LB-1075

A TRANSISTOR FM SOUND DETECTOR CIRCUIT FOR TELEVISION RECEIVERS

RADIO CORPORATION OF AMERICA

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A TRANSISTOR FM SOUND DETECTOR CIRCUIT FOR TELEVISION RECEIVERS

Approved

Stuart Wm Seeley

This bulletin describes an experimental transistor FM detector circuit which is inherently insensitive to AM. Its characteristics make it particularly suitable for the sound detector in intercarrier-sound television receivers. The detector operates in an oscillating mode. This contributes to the high AM rejection and sensitivity.

Also described is a transistor driver, suitable for use with this FM detector. The driver is designed to provide symmetrical limiting for large signals. The combination of detector and driver has been incorporated in a sound strip for use with television receivers. This sound strip can be driven directly from the video amplifier.

Introduction

The desirable characteristics of high sensitivity and good AM rejection can be obtained in a transistor FM detector by operating the transistor as a locked oscillator-detector, as is shown in the circuit of Fig. 1.

The particular feedback arrangement restricts its operation to one slope of the impedance curve of the collector tank circuit. Since the detector operates in an oscillating mode, the voltage swing is limited, and the audio output is maintained at a constant level. The AM rejection is uniformly high over the full detector bandwidth. Drift transistors have characteristics which make them particularly suitable for this circuit.

The injection to the detector is provided by a transistor driver. The driver must accommodate large amplitude variations of sound carrier, as are usually encountered with intercarrier-sound television receivers. By designing the driver to limit symmetrically for large signals the injection to the detector is maintained at a constant level as the driver overloads.

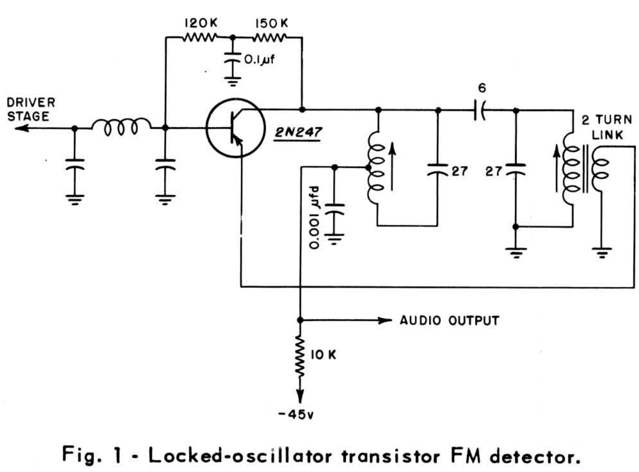


Fig. 1 - Locked-oscillator transistor FM detector.

Detector

An RCA 2N247 drift transistor functions as a slope detector in an oscillating mode. Oscillations are maintained by collector-to-emitter feedback through an overcoupled double-tuned circuit, as shown in Fig. 1. The oscillator is injection-locked to the sound signal which is applied to the base electrode by the driver stage. The detector is coupled to the driver through a pi-network, which matches the higher impedance of the driver to the lower impedance of the detector. The detected audio appears across the 10K collector resistor and is obtained at the r-f ground point of the primary winding. The required forward bias is obtained by bleeding current from the collector into the base through two series-connected resistors. The junction of the two resistors is bypassed to ground to prevent audio and r-f degeneration. The d-c degeneration which is thereby introduced contributes to the stability of the stage.

AM rejection and detector linearity are dependent on the coupling in the transformer. A coefficient of coupling 1.5 times critical coupling gives good AM rejection and reasonably good linearity. Larger values of coupling introduce curvature in the detector characteristic (S-curve); smaller values of coupling reduce the AM rejection. Although the schematic shows high-side capacitance coupling, mutual or a combination of mutual and high-side coupling may be substituted to obtain equivalent performance. The emitter is tightly coupled to the secondary of the transformer through a two-turn link.

The collector characteristics of drift transistors differ sufficiently from conventional bipolar transistors to require explanation. The collector characteristic is employed to limit the amplitude of oscillation, while providing a high degree of AM rejection.

The full zero-bias characteristics of a drift and a conventional p-n-p transistor are shown in Fig. 2. Note that for negative collector voltages, the zero-bias characteristic of the drift transistor is similar to that of the conventional transistor. If a positive voltage is applied to the collector junction of a p-n-p transistor, the collector will act as an 'emitter'; and the emitter acts as a 'collector'. Thus, the applied voltage is a reverse voltage for the emitter junction. The grading of the base layer of drift transistors is in such a sense as to produce breakdown of the emitter junction for relatively low voltages. Three to five volts is a typical value. Breakdown of the emitter junction is reflected in the collector as a large increase of current. The low breakdown voltage shown in the first quadrant of Fig. 2 will be referred to as 'symmetrical breakdown'.

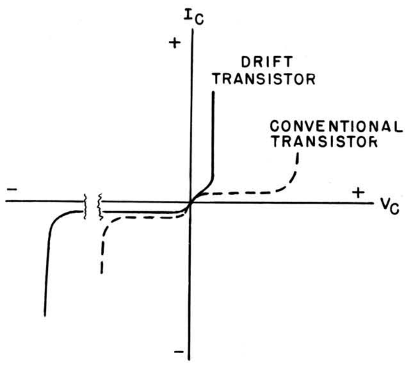


Fig. 2 - Zero-bias characteristics for a drift and for a conventional p-n-p transistor.

The positive peaks of the collector voltage are clamped at the 'symmetrical breakdown' level. The time constant of the clamp which is in the decoupling network corresponds to at least 20 r-f cycles. The collector current adjusts itself to maintain a sinusoidal voltage waveform at the collector electrode. The positive excursions of the collector waveform are held at the 'symmetrical breakdown' level; the negative excursions are limited by the collector voltage. The average collector current and the oscillator amplitude is thus a function of the collector-circuit impedance and the coupling coefficient of the transformer. The link is a convenient means of obtaining a low driving impedance for efficient coupling between the collector and the emitter.

The oscillator is injection-locked to the sound signal, which is applied to the base electrode. The natural frequency of the oscillator is set equal to the carrier frequency. Deviations of the signal about the carrier are followed by the oscillator frequency. The impedance of the collector tank is a function of the oscillator frequency and hence of the signal frequency. In turn, the amplitude of oscillation, as reflected in the collector voltage swing is also a function of the deviation. The positive peaks of the collector waveform are clamped at the 'symmetrical breakdown' level resulting in detection of the frequency modulation. The detected audio component appears in the collector-voltage waveform and is recovered at the r-f ground of the collector tank. An oscillogram of the collector voltage is shown in Fig. 3.

A double-tuned circuit provides emitter excitation. The oscillator operates on either the positive or on the negative slope of the impedance characteristic of the collector tank circuit, as determined by the link polarity. This coupling arrangement prevents the oscillator from following deviations that would pull the oscillator across the resonant frequency of the collector tank. The oscillator synchronizing range is restricted to one slope of the collector tank, thus preventing the detector from introducing excessive distortion which would result from a slope reversal.

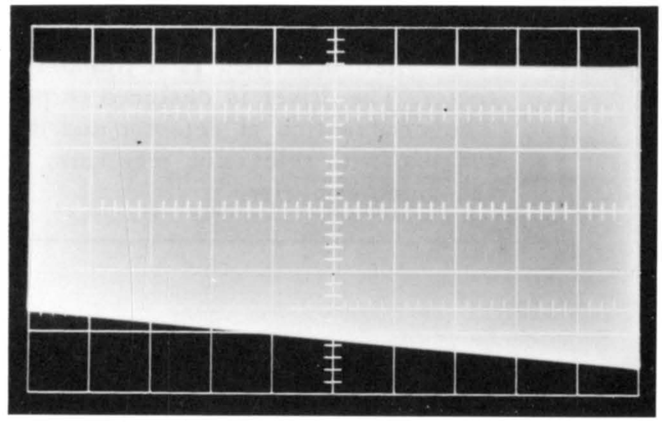


Fig. 3 - Oscillogram of the detector collector-voltage waveform.

Assume that the collector and the emitter tank circuits are resonant at the same frequency f_r. A signal of frequency f_r would experience a 90-degree phase shift in passing through the coupling network between the collector and the emitter. The direction of phase shift (i.e., lead or lag) depends on the link polarity. The phase-shift requirement for self-oscillation cannot be satisfied at the resonant tank frequency, f_r. However, at a frequency f_o which is less than the resonant tank frequency, f_r, the circuital phase-shift is zero degrees and one of the conditions for self-oscillation is satisfied. The circuit will oscillate at the frequency f_o provided that the loop gain is greater than the unity for this frequency.

The mechanism of locking, or synchronizing, an oscillator requires the injection of an external signal into the oscillator loop to alter the circuital phase-shift of the circuit. If the circuital phase requirement for self-oscillations can be satisfied at the injected frequency, and if the injected power level is greater than a minimum level the oscillator will assume the

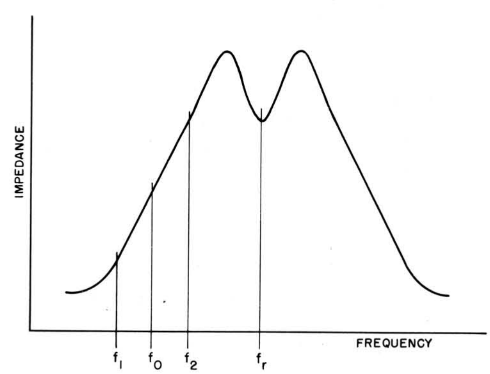


Fig. 4 - Impedance curve of the collector tank circuit.

frequency of the injected signal. A restriction is imposed by the phase characteristics of the coupling network on the maximum deviation that the oscillator can follow. The oscillator cannot follow deviations that would require the coupling network to introduce more than 90 degrees of phase-shift. Thus, the synchronizing range is restricted to either the positive or to the negative slope. Fig. 4 shows the collector tank impedance for a circuit where the link polarity corresponds to synchronization on the positive slope. Frequencies f_1 and f_2 are the limit of the synchronizing range for a given injected power level.

Two restrictions are imposed on the collector voltage swing. The positive peaks are clamped at the 'symmetrical breakdown' level; the average value is set by the effective collector voltage. The ability of the detector to reject amplitude variations is not dependent on the injected signal level. It is implied that the injection is of sufficient level to lock the oscillator over the full carrier deviation. If the injection level is below this threshold, the AM rejection will be maintained only over the synchronizing range. Beyond the synchronizing range, the output contains the beat between the injected signal and the oscillator signal.

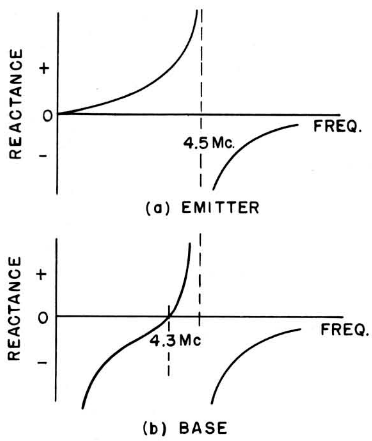


Fig. 5 - Emitter and base driving-point impedance.

The clamping time constant, approximately 10 μsec, is made sufficiently fast to follow the amplitude variations encountered in the application. Thus, the dynamic limiting and the static limiting characteristics can be considered to be similar. The audio output is not dependent on the injection level, provided that the injection is greater than the threshold. Thus, the audio output is held at a constant level.

The network coupling the base of the detector to the driver should be designed to prevent oscillations other than those caused by feedback from collector to emitter. The high input capacitance of the transistor constitutes a feedback path from emitter to base. The high input capacitance of the transistor can result in a sustained oscillation within this loop. It is possible for oscillations to exist simultaneously in both the collector-to-emitter and the emitter-to-base feedback paths. These oscillations interact to produce a beat frequency which modulates the output. When viewed with an oscilloscope this phenomenon appears like squegging.

To obtain stable operation in the circuit of Fig. 1, requires that the coupling network be designed to suppress spurious oscillations. The driving-point impedance of the base network has a positive reactance only at those frequencies that the emitter driving-point impedance also has a positive reactance. Thus, feedback from emitter to base is degenerative. A band-pass pi-network with capacitive elements in the shunt legs is utilized to couple between the detector and the driver. The elements in this network are so proportioned that the driving-point impedance has a pole at 4.5 Mc, and a zero at a frequency less than 4.5 Mc. A zero at 4.3 Mc does not appreciably reduce the power transfer at 4.5 Mc and results in stable operation. Curves of the driving-point impedance for the base and for the emitter are shown in Fig. 5. Thus, the feedback through the transistor input capacitance is degenerative for all frequencies.

Driver

The driver stage (Fig. 6) provides maximum power transfer between the sound take-off and the detector stage for signals below the limiting threshold. Signals that would otherwise overload the detector are symmetrically limited to maintain a constant injection to the detector. The limiting action is sufficiently rapid to respond to the video modulation of the sound carrier.

A double-tuned circuit couples the load to the collector. The primary and the secondary are critically coupled. The coupling is shown as high-side capacity coupling; but, again, mutual coupling or a combination of mutual and high-side capacity coupling may be substituted and equivalent performance obtained. The coupling between the windings is 0.05. The primary is tapped at the midpoint to provide a 5,000-ohm impedance to match the output impedance of the transistors. The

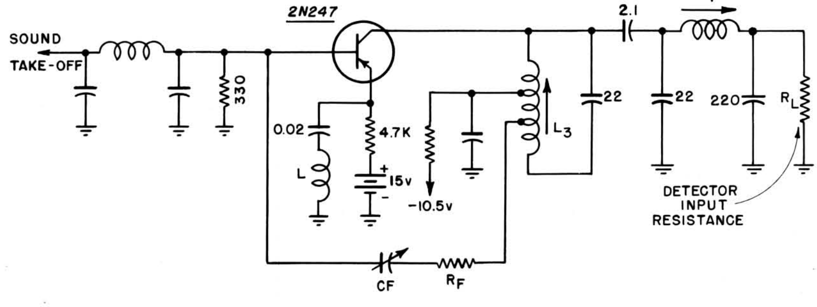


Fig. 6 - Driver stage.

output impedance of the transistors depends on the neutralization and on the source impedance. In this circuit, the output impedance of the 2N247 is about 5000 ohms. A signal of opposite phase to the collector signal is available at the second tap. This signal is is used to neutralize the transition capacity and the back resistance of the collector junction. Since this stage provides amplification over a narrow band of frequencies, a series R-C combination can be used as the neutralization network.

A high degree of d-c degeneration is provided by the biasing networks. The emitter current is set predominantly by the resistor and the positive voltage in the emitter circuit. Collector voltage is set by the negative supply and the decoupling resistor. The transistor is biased at a high g_m point. For large positive swings at the base of the driver, the transistor cuts off; for large negative swings, the transistor is driven into collector-voltage saturation. The quiescent condition is selected so that these effects occur for equal positive and negative swings. This arrangement provides the desired symmetrical clipping of the input waveform.

The transistor has an exponential transfer characteristic that produces a rectified component of emitter current. The rectification effectively reduces the forward bias of the emitter junction; this effect is proportional to signal amplitude. For large amplitudes of input signal that are highly modulated by the video information the driver stage can be cut off during the sync interval. This condition will occur only if the emitter circuit cannot rapidly respond to the required shift of the quiescent operating point. This effect may be greatly reduced by using a large emitter resistance, which reduces the rectification efficiency of the emitter junction, and by limiting the emitter time constant to a maximum value that permits bias adjustments at a horizontal line rate.

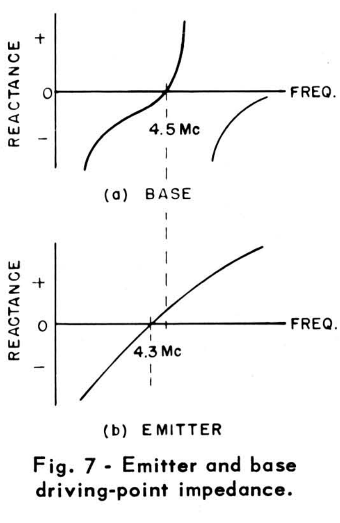


Fig. 7 - Emitter and base driving-point impedance.

The sound signal is direct-coupled to the driver stage. Efficient sound take-off requires that the low input impedance of the driver-stage be matched to the higher output impedance of the sound take-off. The required impedance-matching network must be designed to suppress spurious oscillations caused by input-circuit feedback. As was required for the detector stage, the driver must be designed so that the feedback from emitter-to-base, through the transistor's input capacitance, be degenerative for all frequencies.

A satisfactory method is to use a pi-network with capacitive elements in the shunt legs for impedance matching, and a series L-C circuit, as the emitter bypass. The emitter network is in series resonance at a frequency less than 4.5 Mc (4.3 Mc is a reasonable compromise); the center-frequency of the pi-network is 4.5 Mc. The driving point impedances of the emitter and of the base networks are such (Fig. 7) that for all frequencies for which the base reactance is positive, the emitter reactance is also positive. Thus, the feedback through the transistor input capacitance is degenerative for all frequencies.

Circuit Details and Operation

A schematic of this sound strip as installed in a commercial chassis is shown in Fig. 8. The emitter bypass network of the driver stage is a compromise between conflicting requirements. To prevent excessive degeneration at 4.5 Mc requires a large emitter bypass capacitor. However, the emitter time constant must be limited so as to permit the bias to follow the video modulation of the sound carrier.

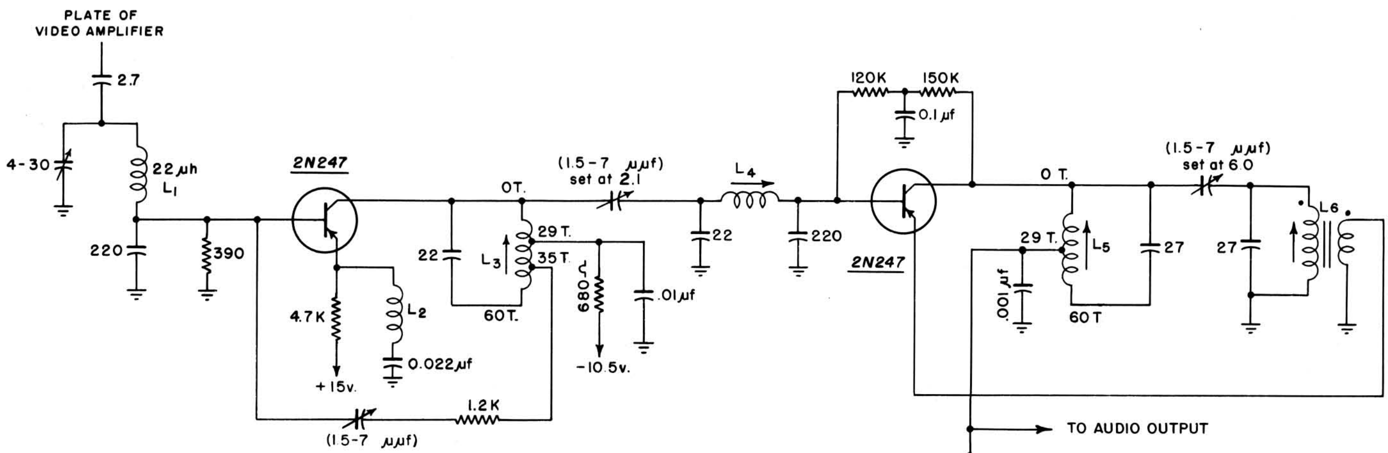
If the emitter time constant is too large, the driver stage can be cut off by rapid decreases of sound signal as was previously explained. Large decreases occur if the sync pulses deeply modulate the sound signal. This is particularly severe in receivers that provide amplification of the 4.5-Mc sound signal in the video stages. The emitter bypass consideration is additionally complicated by the stability requirement, which is satisfied by a circuit that is in series resonance at a frequency less than 4.5 Mc. The capacitor must be larger than that which would be required, if the network were resonant at 4.5 Mc, to obtain an equivalent bypass.

A 4.7K emitter resistor and a 0.022-μf disc capacitor with its leads coiled and cut to be resonant at 4.3 Mc constitute a satisfactory compromise. The impedance in the emitter lead of the driver stage introduces 0.6 db of negative feedback (gain reduction) at 4.5 Mc. The driver stage can follow deep modulation of the sound signal.

The characteristics of the driver stage are shown in Fig. 9. These characteristics were obtained by substituting a resistive load for the detector. A low-level power gain of 26 db was measured. Limiting starts at a 40-mv level with the driver rapidly driven into overload. A constant power output is maintained through the overload region.

The detector operates in an oscillating mode over the full range of input signals provided by the driver. The holding, or lock-in range, is a function of the injection signal level. Fig. 10 gives the upper and the lower frequency limits of the lock-in range as a function of signal level at the driver input.

The link polarity determines the location of the oscillator with respect to the tank resonant frequency. In this circuit, the natural oscillating frequency is less than the resonant frequency; restricting the operation to



L1: 22 μh
L2: COILED-LEADS OF .022μf CAPACITOR RESONANT AT 4.3 Mc.
L3: 60T. No. 36 SNE TAPPED AT 29T FOR B- FEED. 35T. FOR NEUTRALIZATION
L4: 60T. - No. 36 SNE
L5: 60T - No. 36 SNE TAPPED AT 29T.
L6: 60T - No 36 SNE, LINK 2T. - No. 36 SNE UNDER THE 60T. PIE.

1/4" - DIAMETER COIL FORMS
CORES NATIONAL MOLDITE MIX 17, 1/4 - 28 x 3/8
WINDING MACHINE: DRIVE GEAR - 58
CAM GEAR - 55
CAM - 0.125"

Fig. 8 - Experimental intercarrier-sound i-f amplifier and FM detector.

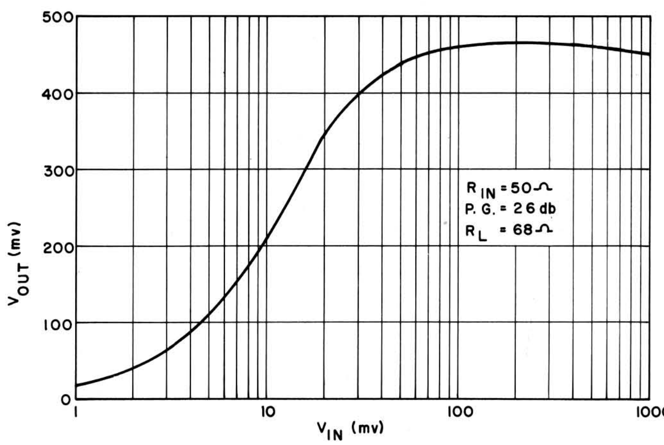


Fig. 9 - Driver transfer characteristic (2N247).

the positive slope of the impedance curve of the collector tank circuit. The lower limit of the holding range corresponds to the frequency at which the tank impedance is too low to support oscillations; this occurs at input levels of 10 mv. The oscillator can follow positive frequency deviations up to the tank resonant frequency.

The oscillator can follow the required 50-kc deviation of the sound signal for input levels in excess of 3 mv. For input level of 5 mv, the oscillator lock-in range increases to 75 kc and at 10 mv, the lock-in range is 93 kc. Above input levels of 10 mv, the center-frequency of the 'S' curve shifts to increasingly higher values as the lock-in range increases to 125 kc. Below input levels of 10 mv, the center frequency of the 'S' curve remains constant. The shift of center-frequency at large signal levels is not significant since the AM rejection is constant over the lock-in range.

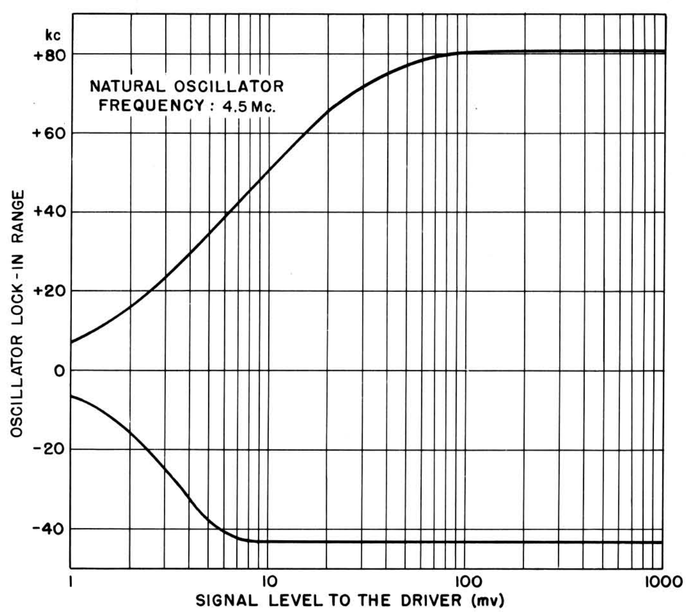


Fig. 10 - Oscillator lock-in range.

The AM rejection characteristics, Fig. 11, were obtained by simultaneously modulating the frequency and the amplitude of the sound carrier; the modulating frequencies are 50 cps and 400 cps, respectively. The detector output is filtered and the ratio of 50-cycle audio recovery to 400-cycle audio recovery is obtained. This ratio is the AM rejection. The AM rejection is obtained for two modulation conditions; for 30 percent and for 100 percent frequency modulation of the carrier, where 100 percent modulation corresponds to 25-kc deviation. In each case, the carrier is 30 percent amplitude modulated. At low signal levels, the AM rejection is 20 db

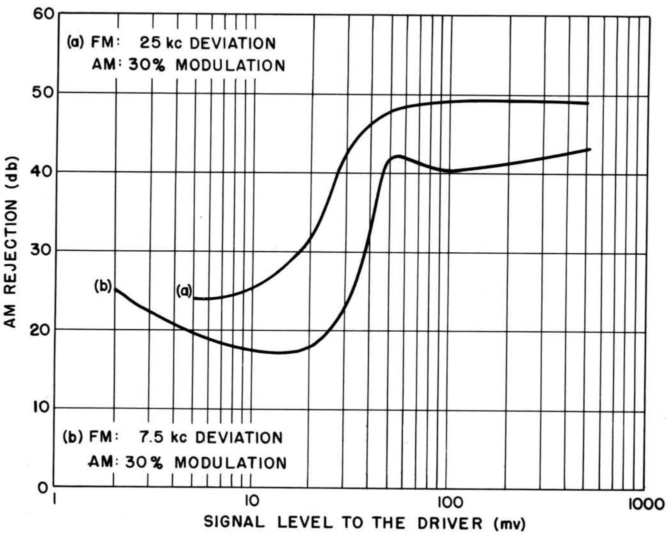


Fig. 11 - AM rejection.

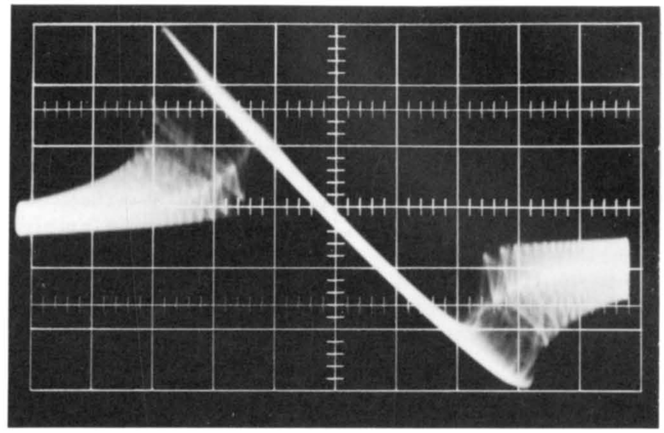
(the inherent AM rejection of the detector alone.) This increases as the driver limits. For input signals of less than 2 mv, the AM rejection is still high.

The oscillograms of Fig. 12 were obtained by passing a carrier that is simultaneously amplitude and frequency modulated through the sound strip. Oscillograms are shown for signal levels of 1.5 mv, 10 mv, and 30 mv at the base of the driver; the captions give the modulation for each oscillogram. For larger signals the oscillograms are similar to that shown for a 30 mv input. Since the AM rejection is constant over the full S-curve, the detector is not critical to center tuning.

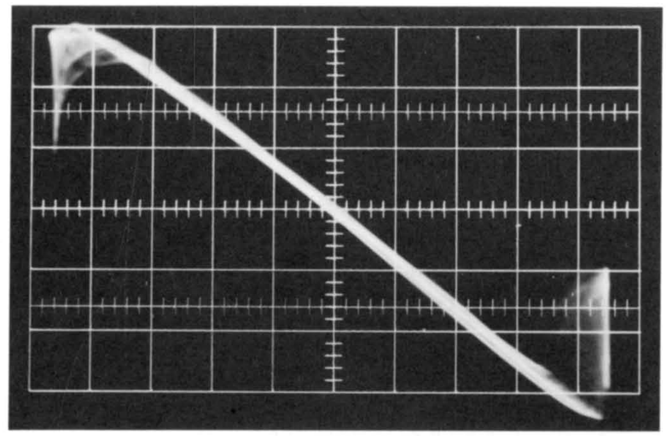
The audio recovery of the detector is 75 mv per kilocycle of deviation. Thus, for 100 percent modulation (i.e., 25 kc deviation) the detector develops an open circuit output of 1.3 volts, rms. The maximum power transferred by the detector into an audio load is -10 dbm. This level of power output is maintained over a wide range of loading and reaches a maximum for a 4,000-ohm load. As the loading varies from 500 to 25,000 ohms the power output is maintained within 3 db of the maximum level. To obtain an output of 2 watts (for 100 percent modulation) an additional 43 to 46 db of audio gain is required, depending on the input impedance of the audio amplifier.

For 25-kc deviation the audio output contained from 2.5 to 3.5 percent of rms harmonic distortion depending on center-tuning and on signal level. As the deviation was increased to 50 kc, the rms harmonic distortion increased in the range of 4 to 5 percent, depending on center tuning.

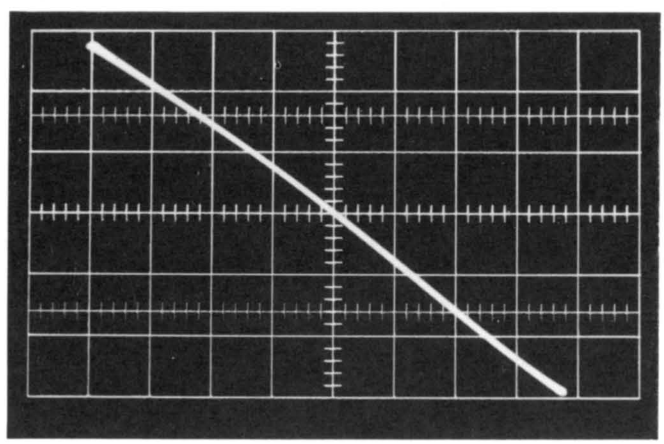
The detector may be aligned in two steps. First, the detector is operated as a passive slope detector by opening the feedback loop and grounding the emitter electrode. The detector is adjusted to operate on the correct slope of the collector tank circuit; this step is accomplished by tuning the primary and secondary tank circuits, L_5 and L_6 respectively, for their correct resonant frequencies. Second, the normal feedback path



(a) Signal level to the driver 1.5 mv.
FM: 25 kc at 50 cps
AM: 30% at 400 cps



(b) Signal level to the driver 10 mv.
FM: 50 kc at 50 cps
AM: 30% at 400 cps



(c) Signal level to the driver 30 mv.
FM: 50 kc at 50 cps
AM: 30% at 400 cps

Fig. 12 - Oscillograms obtained with a signal simultaneously frequency and amplitude modulated.

is completed and the oscillating frequency is set equal to the sound-carrier frequency; this step is accomplished by tuning the base-coil, L_4, which compensates for the transistor phase shift (i.e., beta phase-shift at 4.5 Mc). The alignment of the driver stage is similar to the alignment of a high-gain, unilateralized, r-f amplifier.

To evaluate the improvement obtained by operating in an oscillating mode over that which would be obtained by an equivalent passive detector the feedback in the detector was removed by grounding the emitter electrode. At large signal levels (in the order of 50 mv to the driver) equivalent performance is obtained in either mode. At lower signal levels (in the order of 10 mv), the AM rejection, audio recovery and linearity characteristics of the passive detector are highly inferior as compared with the characteristics of the detector when operated in an oscillating mode.

Marvin Meth