APPLICATION OF THE
MC1374 TV MODULATOR

INTRODUCTION

The MC1374 was designed for use in applications where separate audio and composite video signals are available, which need to be converted to a high quality VHF television signal. It is ideally suited as an output device for subscription T.V. decoders, video disk and video tape players.

The MC1374 contains both FM and AM modulator and oscillator functions. The AM system is a basic multiplier combined with an integral balanced oscillator capable of over 100 MHz operation. Both multiplier signal inputs are brought out without internal bias, permitting flexibility of video dc level and polarity, and separate sound insertion. An external resistor value can be chosen to select video gain.

The FM oscillator/modulator is actually one circuit. It is, more accurately, a voltage-controlled oscillator, which exhibits a nearly linear output frequency versus input voltage characteristic for a wide deviation. This provides a good FM source with few and inexpensive external parts (no varactors). It has a frequency range of 1.4 to 14 MHz, and can typically produce a ±25 kHz modulated 4.5 MHz signal with about 0.6% total harmonic distortion.

The MC1374 can deliver nearly constant output amplitude from a supply voltage of 5.0 V to 12 Vdc. Typical current drain is about 12 mA. With 75 Ω as the optionally selected source impedance, the open circuit RF output voltage is 170 mV p-p, more than sufficient to drive a vestigial side-band output filter and still provide the 3.0 mV RMS permitted by the FCC.

VIDEO MODULATOR (AM MODULATOR)

The AM modulator incorporated in this design is exactly the MC1596 except that the "upper quad" is already connected to a balanced oscillator drive source, and is therefore, not brought out. (See Figure 1.) All other "handles" are available for use. Access to both inputs enables the designer to keep video and inter-carrier sound sources apart. Either input can be used for either signal, as circuit layout demands, but the arrangement shown is preferred to minimize interference between input signals and oscillator circuits, and to assure flexibility of video polarity and amplitude.
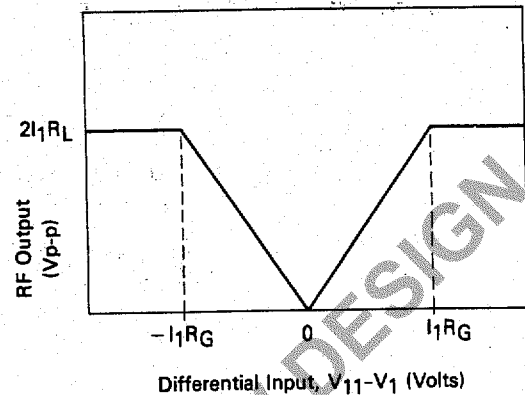
The input-output characteristic is shown in Figure 2, expressing output peak-to-peak carrier as a function of the difference voltage between the inputs, pin 11 and pin 1. This transfer function is extremely linear and basically reflects two simple operating rules:

1. When the inputs are equal, both Q10 and Q11 conduct $I_1 = 1.15$ mA each, established by internal current sources, Q8 and Q9. The output voltage is (theoretically) dc, and is $I_1 R_L$ below V_{CC}.

2. As one of the inputs is lowered with respect to the other, the current in that input leg is transferred to the other side, in the amount of

$$\frac{\pm(V_{11} - V_1)}{R_G}$$

until both current sources feed only one side. (R_G is the gain adjustment resistor between the input

transistor emitters). At this input, the output voltage swings from V_{CC} to $(V_{CC} - 2I_1 R_L)$, for a peak-to-peak RF output of $2I_1 R_L$. The conversion gain of the system is, therefore,

$$\frac{V_{out\ p\text{-}p}}{V_{11} - V_1} = \frac{2I_1 R_L}{I_1 R_G} = \frac{2R_L}{R_G}$$

For a detailed explanation of the balanced modulator, see AN532[1].

FIGURE 2 — AM MODULATOR TRANSFER FUNCTION

FIGURE 1 — THE AM SYSTEM
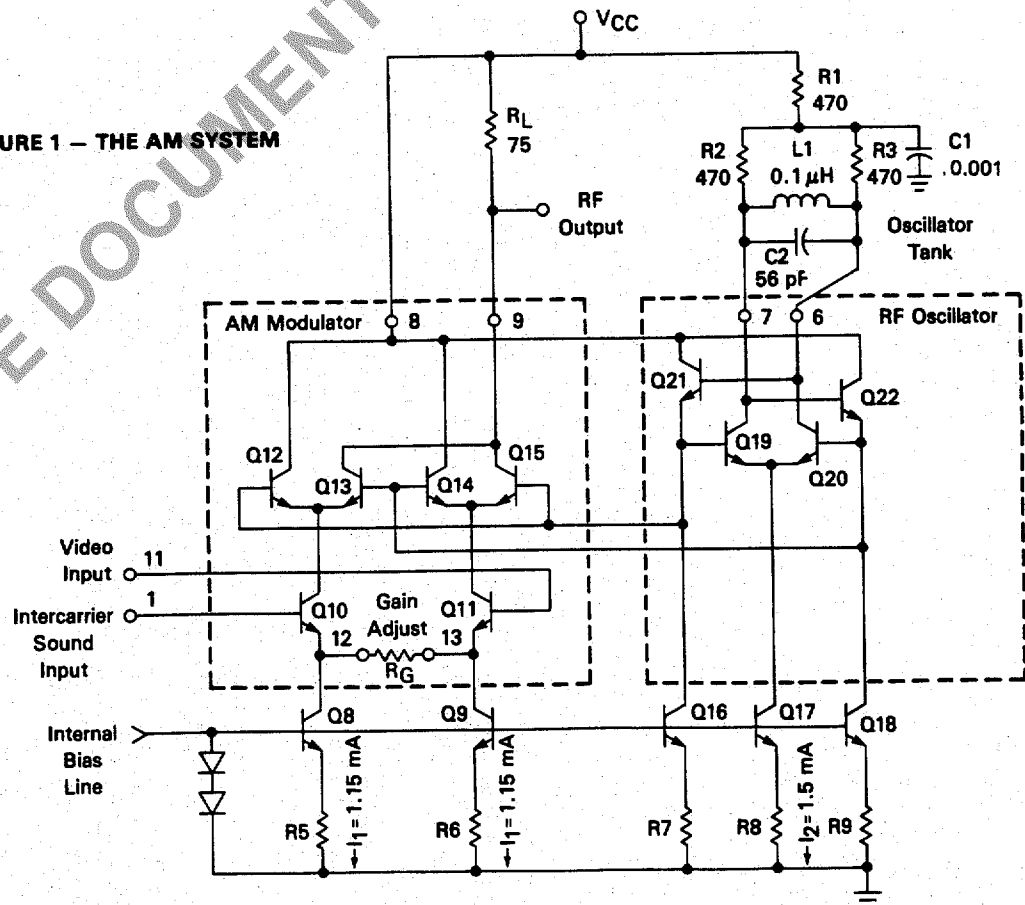
The load resistor R_L is usually 75 Ω to match a constant impedance filter and typical T.V. cable system. Other values are useable but a large value for R_L will impose some limitation. This will be covered a little later under "Biasing the AM Section".

The gain resistor R_G should be chosen in accordance with the available video amplitude. This will be covered in greater detail in the section on 920 kHz beat generation, but a good guideline would be to allow twice the dynamic range which would be anticipated from just the peak (sync level) video:

$$R_G = \frac{2 \text{ (peak video)}}{1.15 \text{ mA}}$$

While the theoretical range of input voltage and corresponding R_G is quite wide, there are other considerations. At the upper end, the on-chip FM sound system can only deliver a maximum of about 500 mV p-p of 4.5 MHz to the AM modulator. This would imply a peak video of about 1.0 V maximum if standard broadcast picture-to-sound ratio is to be observed. At the lower end, the primary limitation is one of noise. In keeping with good practice, to assure that background noise is more than 60dB below standard white, the minimum peak (sync tip) video should be at least 0.25 volt.

Although the MC1374 is a state-of-the-art device with ft = 600 MHz transistors, the application at 60 MHz is not totally free of difficulty. Small phase errors within the device begin to introduce substantial amounts of 2nd harmonic in the RF output. At 61.25 MHz, the 2nd harmonic is only 6 to 8dB below the maximum fundamental. Though this poses no real impairment of performance and would be ignored by a T.V. receiver's selectivity, it is disturbing in the lab work when trying to observe a modulation pattern, and it certainly would not meet FCC approval. For this reason a double pi low pass filter is shown in the test circuit of Figure 3 and works well for channel 3 and 4 lab work. For a fully commercial application, a vestigial sideband filter will be required. (The general form and approximate values are shown in Appendix I.) Since it is used to carefully truncate the lower AM sidebands, it must be exactly aligned to the particular channel.

FIGURE 3 — AM SYSTEM TEST CIRCUIT
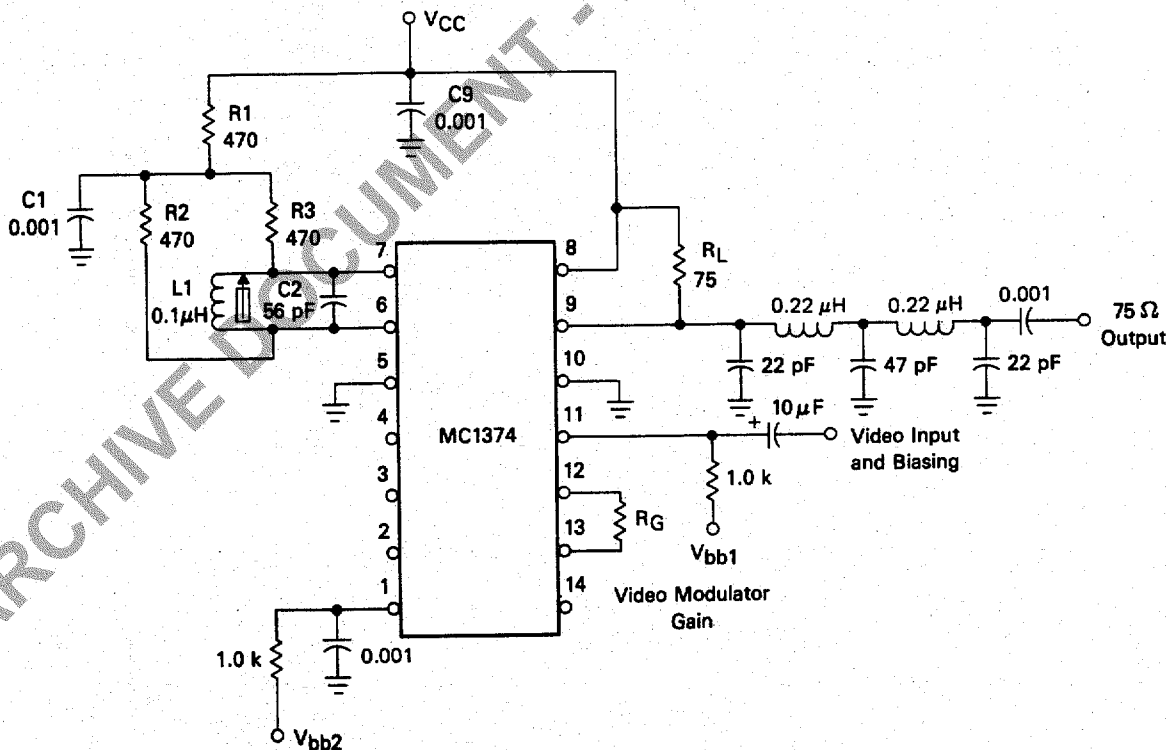
THE AM OSCILLATOR

The AM oscillator can be used dependably to about 105 MHz. This goes well beyond the usual U.S. system channels 3 and 4 requirements (61.25 and 67.25 MHz), and is high enough to cover channels 1, 2 and 3 in Japan (91.25, 97.25 and 103.25). Remote electronic bandswitching and crystal control can be readily accommodated. Higher frequency operation, up to U.S. channel 7 (176.25 MHz) has been achieved, but is not recommended, due to problems with oscillator startup and unpredictable oscillator mode shifts.

The oscillator requires only a parallel LC from pin 6 to pin 7 with simple provisions for connecting supply voltage. Over a very broad range of Q, the oscillator will operate stably and start dependably, but an operating Q of 10 to 20 is recommended as a compromise between parasitic tendencies and poor starting. It is best to keep the coil small and capacitance large to minimize the variation due to the IC capacitance. The capacitance added by the IC is approximately 4.0 pF, but can approach 6.0 pF with socket and wiring.

Unbalanced operation; i.e., pin 6 or 7 bypassed to ground, is not recommended. Although the oscillator will still run, and the modulator will produce a useable signal, this mode causes substantial base-band video feedthrough. The only reason for using the unbalanced tank would be simplification of bandswitching, but as Figure 4 shows, this can be accomplished just as economically without using the unbalanced method.

FIGURE 4 — OSCILLATOR COMPONENTS
FOR CHANNEL 3 AND 4 OPERATION
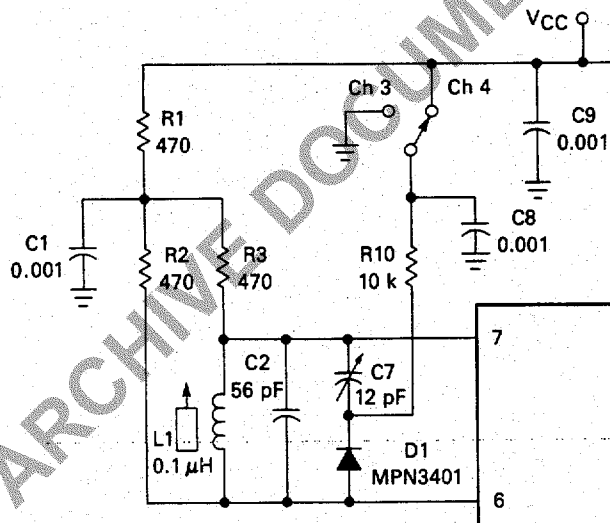
Note:
First tune L1 on Ch 4,
then C7 on Ch 3.

The oscillator frequency with respect to IC chip temperature is extremely well compensated. Performance of the channel 3 standard test circuit shows less than ±20 kHz total shift from 0°C to 50°C as shown in

Figure 5. At higher temperatures the slope approaches 2.0 kHz/°C. Improvement in this region would require a temperature compensating tuning capacitor of the N75 family (75PPM negative), but note that many commercial designs only require 8.0 kHz/°C.

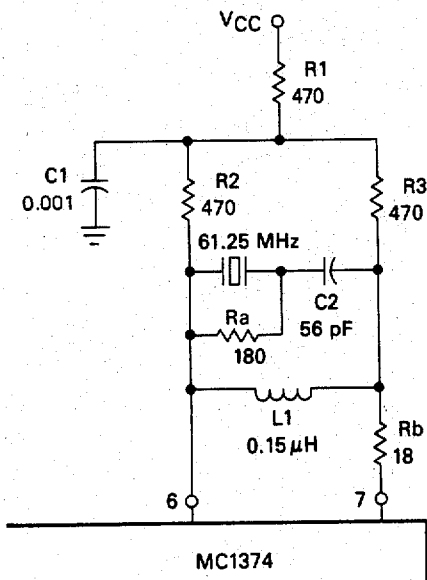FIGURE 5 — RF OSCILLATOR FREQUENCY
versus TEMPERATURE
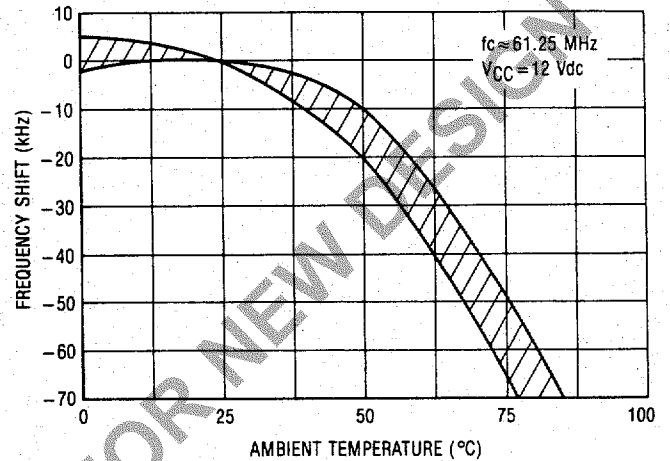
Oscillator supply voltage stability is also good, particularly toward the 12 V end, as shown in Figure 6. Operation near the low voltage end may require some supply regulation in stringent applications.

FIGURE 6 — RF OSCILLATOR FREQUENCY
versus SUPPLY VOLTAGE
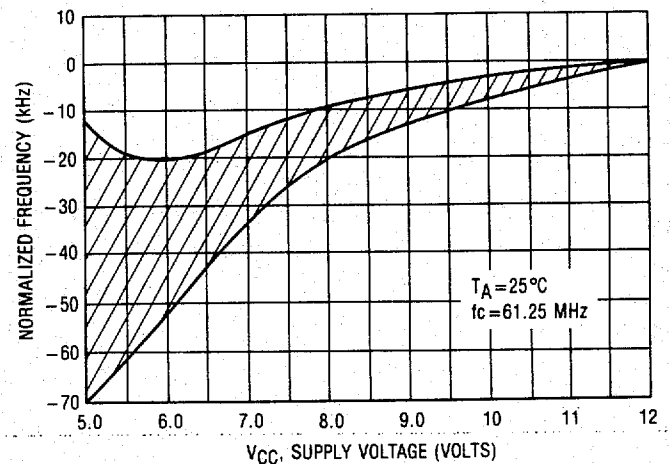
Crystal control is feasible using the circuit shown in Figure 7. The crystal is a 3rd overtone series type, used in series resonance. The L1, C2 resonance is adjusted well below the crystal frequency and is sufficiently tolerant to permit fixed values. A frequency shift versus temperature of less than 1.0 Hz/°C can be expected from this approach. The resistors Ra and Rb are to suppress parasitic resonances.

FIGURE 7 — CRYSTAL CONTROLLED RF OSCILLATOR FOR CHANNEL 3, 61.25 MHz

MC1374

OSCILLATOR FEEDBACK TO AM MODULATOR INPUTS

The circuit designer should be aware of the possibility of introducing carrier frequency shift in the AM system. Inattention to wiring and components on pins 1 and 11 can cause as much as 300 kHz shift in carrier (at 67 MHz) over the video input range. This appears to be caused by output RF being transmitted to components and wiring on the input pins. A careful layout can be expected to keep this shift below 10 kHz. Short leads are important everywhere in the AM system. If the video source impedance is low, pin 11 may be shunted by a small bypass (<100 pF), further reducing the possibility of oscillator feedback. Oscillator may also be inadvertently coupled to the RF output, with the undesired effect of preventing a good null, or carrier rejection, when $V_{11} = V_1$. Reasonable care will yield carrier rejection ratios of 36 to 40dB below sync tip level carrier.

THE "920 BEAT" PROBLEM

Non-linear devices cause signal mixing and intermodulation products. In television, one of the most serious concerns is the prevention of the intermodulation of color (3.58 MHz) and sound (4.5 MHz) frequencies, which causes a 920 kHz signal to appear in the spectrum. The concern is very great because this is a relatively "coarse" video frequency, with very high visibility. In fact, a level of "920" which is 54dB below the picture carrier is considered to be at the threshold of perceptibility. Very little (3rd order) non-linearity is needed to cause this problem, and even though the MC1374 appears extremely linear, it does produce "920". This is one of the most important considerations in choosing gain and signal input levels.

The most common test method used in the industry today for measuring "920" is to establish a reference sync level of video, then add 30% chroma and -12dB of sound. This is usually interpreted to mean, for example:

Video reference = 1.0 V
Chroma (3.58 MHz) = 300 mV p-p
Sound (4.5 MHz) = 250 mV p-p

A spectrum analyzer viewing the modulator output is first set up to 0dB on the video reference. Then chroma and sound are added. (These will appear at -22dB and -24dB, respectively, assuming the gain setting value of R_G is high enough to prevent overload). Finally, the amount of "920" with respect to the video carrier is measured over the useful video carrier range.

While this signal ratio may be widely used for comparative tests, it does not represent very closely the picture, chroma, and sound levels normally transmitted. A normal picture contains considerably less 3.58 MHz energy, due to the suppressed carrier encoding. On the other hand, a standard T.V. station transmits a much stronger sound signal, typically at -12 to -20dB on the spectrum analyzer. This appears as a single sideband, and is actually a separate transmitter, usually operated at half the power of the video transmitter. A sound level of 500 mV p-p in the previous example would produce a spectrum analyzer level of -18dB. This is a more realistic test signal for "920" evaluation.

Figures 8, 9 and 10 summarize a series of "920" measurements taken with different relative sound levels, video reference levels and values of gain resistor R_G. The results in Figure 8 are unsatisfactory by either measurement standard, and demonstrate that too much of the available dynamic range of the MC1374 has been used. The other examples show that by either reducing standard signal level, or reducing gain (R_G), acceptable results may be obtained.
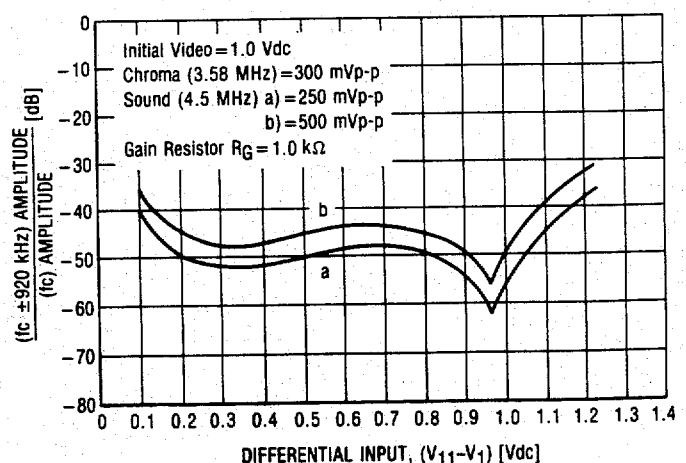
FIGURE 8 — 920 kHz BEAT

Initial Video = 1.0 Vdc
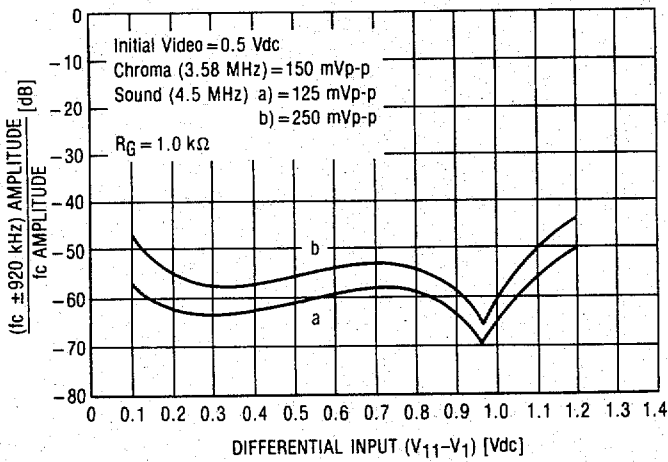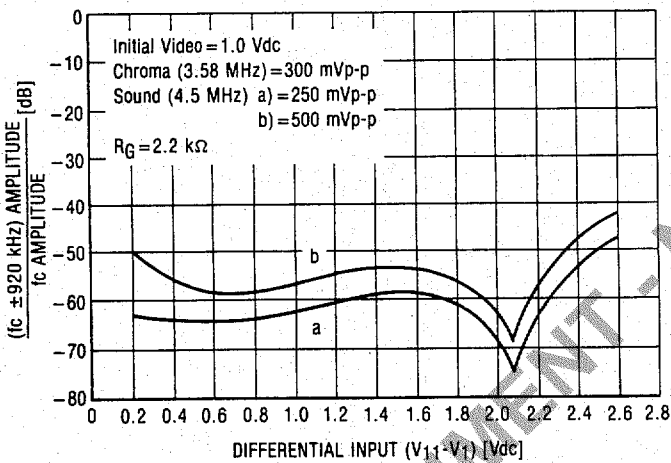Chroma (3.58 MHz) = 300 mVp-p
Sound (4.5 MHz) a) = 250 mVp-p
b) = 500 mVp-p
Gain Resistor R_G = 1.0 kΩ

DIFFERENTIAL INPUT, $(V_{11}-V_1)$ [Vdc]

FIGURE 9 — 920 kHz BEAT

Initial Video = 0.5 Vdc
Chroma (3.58 MHz) = 150 mVp-p
Sound (4.5 MHz) a) = 125 mVp-p
                b) = 250 mVp-p
$R_G = 1.0\ k\Omega$

(Y-axis: $\frac{(fc \pm 920\ kHz)\ AMPLITUDE}{fc\ AMPLITUDE}$ [dB])

DIFFERENTIAL INPUT ($V_{11}-V_1$) [Vdc]

FIGURE 10 — 920 kHz BEAT

Initial Video = 1.0 Vdc
Chroma (3.58 MHz) = 300 mVp-p
Sound (4.5 MHz) a) = 250 mVp-p
                b) = 500 mVp-p
$R_G = 2.2\ k\Omega$

(Y-axis: $\frac{(fc \pm 920\ kHz)\ AMPLITUDE}{fc\ AMPLITUDE}$ [dB])

DIFFERENTIAL INPUT ($V_{11}-V_1$) [Vdc]

BIASING THE AM SECTION

In this section there is frequent use of the letter ϕ, which represents one diode forward drop and is approximately 0.75 volts. The assumption has been made, and in most cases borne out experimentally, that avoidance of saturation in **any** stage is desirable to minimize non-linearities and interaction on the IC chip. With this in mind, the following guidelines are helpful in establishing bias levels. (Refer to Figure 1.)

The oscillator produces a symmetrical waveform of 2ϕ peak-to-peak at pins 6 and 7. The values of R1, R2 and R3 should be chosen to assure that pins 6 and 7 are at least ϕ below V_{CC}. Note that current source $I_2 = 1.5\ mA$. This is the total current in pins 6 and 7. The resistor values shown provide sufficient drop while giving the best compromise of decoupling and Q. The oscillator outputs, via Q21 and Q22, drive the bases of the "upper quad" Q12, Q13, Q14 and Q15. The collectors of Q13 and Q15 can be as low as $2I_1\ R_L$ below V_{CC}; not very important when $R_L = 75$, but worthy of consideration at higher loads. The supply voltage which should be established at the oscillator tank:

Average V pin 6 or 7 = $V_{CC} - \phi - 2I_1\ R_L$

And since the emitters of Q12 through Q15 are 2ϕ below the voltage on pin 6 or 7, the maximum voltage which should be applied at pins 1 and 11 is given by:
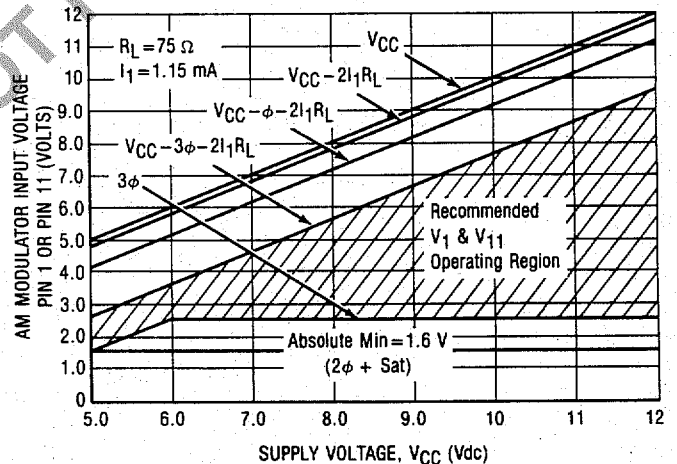
max V pin 1 or 11 = $V_{CC} - 3\phi - 2I_1\ R_L$

For the 75 Ω case:

$$V\ \text{pin 6 or 7} \equiv V_{CC} - 0.9$$
$$\text{max V pin 1 or 11} \equiv V_{CC} - 2.4$$

On the low end, the bases of the current source transistors Q8 and Q9 are at 2ϕ above ground. Conservatively, the input pins 1 and 11 should never go below 3ϕ above ground, but in fact the current sources can be saturated without apparent problems. No distortions are evident down to 1.6 V on either input. Operation in this region is necessary when using a 5.0 V power supply, but should not be used when higher power supply is available. In summary, the useful "window" for pin 1 and pin 11 input voltages is shown in Figure 11.

FIGURE 11 — THE OPERATING WINDOW

$R_L = 75\ \Omega$
$I_1 = 1.15\ mA$
V_{CC}
$V_{CC} - 2I_1R_L$
$V_{CC} - \phi - 2I_1R_L$
$V_{CC} - 3\phi - 2I_1R_L$
3ϕ
Recommended V_1 & V_{11} Operating Region
Absolute Min = 1.6 V
(2ϕ + Sat)

(Y-axis: AM MODULATOR INPUT VOLTAGE PIN 1 OR PIN 11 (VOLTS))

SUPPLY VOLTAGE, V_{CC} (Vdc)

A biasing divider to pin 1 and another to pin 11 can be chosen to establish nominal conditions for a static picture, such that a test pattern signal can be ac coupled to the input. Figure 12 is an illustration of the signal voltages as used in the test circuit. Note that the dc voltages on pin 1 and pin 11 are arbitrary in the absolute sense (within the "window" of Figure 11) but the **relative** polarity and exact difference between these dc levels is critical to the establishment of standard levels. If V_{CC} changes, divided voltages will change proportionately, as will the difference between them. This is unacceptable, as it changes modulation depth. Similar difficulties occur if the video input signal changes in average value, such as a full black or full white scene.

FIGURE 12 — APPROXIMATE BIAS FOR AC COUPLED INPUT

Vpin 11 = Vpin 1 = 0% carrier

White = 12.5%

Vpin 11 average bias

Black = 75%

Vpin 11 peak = 100%
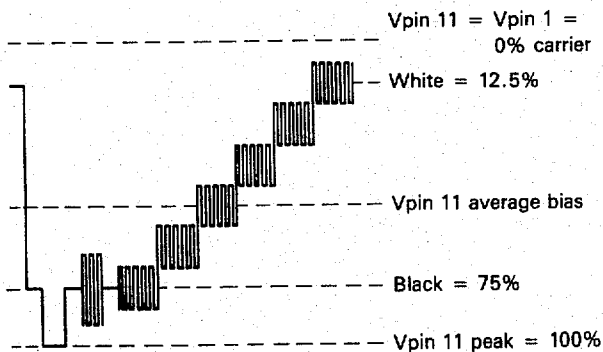
In many cases the video source itself is dc referenced, and can be made to provide both pin 1 and pin 11 reference levels. If not, then the two divider voltages must be regulated, moved a bit farther apart and the sync signal clamped to the pin 11 bias by means of a diode, as shown in Figure 13. The divider impedance should be kept low to minimize the time constant of clamping corrections as video content changes. This is the classical sync clamping design problem, and workable compromises are achievable.[2]

FIGURE 13 — SIMPLE VIDEO CLAMP

V_{CC}

560

220

11

10 μF

Video Input Signal

56 k
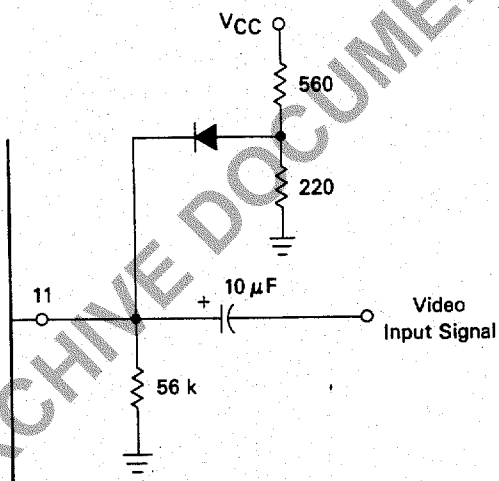
THE AM MODULATOR PERFORMANCE

A widely accepted measurement tool, which is very effective in evaluation of a video modulator, is the IRE test signal. The photographs in Figure 14 and 15 show this video signal and the resulting modulated RF output from the MC1374. This signal contains sync, color burst, standard black and white levels and four equally spaced gray steps. Also, each step contains a bar of

color of equal phase and amplitude (20 IRE Units). This signal is supplied to the MC1374, and bias is adjusted so that the white step produces 12.5% carrier, compared to sync tips. The output of the modulator is fed to a linear RF amplifier and a known high quality detector. The maximum measured phase difference between detected color bars is defined as differential phase error. The MC1374 typically gives less than a 2° total spread.

The difference in amplitude between the largest and smallest color bar is called differential gain distortion. In the MC1374, the test results range from 5 to 7%. (Note that this is the relative amplitude between bars which are only 20 IRE units in amplitude.) It is equivalent to an overall linearity (from below white to above black) of a little over 1%. This is good peformance for a video amplifier, exceptional for a modulator.

The video input frequency response is, for all practical purposes, flat. Driven from a 75 Ω source, there is no rolloff at 30 MHz.

FIGURE 14 — IRE TEST SIGNAL
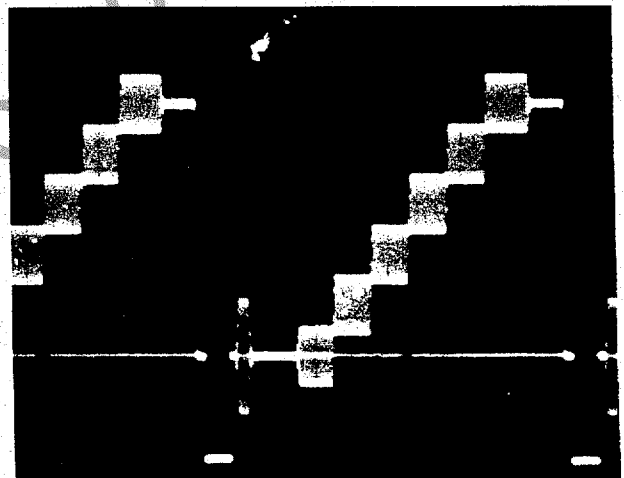
FIGURE 15 — MC1374 MODULATED OUTPUT
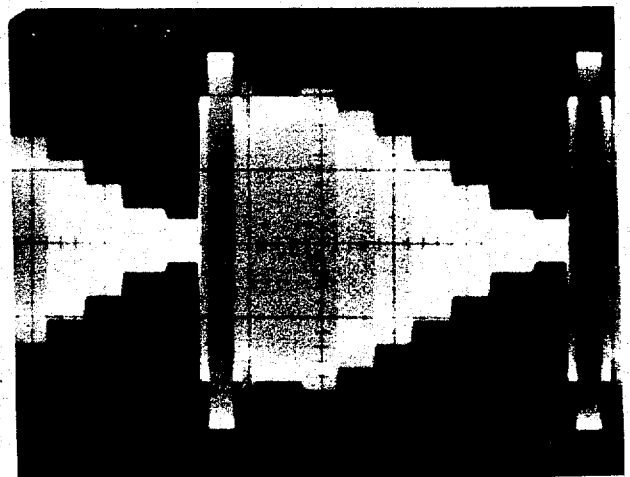
THE FM SECTION

The FM system was designed specifically for the T.V. intercarrier function at 4.5 MHz for the U.S. and 5.5 MHz for CCIR countries. For circuit economy, one-phase shift circuit was built into the chip. This had the benefit of saving components and pin outs, and the drawback of limiting the frequency range of this section. Still, it will operate from 1.4 MHz to 14 MHz, enough to be used in a cordless telephone base station (1.76 MHz), and high enough to possibly be used as an FM IF test signal generator.[3]

The ability of this oscillator/modulator to be linearly frequency modulated is quite impressive. While certainly not capable of the fidelity required in "HI-FI" FM, the performance of this system compares favorably to many laboratory generators, and exceeds the distortion performance of varactor modulators by several times. At 4.5 MHz, a deviation of ±25 kHz can be achieved with 0.6% distortion (typical).

In the circuit of Figure 16 all seven devices Q1 through Q7 are active in the oscillator/modulator function. Differential amplifier Q3, Q4, Q5, Q6 acts as a gain stage, sinking current from input section Q1, Q2 and the phase-shift network R17 and C1. Input amplifier Q1, Q2 can vary the amount of "in phase" Q4 current, to be combined with phase-shifter current in load resistor R16. The R16 voltage is applied to emitter follower Q7 which drives an external series L–C circuit. Feedback from the center of the L–C circuit back to the base of Q6 closes the loop. As audio input is applied which would offset the stable oscillatory phase, the frequency changes to counteract.

It would seem natural to take the FM system output from pin 2, the emitter-follower output, but this output is high in harmonic content. Taking the output from pin 3 sacrifices somewhat in source impedance but results in a clean output fundamental, with all harmonics more than 40dB down. This choice removes the need for additional filtering components. The source impedance of pin 3 is approximately 2 kΩ, and the open-circuit amplitude is about 900 mV p-p for the test circuit shown in Figure 17.

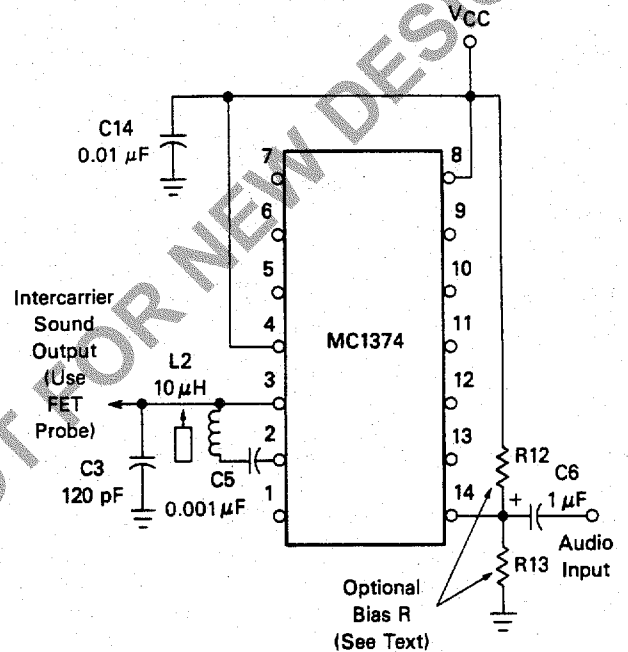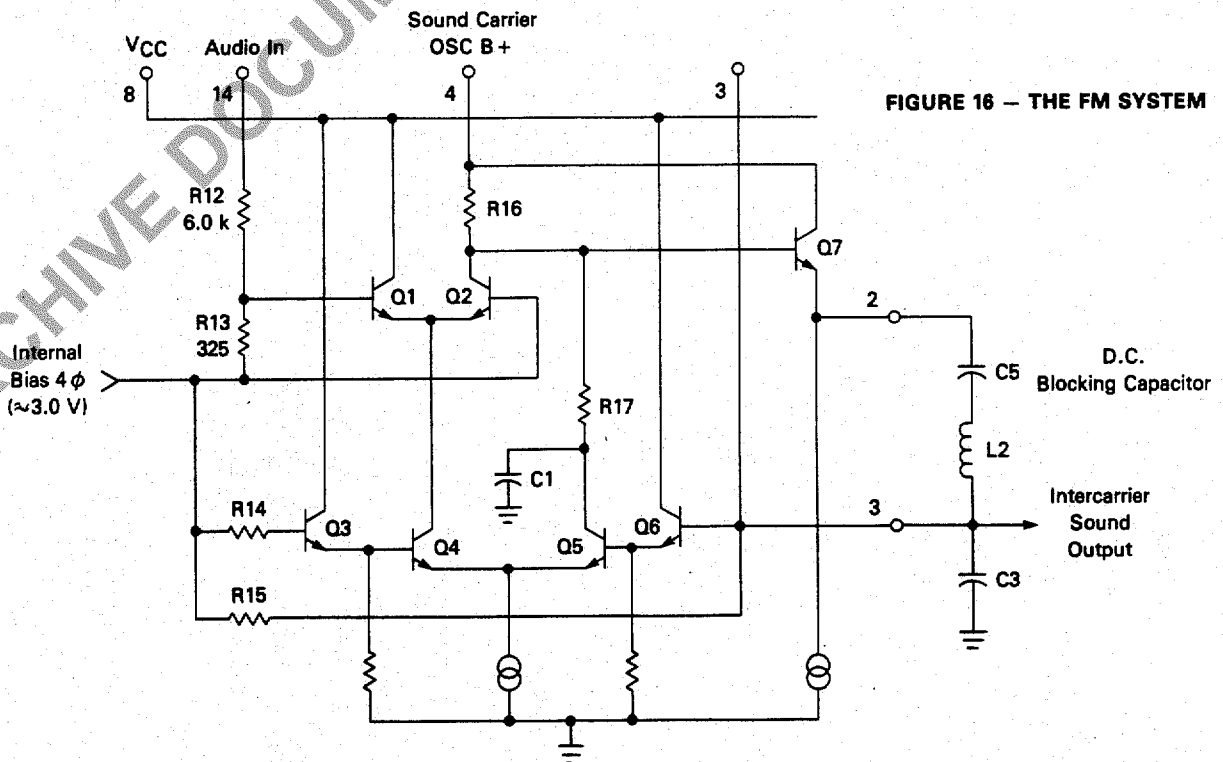**FIGURE 17 — FM TEST CIRCUIT**

FIGURE 16 — THE FM SYSTEM

FM SECTION CIRCUIT VALUES

The oscillator center frequency is approximately the resonance of the inductor L2 from pin 2 to pin 3 and the effective capacitance C3 from pin 3 to ground. Include approximately 6 pF (internal) when making frequency calculations. For overall oscillator stability, it is best to keep X_L in the range of 300 Ω to 1 kΩ.

The modulator transfer characteristic at 4.5 MHz is shown in Figure 18. The curve should be interpreted as a transfer function relating instantaneous pin 14 voltage to output frequency. Transfer curves at other frequencies have a very similar shape, but differ in maximum deviation per input volt, as shown in Figure 19.

FIGURE 18 — MODULATOR TRANSFER FUNCTION 4.5 MHz
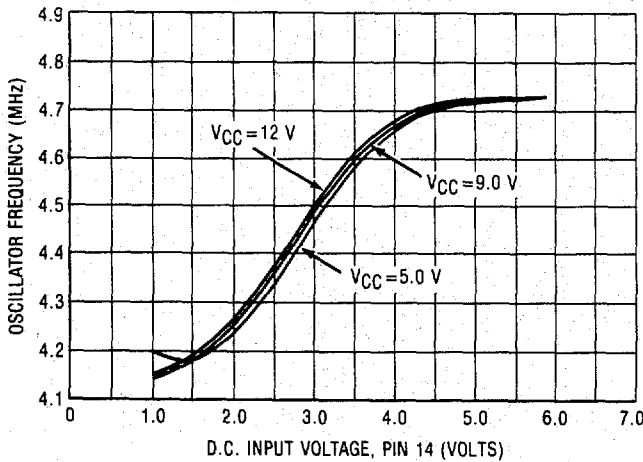
FIGURE 19 — MODULATOR SENSITIVITY

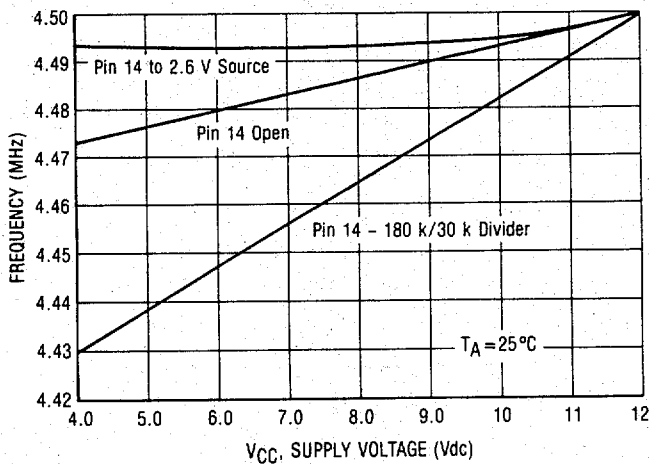### FIGURE 20 — DISTORTION versus MODULATION DEPTH
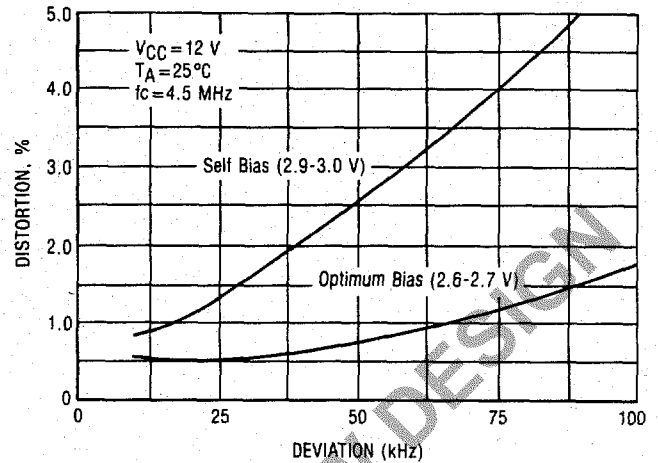
The impedance of the divider has a bearing on the frequency versus temperature stability of the FM system. Figure 21 was taken using an adjustable regulated bias source and varying the "pull down" resistor from pin 14 to the bias source to determine the most stable impedance. The resulting value of 27 kΩ can be replaced by a divider of 180 kΩ and 30 kΩ (for V_{CC} = 12 V) with equally good temperature stabilization results.

FIGURE 21 — FM SYSTEM FREQUENCY versus TEMPERATURE

Most applications will not require dc connection to the audio input, pin 14. However, some improvements can be achieved by the addition of biasing circuity. The unaided device will establish its own pin 14 bias at 4φ, or about 3.0 V. A brief study of the transfer characteristic shows that this bias is a little too high for optimum modulation linearity. This can be verified by means of distortion measurements using a high quality FM detector and distortion analyzer. Figure 20 shows better than 2 to 1 improvement in distortion between the unaided device and pulling pin 14 down to 2.6 to 2.7 V. This can be accomplished by a simple divider, if the supply voltage is relatively constant.

However, as Figure 22 shows, a divider is not a good method if the supply voltage varies. The designer must make the decisions here, based on considerations of economy, distortion and temperature requirements and power supply capability. If the distortion requirements are not stringent; i.e., 2% at ±25 kHz deviation, then no bias components are needed. If, in this case, the temperature compensation needs to be improved in the high ambient area, the tuning capacitor from pin 3 to ground can be selected from N75 or N150 temperature compensation types.

FIGURE 22 — FM SYSTEM FREQUENCY versus V_{CC}

PRE-EMPHASIS

Standard practice in television is to provide pre-emphasis of higher audio frequencies at the transmitter and a matching de-emphasis in the T.V. receiver audio amplifier. The purpose of this is to counteract the fact that less energy is usually present in the higher frequencies, and also that fewer modulation sidebands are within the deviation window. Both factors degrade signal-to-noise ratio. Pre-emphasis of $75\,\mu s$ is standard practice. Usually the audio source to the T.V. modulator already has pre-emphasis, but for cases where it has not been provided, or is not capable of supplying the $6\,k\Omega$ input impedance of the MC1374, a suitable pre-emphasis network is covered in Appendix II.[4]

Another reason for dc input to pin 14 is the possibility of automatic frequency control. In some systems where high accuracy of intercarrier frequency is required, it may be desirable to feed back the dc output of an AFC or phase detector for nominal carrier frequency control. Obviously the filtering and response time of such a system will have to be slow enough so as not to follow the desired audio. Only limited control range could be used without adversely affecting the distortion performance, but as shown earlier, very little frequency compensation will be needed.

One added convenience in the FM section is the separate pin "oscillator B+" which permits disabling of the sound system during alignment of the AM section. Usually it can be hard wired to the V_{CC} source without decoupling.

ASSEMBLING A COMPLETE MODULATOR

Using the information developed in the preceding sections, a complete T.V. modulator circuit is presented. The schematic is shown in Figure 23. It includes the simple and almost lossless second harmonic output filter, rather than the more elaborate vestigial sideband type. The gain resistor, R8 in this case, is $2.2\,k\Omega$, for an intended video input of approximately 1.0 V peak at sync tip. This produces an output of 70 m V p-p unterminated, for a max RMS output of about 12 m V. This is 12dB greater than FCC rules permit, so it must be padded down for commercial applications.

FIGURE 23 — MODULATOR CIRCUIT

L1 - 4 Turns, #22, 1/4" Dia.
L2 - 40 Turns, #36, 3/16" Dia.
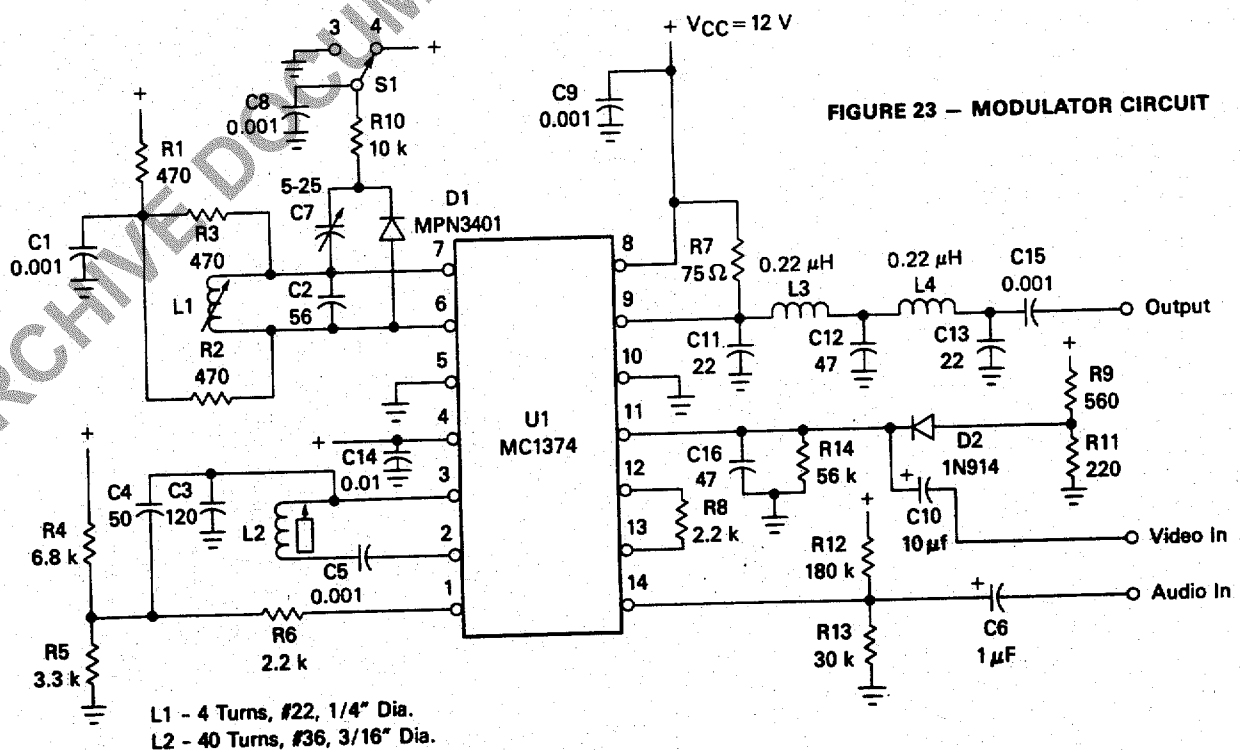
The modulator circuit includes channel 3 and channel 4 bandswitching, video sync tip clamping, and audio bias to reduce distortion. All 3 of these features can easily be deleted when minimum cost is needed.

One area which was touched upon earlier, but not fully developed, is the coupling of the intercarrier sound output from pin 3 to the sound side of AM modulator input, pin 1. The method shown in Figure 23 is the preferred approach, primarily because it permits easy adjustment of intercarrier amplitude with the minimum of "antenna" on pin 1. The input impedance at pin 1 is very high, so the intercarrier level is determined by the source impedance of pin 3 (about 2K), driving through C4 into the bias circuit impedance of R4 and R5, about 2.2K. This provides an intercarrier level of nearly 500 mV p-p, just right for the video level chosen here.

The artwork for a printed circuit version of this design is provided in Appendix III. Performance of the board is consistent with the data presented earlier and has been used successfully with both static (test pattern) and video disk sources. With a 12 V regulated supply there is less than ±10 kHz shift of RF carrier frequency from 0° to 50°C for any video input level.
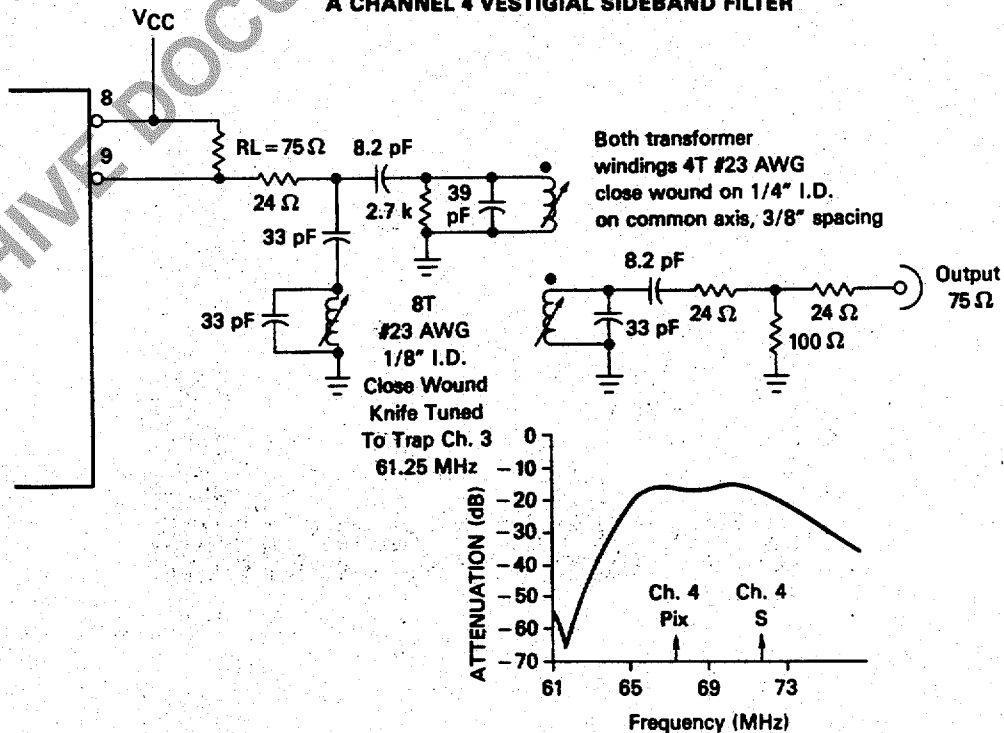
REFERENCES:

1. Hejhall, R. "MC1596 Balanced Modulator" Motorola AN531, July 1975.
2. Giles, M. "Television Sync Separator Design" CER105, April 1973.
3. MC1376 — FM Modulator, Advance Information Data Sheet.
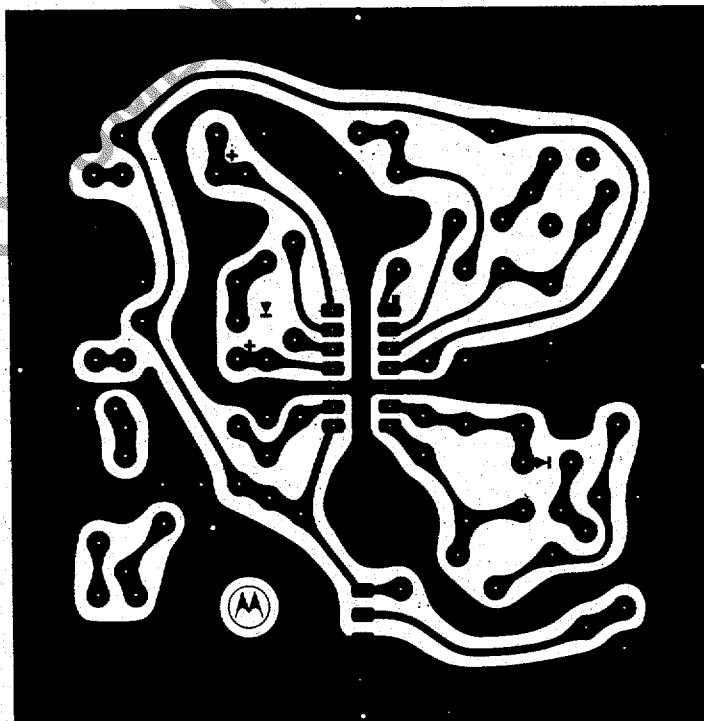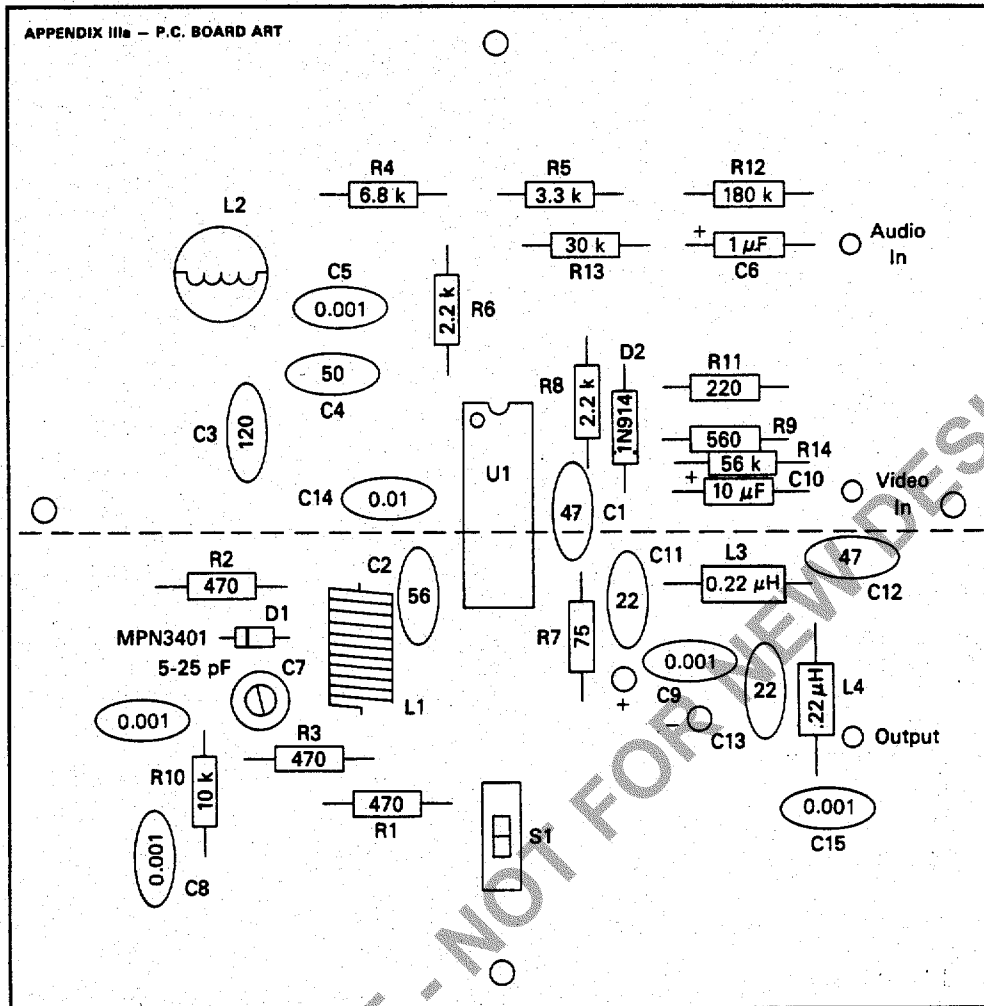4. ITT Handbook, p. 21-11.

APPENDIX II — AUDIO PRE-EMPHASIS CIRCUIT

$$\text{pre-emphasis} = 75\ \mu s = rC = \frac{1}{2\pi(2100\ \text{Hz})}$$
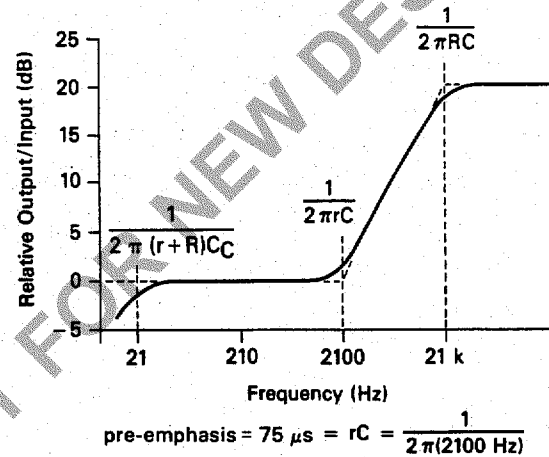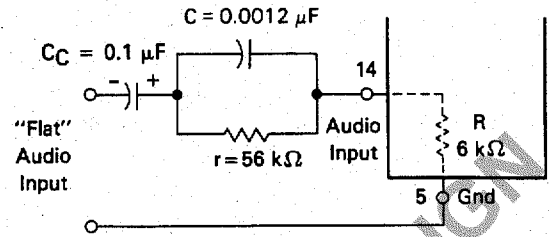
APPENDIX I
A CHANNEL 4 VESTIGIAL SIDEBAND FILTER

APPENDIX IIIa — P.C. BOARD ART