APPLICATION ENGINEERING NOTES

HUGHES SEMICONDUCTOR DIVISION
NEWPORT BEACH, CALIFORNIA

For background information on similar transistor applications see:
TRANSISTOR TECHNICAL NOTES
Silicon Double-Diffused Mesa Series (for Amplifiers)

FM TUNER

Paper prepared by:
Dave English, Member of Technical Staff Hughes Semiconductor

GENERAL DESCRIPTION

The tuner uses nine transistors: seven 2N1197 high frequency silicon transistors and two audio frequency germanium transistors. It consists of an RF amplifier, mixer, local oscillator, three IF amplifiers, a limiter, a discriminator using two Hughes 1N191 diodes, an emitter follower audio output stage, a DC amplifier for the tuning indicator and an HC7002 silicon capacitor for the AFC element. The tuner requires a signal strength of about 10μv or greater across the 300 ohm input for limiting and with that signal, an audio signal of about 0.5 to 1.0 v RMS is obtained at the output. With a piece of wire 3 feet long for an antenna about fourteen stations can be picked up clearly in the Los Angeles area. The tuner operates on a +6 volt supply for the emitter bias and a collector supply of from −9 to −30 volts. Best performance is obtained at the higher collector supply voltage, but the tuner should be aligned with the desired operating supply voltage because of the variation of collector capacity with bias voltage. Total current drain from each supply is about 10 milliamperes.

CONSTRUCTION

The tuner is built on a brass chassis with the stages in line. Each IF amplifier stage has an individual compartment in the chassis for isolation purposes; and the RF amplifier, mixer and local oscillator occupy a single compartment. The tuning capacitor along with its associated trimmer and padder capacitors are mounted in a small box on the side of the main chassis. Ladder type filters are used for de-coupling the collector and emitter supply leads of the IF amplifiers. Each ground lead is connected to the chassis at the transistor socket of the associated stage or as near as possible so as to prevent ground loops. The layout provides for the shortest leads between high frequency stages. This type of construction was used to reduce all possible sources of feedback.

Because of the capacity between the internal elements of the transistor and its case, it is possible to get feedback between stages from case to case. The cases should either all be grounded or effective shields provided. Alignment should be done with the shields in place or the cases grounded.

FRONT END

The RF amplifier provides about 10 db of gain but its main function is to increase image rejection. T-1 matches the antenna to the input impedances of the transistor and the base is tapped down on the secondary in order to provide the loaded Q necessary for a bandwidth of approximately 20 Mc. With the collector tapped down on T-2, a total bandwidth of about 6 Mc is obtained for the RF stage. The secondaries of T-1 and T-2 must be connected for phase reversal for neutralization. The data for all transformers is given in Table I. The values of input and output impedances given were typical values measured in power gain test sets. The feedback capacitors C_n−1 and C_f can be made by twisting two pieces of teflon wire together while measuring the C on a "Q" meter. The secondary of T-8, the local oscillator transformer, is just a single loop which is adjusted for very loose coupling by varying the distance from the end of the core on which the primary is wound.

The diode in the emitter circuit of the mixer is connected so that it is in the forward direction when the emitter goes in the reverse direction. This diode improves the performance of the mixer by increasing the gain and lowering the noise. The mixer gives about 10 db gain.

Because of the very high capacitance of the HC7002 used for AFC, a 5 $\mu\mu$f capacitor is connected in series with it across the local oscillator tank. The diode is self biased slightly in the reverse direction by the local oscillator signal charging C_b through the diode. When the local oscillator frequency is the correct value the discriminator DC output is about zero. As the local oscillator is varied around this frequency, the DC output varies from +1 volt to −1 volt. This DC signal is applied to the diode via the output emitter follower. The small change in capacitance of the diode with bias is sufficient to provide a sensitive AFC.

IF AMPLIFIER

The amplifier provides more than 60 db gain with a band width of about 300 Kc. The neutralizing capacitors are made variable so that transistors of different collector capacities may be used. They may be replaced with fixed capacitors after the approximate value is found as described in the alignment instructions. The interstage transformers, T-3 through T-6, were designed to match 5,000 ohms to 250 ohms which are typical values of output and input impedances for the transistor at 10 Mc. The secondaries of the transformers must be connected to get phase reversal from the collectors for neutralization. By using the highest possible L/C ratio for the primary, the band width would be in the order of several Mc with the collector connected across the whole primary. Therefore, to get a lower bandwidth, the operating "Q" is increased by tapping the collector down about halfway on the primary.

LIMITER, DISCRIMINATOR, TUNING INDICATOR AND OUTPUT CIRCUITS

The limiter has low DC collector voltage and current and the collector is alternately driven to zero voltage and zero current by the signal. The signal is thus limited to about 3 or 4 volts peak-to-peak at the collector.

The discriminator transformer is a commercial unit which has a 5-turn winding added for neutralization. This winding is connected for phase reversal from collector. The neutralization winding and capacitor have little effect on the limiter with large input signals but provide small signal stability for the stage.

The discriminator output must be taken from the side (other side grounded) which gives the proper phase for AFC action. If connected backwards the tuner will motorboat. The procedure for determining the proper connection will be given below. For initial alignment the AFC is disabled and the discriminator may be connected without regard to polarity. Because the output impedance of the discriminator is fairly high, an emitter follower is used to obtain a low impedance audio output.

The emitter follower is DC coupled so that the DC signal for the AFC and tuning indicator may also be taken from it. The audio signal must be filtered from the DC before application to the AFC diode. A DC amplifier is used to drive the tuning indicator, a 1 milliampere miniature meter. The base bias on the indicator stage is adjusted with R_1 so that the meter reads half scale with no signal in. This stage could probably be eliminated by using a center scale (100 μamp meter with a series resistor) to monitor the DC output voltage of the emitter follower.

ALIGNMENT PROCEDURE

The IF amplifiers are adjusted first. The tuning and neutralizing capacitors are initially set at center values. A sensitive, high frequency voltmeter (Boonton Electronics 91C or a communications receiver with a 1K resistor in series with the antenna cable) is connected at the base of the limiter. A 10.5 Mc CW signal is fed into the base circuit of the last IF amplifier stage through a 250 ohm series resistor with the precaution that the signal is small enough not to overdrive the stage. The collector trimmer capacitor is adjusted for maximum output. The signal generator and voltmeter probes are then interchanged and with the voltmeter on maximum sensitivity, the neutralization capacitor is adjusted for a null on the voltmeter. The voltmeter and signal generator are then connected back in the original positions and the collector trimmer readjusted.

The process is repeated for each individual IF stage back to the mixer. Finally, a small signal is put into the mixer collector circuit through a 5,000 ohm resistor and

with the voltmeter probe at the base of the limiter, the collector trimmers are readjusted for maximum output. When aligned properly, the voltage gain from the base of the first IF stage to the base of the limiter should be 1,000 (60db) or greater.

A sweep generator with 10.5 Mc center frequency and sweep width of at least 500 Kc is then connected in place of the CW generator at the mixer collector. With an oscilloscope connected at the discriminator output, the discriminator transformer slugs are adjusted to get an "S" pattern with the best slope and linearity.

The local oscillator is aligned next with the AFC feedback voltage disabled. The main tuning capacitor C_1 has both trimmers and padders for aligning at the low and high ends of the FM band. The local oscillator trimmer and padder are set to the centers of their ranges and the main tuning capacitor is set to maximum. A CW signal of 88 Mc and 100 μv is injected into the base of the mixer through a 250 ohm resistor and the local oscillator padder is adjusted for max signal at the output of the IF amplifiers (measured at the base of the limiter). The signal frequency is then set to 108 Mc, the main tuning capacitor to minimum, and the local oscillator trimmer is adjusted for maximum IF output.

This procedure is repeated several times as the adjustments for the high and low ends of the band are interacting. The local oscillator frequency should be set below the signal frequency.

The RF amplifier is aligned next with an 88Mc signal injected at the antenna jack through a 250 ohm resistor and the voltmeter still at the base of the limiter. The tuning capacitor C_1 is adjusted to get the most output and then the RF amplifier padder is adjusted. A 108 Mc signal is injected next and C_1 and the RF amplifier trimmer are adjusted. These steps are repeated, as in the LO adjustment. The antenna trimmer is adjusted with a signal at the center of the FM band.

The proper polarity of discriminator output for AFC must now be determined. A signal of any frequency in the band is injected at the antenna jack and the main tuning capacitor is adjusted for maximum output of the IF amplifiers. A center scale DC voltmeter is connected at the audio output jack. Increase the capacity of the main tuning capacitor slightly so that the DC meter reads either slightly positive or negative (the DC output should be approximately zero when perfectly tuned). Since the local oscillator capacitance is now too high, the AFC should provide a bias on the diode which decreases its capacitance; that is, the feedback voltage should bias the diode more in the reverse direction. If the polarity is wrong, either the AFC diode or the discriminator output terminals may be reversed. When operating properly, the AFC should "snap in" the local oscillator as soon as the IF signal goes over the hump of the discriminator "S" curve. As the main tuning capacitor is tuned across the frequency of a strong input signal, the tuning indicator should vary from near zero to full scale (about ± 1 volt at the output of the discriminator).

PERFORMANCE NOTES

After the tuner has been aligned with transistors having the specifications given in Table I, other transistors may be plugged into the various stages to see if there are any effects of detuning or instability due to parameter differences in the transistors.

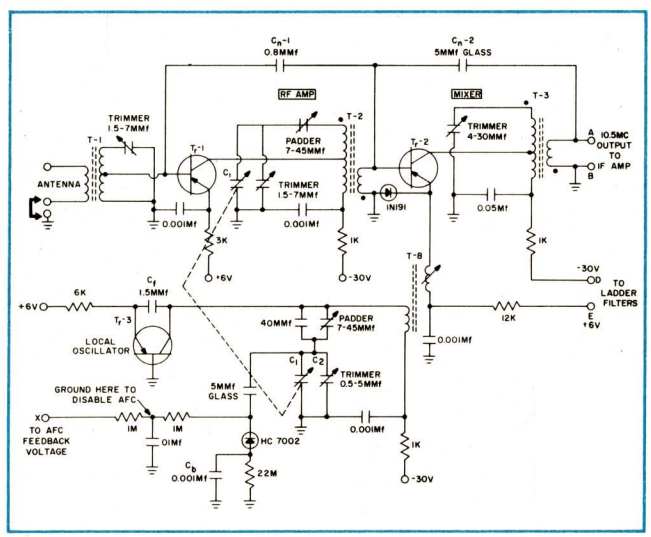

FIGURE 1. FRONT END OF FM TUNER

Transistors having f_{max}'s greater than about 80 Mc and with collector capacities varying by several $\mu\mu$f may be substituted in the mixer, IF amplifier, and limiter stages, with no noticeable effects on the performance of the tuner.

The local oscillator will work well with most transistors having f_{max}'s greater than about 130 Mc (at the specified bias conditions), but almost invariably the tuning control has to be readjusted to get back on the station when a new transistor is inserted for the oscillator. Only selected transistors with f_{max}'s greater than about 230 Mc perform satisfactorily in the RF stage.

TRANSFORMER DATA

T-1, T-2 and T-8 are wound on Ferroxcube tubes, type 56-062-78/4F, 7/16" long by 5/32" diameter. The core is insulated from the winding with thin teflon tape.

T-1 *Secondary*—9 turns No. 18 formex wire, distributed along length of core, tapped 3 turns from ground side for base input. Resonates at 100 Mc with about 7 $\mu\mu$f.

Primary—3 turns No. 18 formex wire close wound around center of secondary. T-1 matches 300 ohms to about 200 ohms and when loaded provides a bandwidth of about 20 Mc.

T-2 *Primary*—6 turns No. 18 formex, center-tapped for collector, spaced along length of core.

Secondary—1 turn No. 18 formex, tight around center of primary. Unloaded Q of primary about 120 when resonated with 10 $\mu\mu$f at 98 Mc. T-2 matches 1.5K to about 200 ohms and the loaded Q of 15 provides a bandwidth of about 6 Mc.

T-8 *Primary*—6 turns No. 18 formex, spaced along length of core. Resonates with about 17 $\mu\mu$f at 88 Mc with an unloaded Q of about 150.

Secondary—1 turn No. 18 formex, spaced slightly away from end of core. Distance adjusted for optimum coupling to mixer.

T-3, T-4, T-5, and T-6 are wound on National Moldite Toroidal Cores type NM-13, OD-½" ID-¼", ⅛" long.

Primary—50 turns No. 24 formex wound in two layers on core, center-tapped for collector.

Secondary—5 turns No. 24 formex. These transformers match 5K to 250 ohms and the unloaded Q of primary is about 150.

T-7 T-7 is a Miller discriminator transformer No. 1452. The miniature version of this would also be suitable.

L-7 L-7 is a 5 turn winding added on the secondary for neutralization. One side of this winding is connected to terminal f, noting direction of windings in order to get a phase reversal from collector.

NOTES ON TRANSFORMERS

The number of turns necessary to obtain the stated impedance matches of the above transformers were determined with the Boonton RX meter. The secondaries of T-1 through T-6 must be connected so as to get phase reversal from collector.

CAPACITOR DATA

C_1 is a 1.5 to 15 $\mu\mu$f dual tuning capacitor.

C_2 is a JFD VC-5, 0.5 to 5 $\mu\mu$f piston trimmer.

C_n-1 and C_f are "gimmicks" made by twisting two pieces of teflon wire together, until the desired capacitance is obtained as read on the RX meter.

C_n-2 and C_n-6 are 5$\mu\mu$f glass.

All other trimmers are ceramic type.

All other fixed capacitors are ceramic disc-caps.

TRANSISTORS

TR-1 through TR-7 are Hughes 2N1197 (see text about TR-1 and TR-3)

TR-8 and TR-9 are low frequency, low power germanium transistors.

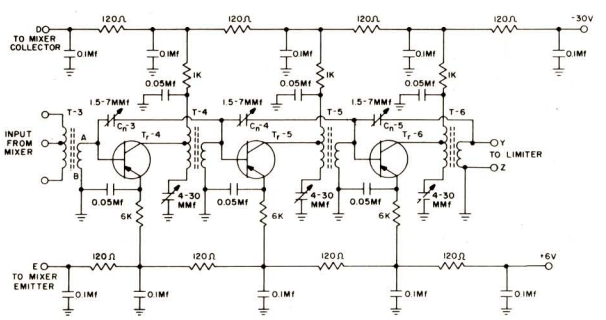

FIGURE 2. 10.5 Mc IF AMPLIFIER FOR FM TUNER

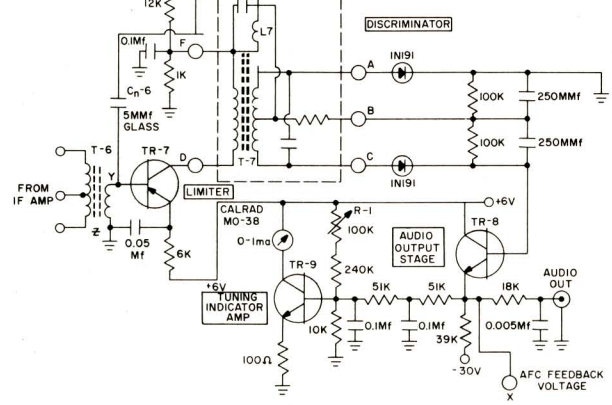

FIGURE 3. LIMITER, DISCRIMINATOR, AUDIO OUTPUT AND TUNING INDICATOR FOR FM TUNER

HUGHES

SEMICONDUCTOR DIVISION
NEWPORT BEACH, CALIFORNIA