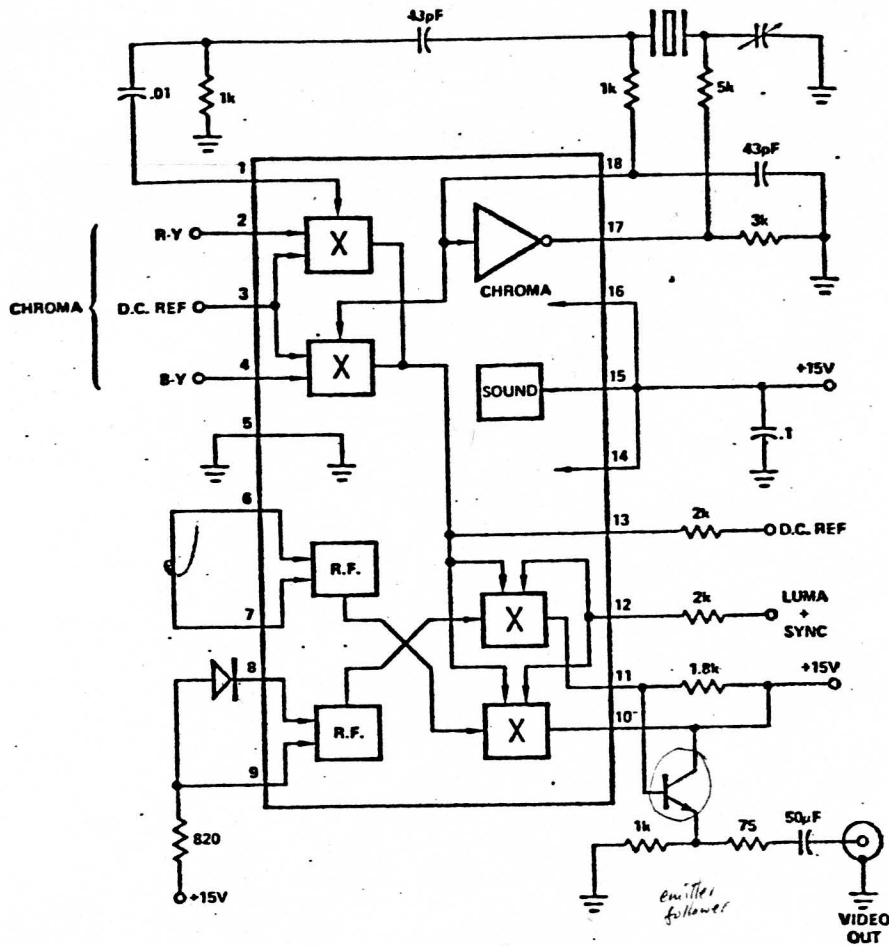


FIGURE 15. Composite Video Encoder

lator d.c. reference is set by grounding pin 13 and the modulation depth is adjusted by varying the offset current at the inverter input.

This system gives true d.c.-coupling, i.e. peak carrier level is independent of picture information. When only one channel is required the other oscillator tank pins are shorted together and left floating as shown.

Composite Video Encoder

In the application shown in Figure 15 the requirement is only to encode a 1V_{p-p} composite video signal from the color difference and luma + sync components. The chroma encoding section is operated as in Figure 13; however, one R.F. oscillator is permanently offset by connecting a diode across the tank pins. This offsets the corresponding modulator top quad which passes the subcarrier and luma + sync signals summed in the lower pair through to the output pin. An external emitter follower is used to drive a 75-ohm load.

RESULTS

One of the primary concerns in the development of the integrated video modulation system was oscillator stability. The

need for crystal control of the R.F. oscillators. The chroma oscillator output has less than 30nSec rise and fall times, making it suitable for clocking any associated digital logic.

**TABLE 2
OSCILLATOR STABILITY**

	vs. TEMP	vs. SUPPLY
Chroma	1Hz/°C	3Hz/V
Sound	-50Hz/°C	500Hz/V
R.F.	-2kHz/°C	10kHz/V

Figure 16 shows the modulator input common mode range as a function of supply voltage. The modulator output levels are a function of the pin 13 and R.F. output load resistors. Table 3 gives A.C. parameters measured in the application circuit of Figure 13.

**TABLE 3
A.C. PARAMETERS**

Chroma Oscillator Output, Pin 17	5V _{p-p} square wave
Chroma Modulator Conversion Gain	0.6V _{p-p} /Volt
R.F. Modulator Conversion Gain	10mV _{rms} /Volt
Output Beat Products	-60dB
Output Harmonics (un-filtered)	
2nd 3rd	-12dB

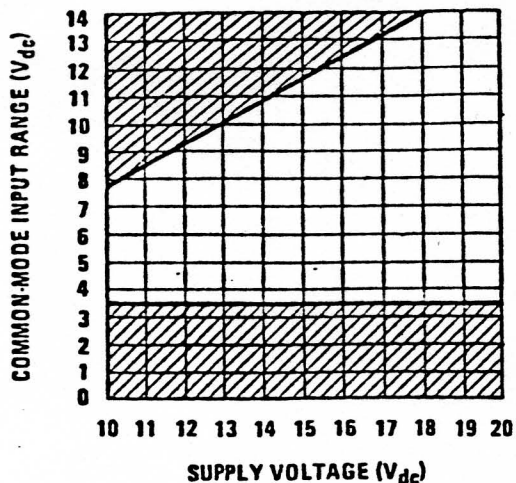


FIGURE 16. Common-Mode Input Range

The R.F. gain leaves room for considerable V.S.B. filter loss and still make the output level requirement. Furthermore, the harmonic level at the output does not place stringent demands on the filter out of band attenuation. An actual photograph of the R.F. output spectrum in Figure 17 shows the extremely low beat products.

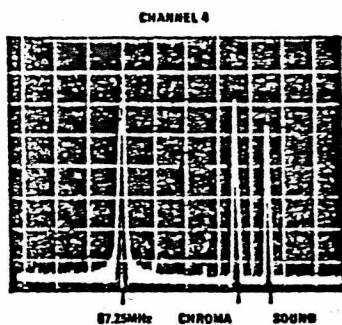
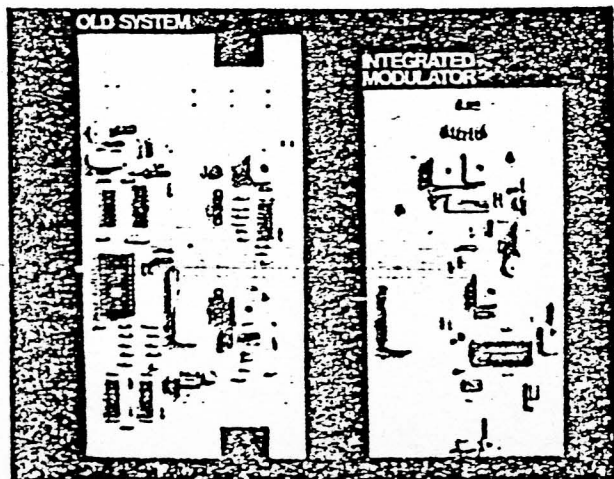


FIGURE 17. Output Spectrum

The board savings in a T.V. game with color and sound are shown in Figure 18. In the old system individual multiplier and transistor array IC's were used for chroma encoding and R.F. modulation, and two switches were required to change channels. The 1-chip modulation system greatly reduces parts count and simplifies the board layout.



CONCLUSION

The requirements for interfacing video signals to the antenna terminals of a color T.V. receiver are clearly defined. To meet these requirements, high-frequency design problems must be considered.

The 1-chip approach described successfully performs all encoding and modulation functions. D.C. channel switching and good flexibility make the device easy to use in a variety of applications. Significant board savings are achieved over previous systems.

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3. "Performance Guidelines for Video Players," *Consumer Products Bulletin No. 5*, Electronic Industries Association, May 1973.
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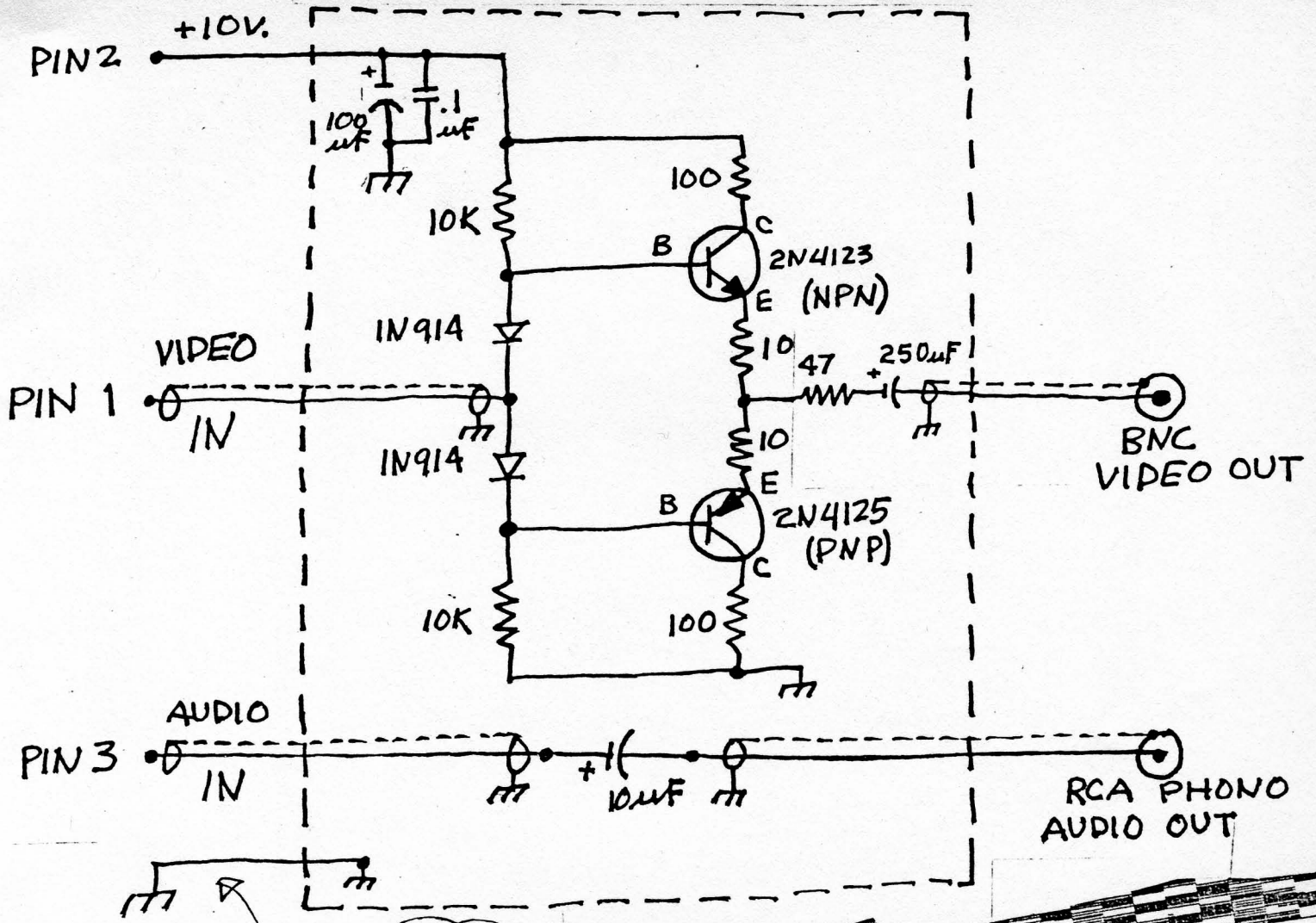
BIOGRAPHY

Milton E. Wilcox has been head of the TV and Radio IC Development section of Linear Integrated Circuits at National Semiconductor Corp. since 1975. He holds eleven patents in the field of integrated circuit system and design techniques and has published four papers in the consumer field.

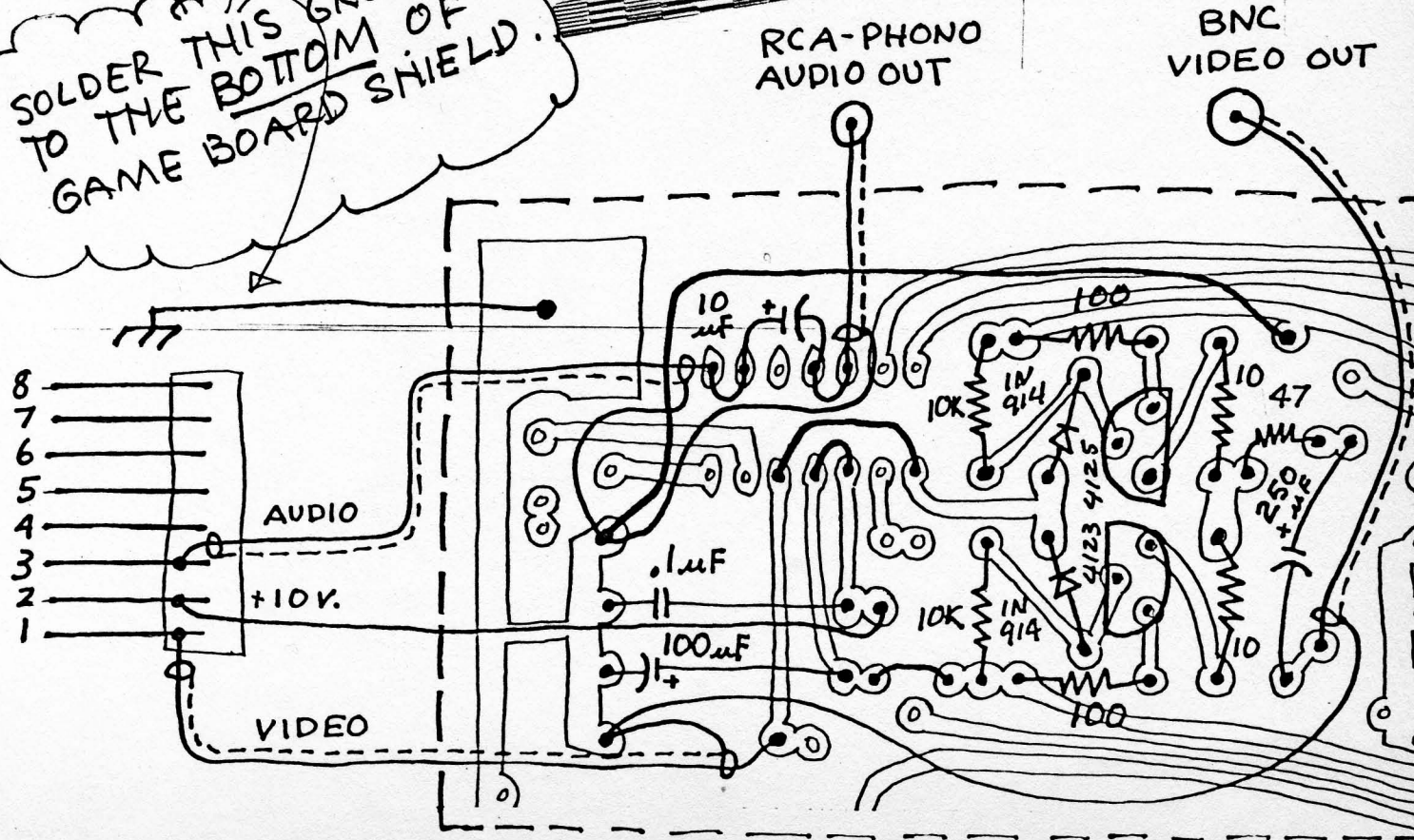
Prior employment includes seven years at Motorola in development of television ICs in the Consumer IC Group.

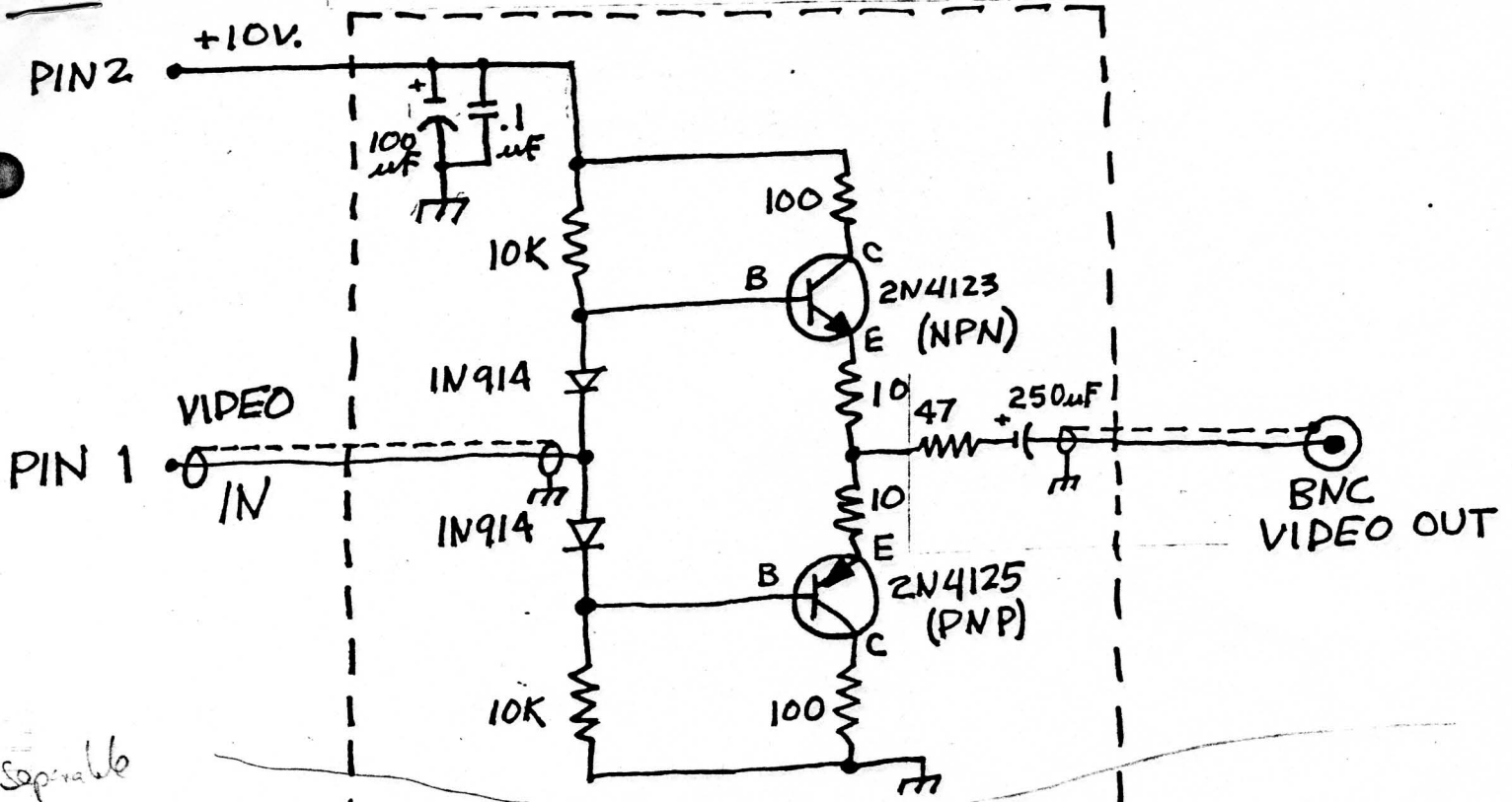
Holder of a MSEE from Arizona State University, Mr. Wilcox is a member of IEEE, Tau Beta Pi, and Eta Kappa Nu.



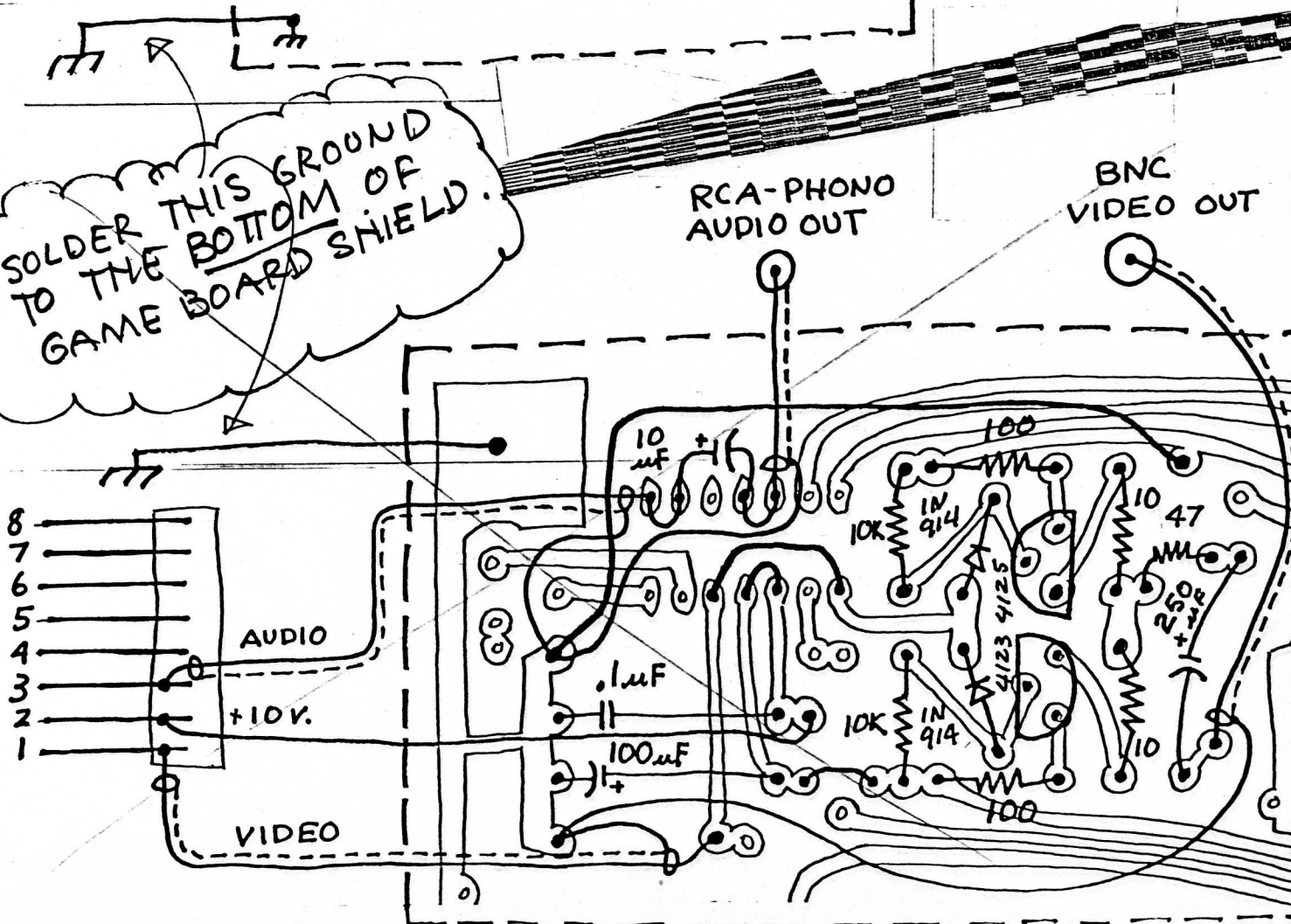


SOLDER THIS GROUND TO THE BOTTOM OF GAME BOARD SHIELD.





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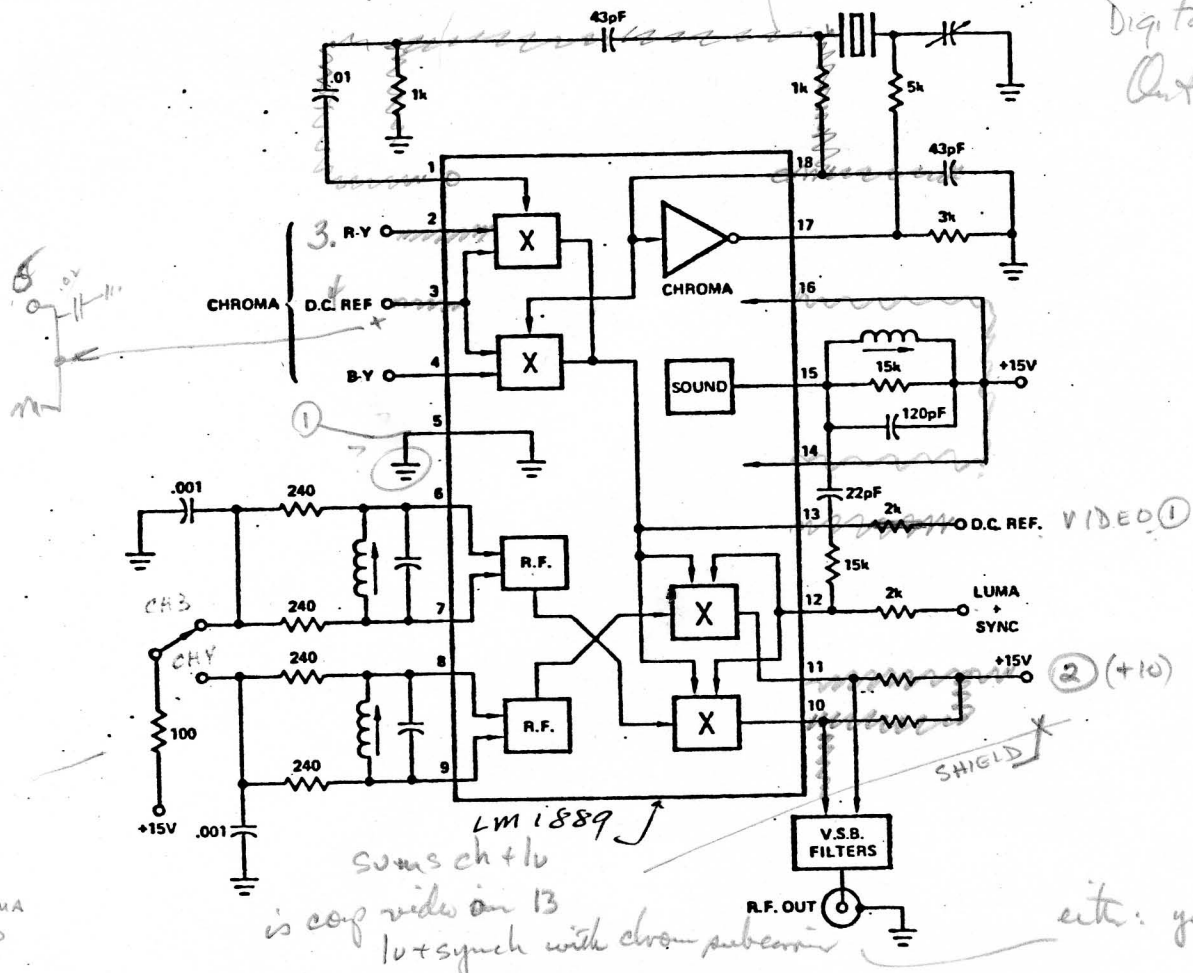


FIGURE 13. 2-Channel Encoder/Modulator

- 0-5
- 0-8-Y
- 0-R-Y
- 0-+2.5
- 0-4 CHROMA
- 0-AUDIO
- 0-+10
- 0-1 VIDEO

etc: yes, use emitter follower
no subcarrier only
∴ video in pin 12

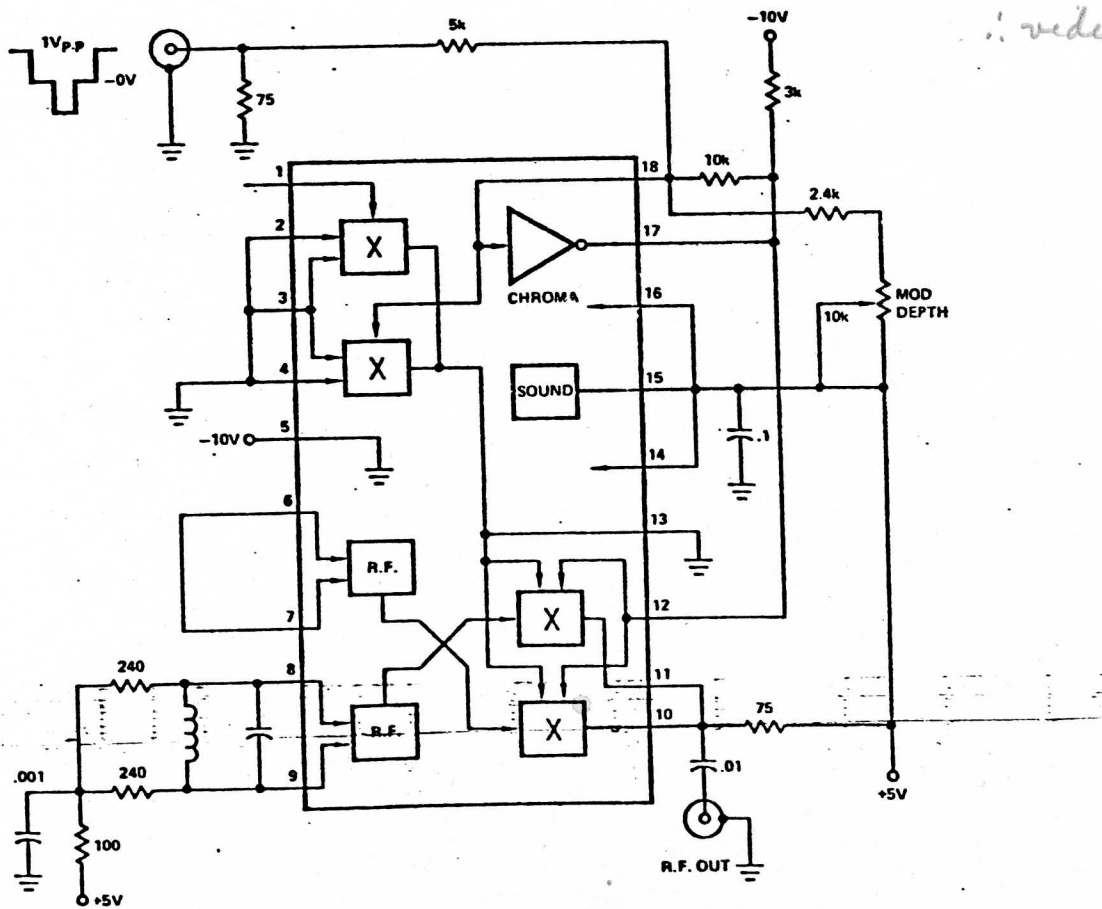


FIGURE 14. Color NTSC Modulator

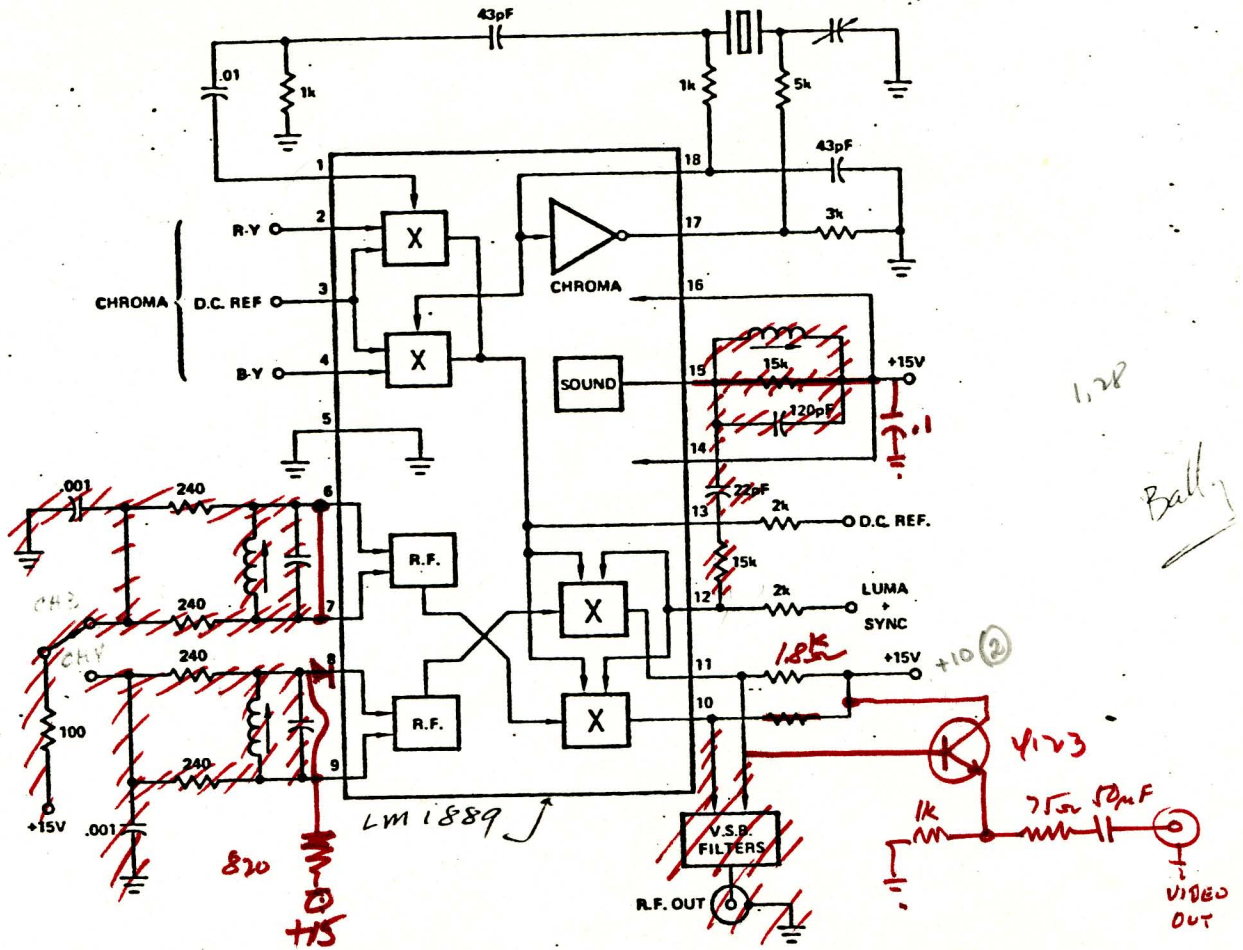
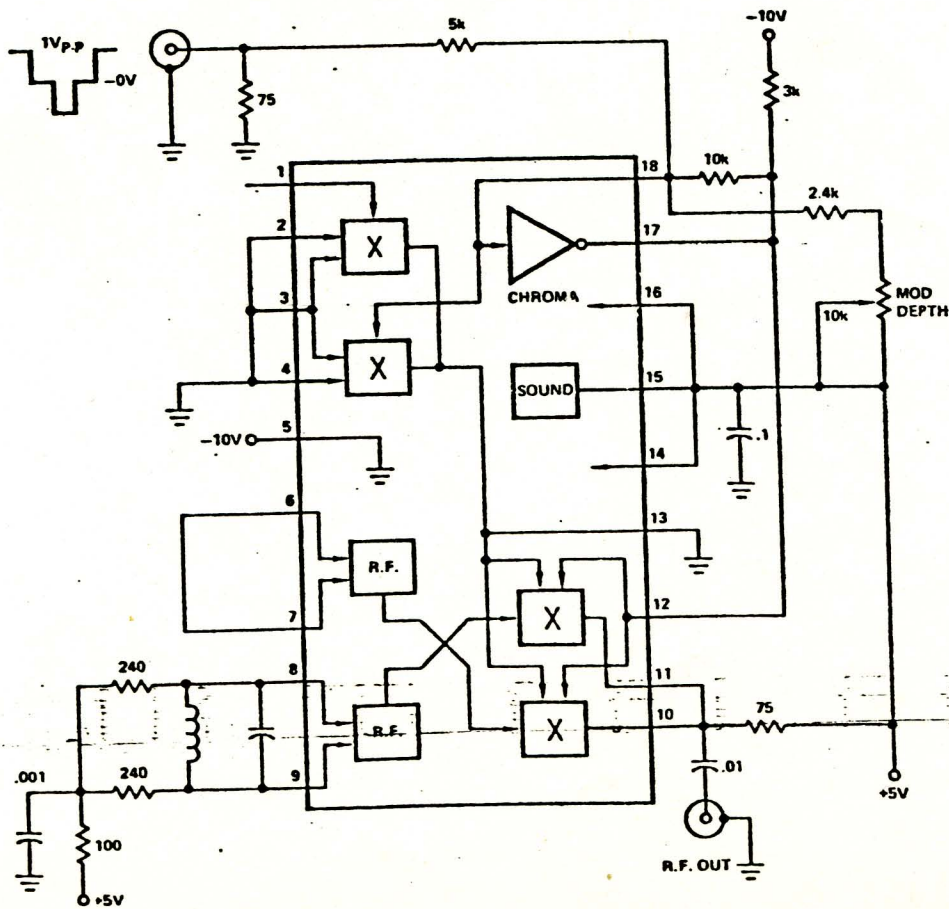


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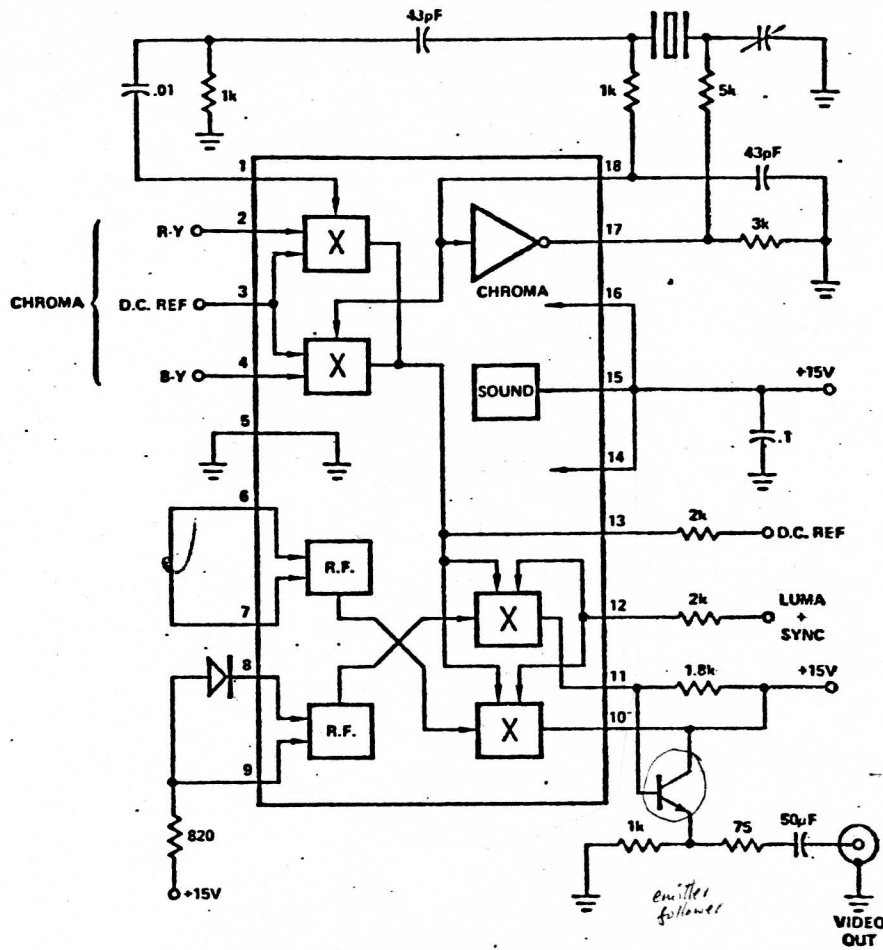


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RESULTS

One of the primary concerns in the development of the integrated video modulation system was oscillator stability. The results for the actual I.C. are summarized in Table 2. The per-

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Chroma Oscillator Output, Pin 17	5V _{p-p} square wave
Chroma Modulator Conversion Gain	0.6V _{p-p} /Volt
R.F. Modulator Conversion Gain	10mV _{rms} /Volt
Output Beat Products	-60dB
Output Harmonics (un-filtered)	
2nd, 3rd	-12dB

