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THROW-AWAY RADIO (TAR).(U)

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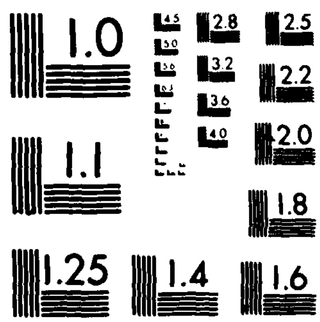

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RESEARCH AND DEVELOPMENT TECHNICAL REPORT
CORADCOM- 80-2

THROW-AWAY RADIO (TAR)

Joseph Lee
CENTER FOR COMMUNICATIONS SYSTEMS

NOVEMBER 1980

CORADCOM
U S ARMY COMMUNICATIONS RESEARCH & DEVELOPMENT COMMAND
FORT MONMOUTH, NEW JERSEY 07703

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Throw-Away Radio (TAR)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Military grade components, extensive testing and modular construction are generally required for military communication equipments to provide high reliability and maintainability. The full military environment is rarely encountered in non-critical mission communications, and thus a low cost, throw-away radio could be used in these missions.

This report covers the investigation of a low cost,handheld transceiver concept. Representative schematics and discussions are presented,and (OVER)

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the cost for components are estimated. Although a working model was not completed, the investigation demonstrated that a low cost radio can be developed and fabricated at approximately one-fourth the cost of a similar, fully militarized unit.

TABLE OF CONTENTS

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INTRODUCTION:

The AN/PRC-68 developed by Magnavox is a portable handheld transceiver operating in the frequency range of 30 to 80 MHz. The present selling price of the AN/PRC-68 is approximately $2000 each. It was suggested that for non-critical missions, perhaps a low cost, not to be repaired, throw-away radio could be developed. The purpose of this program was to investigate the feasibility of developing such a radio.

The main objectives of designing the throw-away radio were as follows:

* Low cost
* Synthesized multiple channels
* Small size (handheld)

In order to keep the cost to a minimum, commercial grade components and conventional techniques were used. Commonly available integrated circuits (IC) were used to reduce the physical size. Instead of maintaining a large number of crystals for different operating frequencies, a digital frequency synthesizer was used to generate multiple channels.

TECHNICAL DESCRIPTION:

For experimentation, the following operating specification was chosen:

* Frequency range : 220 to 230 MHz
* Channel spacing : 50 KHz
* Modulation : FM (± 8 KHz)
* Single channel operation with internal channel selection

The block diagram of the throw-away radio (TAR) is shown in Figure 1. In the receiver section, single conversion instead of double conversion is used to lower cost and to reduce size. Frequency multiplication is used in the synthesizer instead of an expensive prescalar divider chip.

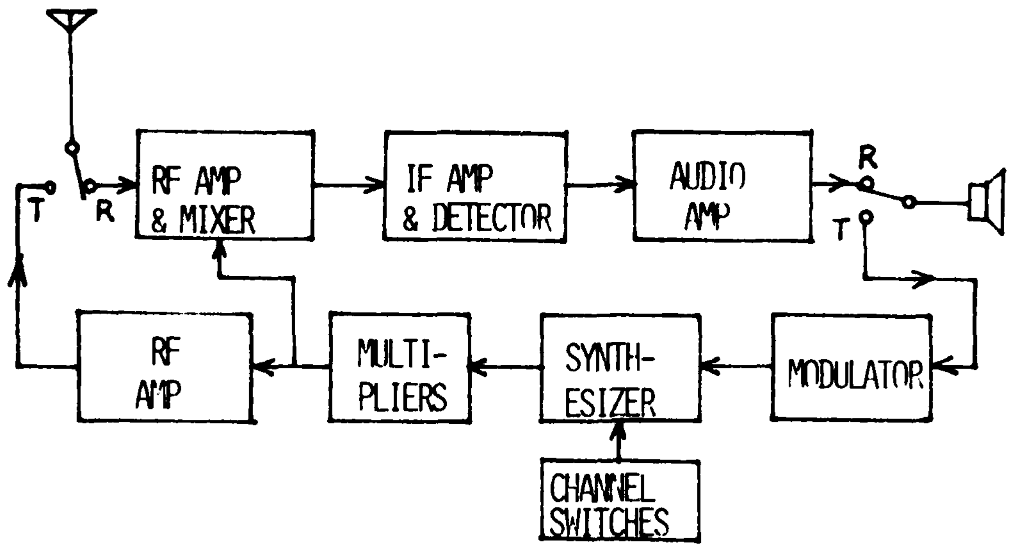

FIG. 1 TAR BLOCK DIAGRAM

A description of the various completed sections of the radio is given below. The synthesizer is the heart of the radio and it will be described in more detail than the other parts.

1. FREQUENCY SYNTHESIZER

The synthesizer is of the phase-lock-loop (PLL) type. A brief review of PLL fundamentals follows.

The basic phase-lock-loop system is shown in Figure 2. It consists of three parts: phase comparator, low pass filter, and voltage controlled oscillator (VCO). These three parts are connected to form a closed loop frequency feedback system.

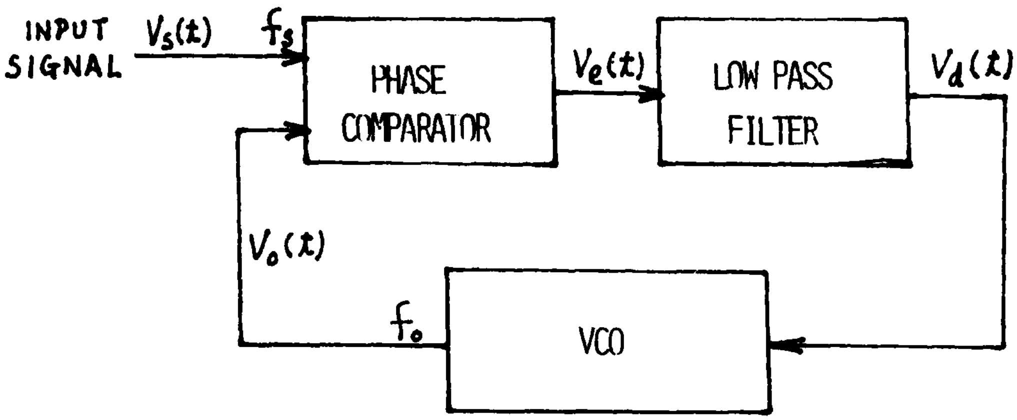

FIG. 2 PHASE LOCK LOOP SYSTEM

With no input signal applied to the system, the error voltage Ve is equal to zero, and the voltage from the low pass filter V_d is also equal to zero. When $V_d = 0$, the VCO operates at a set free-running frequency f_o. If an input signal is applied to the system, the phase comparator compares the phase and frequency of the input signal with the VCO frequency and generates an error voltage Ve which is related to the phase and frequency difference between the two signals. The error voltage Ve is filtered and applied to the control terminal of the VCO. The filtered voltage V_d varies in a direction that reduces the frequency difference between the two signals. When the input frequency is sufficiently close to the VCO frequency, the feedback nature of the PLL causes the VCO to synchronize, or lock, with the incoming signal. Once in lock, the VCO frequency is identical to the input signal, except for a finite phase difference.

A block diagram of the throw-away radio (TAR) synthesizer is shown in Figure 3.

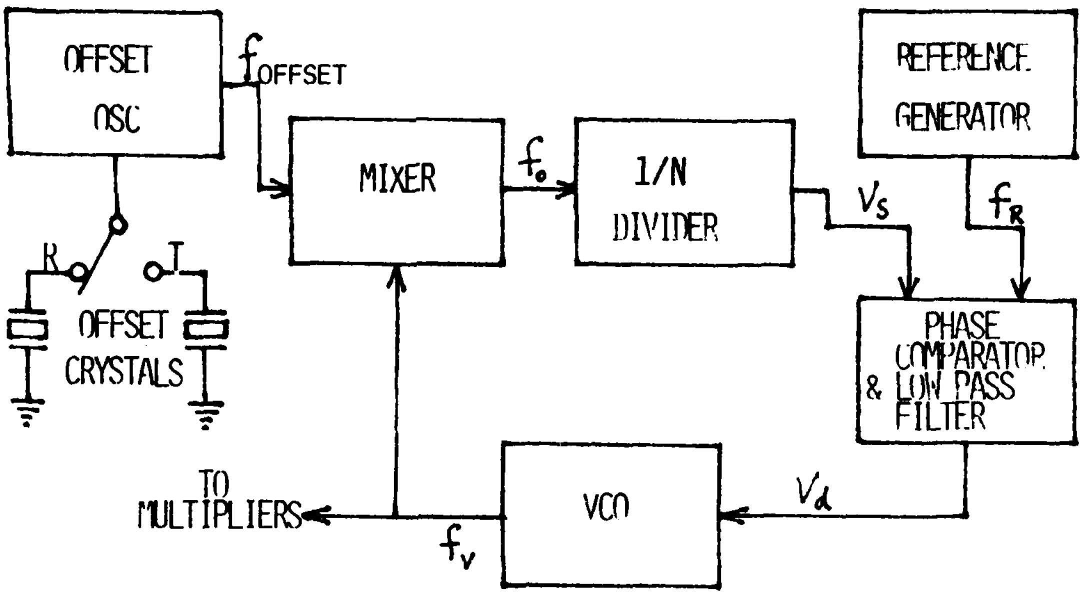

FIG. 3 SYNTHESIZER BLOCK DIAGRAM

a. SYNTHESIZER DESIGN CALCULATION

For investigation flexibility, the operating channel spacing was designed to be 5 kHz instead of 50 kHz as specified earlier. In order to use the commonly available commercial devices, the operating frequency (220 ~ 230 MHz) must be scaled down to within the operating range of the devices used in the synthesizer. A scaling factor of nine was chosen. The VCO frequency must then be nine times below that of the actual operating frequency.

Transmit frequencies f_t = 220 ~ 230 MHz.

VCO frequencies ($f_t/9$) = 24.444444 ~ 25.555555 MHz = f_{to}

Receive LO frequencies f_r = 209.300 ~ 210.300 MHz

VCO frequencies ($f_r/9$) = 23.255555 ~ 24.366666 MHz = f_{ro}

∴ VCO frequency range = 23.255555 ~ 25.555555 MHz.

Operating channel spacing f_c = 5 kHz

Reference generator frequency $f_R = f_c/9$ = 555.555555 Hz

In order to provide direct frequency reading with channel switch settings, the CD4059 programmable divider chip was used in the synthesizer. The CD4059 can be used in different modes to provide different dividing ranges. For the TAR application, the CD4059 is used as follows:

BCD switch settings	Transmit frequency	Dividing # N
2000	220.000 MHz	4000
2500	225.000 MHz	5000
3000	230.000 MHz	6000

Therefore, the range of the input frequency f_o for the divider CD4059 must be:

$$f_o/4000 = f_R = 555.555555 \text{ Hz}$$
and $$f_o/6000 = f_R = 555.555555 \text{ Hz}$$
$$4000\ (555.555555 \text{ Hz}) \leq f_o \leq 6000\ (555.555555 \text{ Hz})$$

$$2.222222 \text{ MHz} \leq f_o \leq 3.333333 \text{ MHz}.$$

This frequency range is within the operating range of the CD4059, but the VCO frequencies are too high to be applied directly to the divider. Therefore, the VCO frequencies must be scaled down to the range of f_o. An offset frequency can be mixed with the VCO frequency to provide the required input frequency for the divider.

$$\text{Transmit} = f_{to} - f_{t\text{-offset}} = f_o$$

$$\text{Receive} = f_{ro} - f_{r\text{-offset}} = f_o$$

Where $f_{to} = f_t/9 = 24.444444 \sim 25.555555$ MHz
$f_{ro} = f_r/9 = 23.255555 \sim 24.366666$ MHz
$f_o = 2.222222 \sim 3.333333$ MHz

$f_{t\text{-offset}}$ and $f_{r\text{-offset}}$ are calculated to be:

$$f_{t\text{-offset}} = 22.222222 \text{ MHz}$$
$$f_{r\text{-offset}} = 21.033333 \text{ MHz}.$$

b. REFERENCE FREQUENCY GENERATOR (FIGURE 4)

The accuracy and stability of the operating frequency ($220 \sim 230$ MHz) are dependent on the accuracy and stability of the synthesizer reference frequency. The CD4060 is an oscillator-divider chip. The oscillator is crystal controlled operating at a frequency of 4.551111 MHz. This frequency is fine tuned by a variable trimmer capacitor and divided by 2^{12} to provide a reference frequency of 555.555555 Hz. The accuracy and stability of the reference frequency are mainly dependent on the quality of the crystal.

c. PHASE COMPARATOR (FIGURE 4)

The CD4046 is an integrated circuit comprised of the two major components of a phase-lock-loop, namely the phase comparator and the VCO. The output voltage of the phase comparator varies continuously with the phase difference of the two input signals at pin 3 and pin 14. The output at pin 13 of the phase comparator is filtered and applied to control the frequency of the VCO. The internal VCO of the CD4046 has a frequency limit of approximately 1.5 MHz which is not high enough for our application (2.222222~3.333333 MHz). Therefore a seperate external VCO must be used.

d. VOLTAGE CONTROLLED OSCILLATOR (VCO) (FIGURE 4)

The field effect transistor (FET) 3N128 is connected as a Colpitts oscillator. The frequency of oscillation is determined by the combination of L_1, C_1, C_2, C_3 and the varactor VR_1. The varactor VR_1 is a voltage controlled variable capacitor and the capacitance varies with the applied voltage. The control voltage is generated by the phase comparator and the nominal operating frequency of the VCO is 25 MHz.

e. OFFSET OSCILLATOR AND MIXER (FIGURE 4)

In order to bring the VCO frequency down to a suitable range for the divider chip CD4059, an offset frequency is mixed with the VCO frequency and their difference is then amplified and level shifted to feed into the divider. The offset oscillator is also connected as a Colpitts oscillator. The oscillation frequency is 22.222222 MHz during transmit and 21.033333 MHz during receive.

f. DIVIDER, CHANNEL SELECTOR (FIGURE 4)

As mentioned earlier, the dividing number ranges from 4000 to 6000. This provides 2000 channels of operation if 5 kHz channel spacing is used. In the actual laboratory breadboarding, 10 kHz channel spacing was used and the number of channels is reduced to 1000. The RCA-CD4059 is a five section programmable divider chip. The dividing number can be pre-set with BCD switches. For 10 kHz channel spacing, only three BCD switches are required to select the MHz, 100 kHz and 10 kHz increments. The input signal is fed from the offset oscillator-mixer stages with a frequency ranging from 2.222222 to 3.333333 MHz. The output frequency of the divider remains constantly at 555.555555 Hz as long as the PLL is in lock condition. This output signal is connected to one of the two inputs of the phase comparator.

2. MULTIPLIER (FIGURE 5)

The VCO frequency ranges from 24.444444 to 25.555555 MHz for transmit and from 23.255555 to 24.366666 MHz for receive. Two separate 9X multipliers are used for transmit and receive in order to improve isolation between various stages. Each multiplier consists of two triplers and a buffer stage. The output of one multiplier is applied to the receiver mixer as the local (LO) injection signal and the other one is for driving the transmitter RF amplifiers.

3. MODULATOR (FIGURE 6)

The modulator is basically an audio amplifier consisting of two amplifying stages utilizing the LM1458 dual op-amp. The modulator amplifies the signal from the microphone (the speaker is used as a microphone during transmit) and the output is applied to the VCO for modulation. The modulation level is set by adjusting the output level of the modulator.

4. RECEIVER I.F. AMPLIFIER (FIGURE 7)

The CA3189 is a complete I.F. strip with built-in audio preamplifier and muting circuitries. The CA3189 is operating at an I.F. frequency of 10.7 MHz. A crystal filter preceding the CA3189 limits the I.F. bandwidth to approximately 15 kHz. Two stages of amplification are added to compensate for the loss in the crystal filter and to provide additional gain for the CA-3189. The audio output of the CA3189 is sufficient to drive the audio power amplifier.

5. AUDIO POWER AMPLIFIER (FIGURE 7)

The LM380 is a commonly available general purpose audio power amplifier. At rated supply voltage (15V), the LM380 can provide as high as 2W of audio output power. At a supply voltage of 8V, its power drops down to about 200mW. The volume control can also serve as the power ON-OFF switch.

6. TRANSMITTER R.F. AMPLIFIERS (FIGURE 8)

The preamplifier, driver and power amplifiers are of typical designs. The preamplifier and the driver amplifier are both class A, and the final power amplifier is class C. Various LC resonance circuits are needed for peaking and impedance matching between stages.

7. RECEIVER R.F. AMPLIFIER AND MIXER

Not completed.

DISCUSSION:

Various sections of the throw-away radio have been breadboarded with the exception of the receiver R.F. amplifier and mixer stages. The synthesizer, I.F. amplifier, modulator, and the multiplier stages are designed to operate at a regulated voltage of 8 volts while the supply voltage for the audio power amplifier and the transmitter R.F. amplifier stages are not regulated. The intended voltage of the battery is 15 volts.

Performance of the synthesizer was satisfactory. It provided the entire range of frequencies for the intended operating band. Lock up was a little slow near the band edges. This was due to the low reference frequency used. However, this should impose negligible effect on operation.

Performance of the two multiplier stages was marginal due to the high multiplication factor and high operating frequency.

The modulator amplifier is a high gain audio amplifier. It generates a 3V (p-p) signal with a maximum input signal of 14mV (p-p) before clipping.

The I.F. amplifier requires approximately 15uV input signal to provide a noise-free audio output, and the 200mW from the audio power amplifier should be enough level for most situations.

At a supply voltage of 12 volts, the three transmitter R.F. amplifier stages provided a total gain of 30 dB. This corresponds to an input signal of approximately 200mV and an output power of 1 watt.

The total power consumption of the various sections was quite a bit higher than anticipated. The standby current was approximately 150mA. The sources of the excessive current drain have been traced to the I.F. amplifier, audio power amplifier and the multiplier stages. A different device (SL664 made by Plessey) has been identified and can be used in place of the I.F. amplifier (CA3189) and the audio power amplifier (LM380).

The SL664 has a current drain of approximately 10mA instead of 60mA for the CA3189 and LM380. Although it is not objectionable, lock up time of the synthesizer near the band edges can be improved by using a higher reference frequency. Raising the reference frequency and reducing the multiplication factor will also improve the efficiency of the multiplier stages. Raising the reference frequency will slightly increase the current drain, but this will be compensated by lowering the reference oscillator frequency and using a smaller dividing number.

CONCLUSION:

Due to the financial and schedule constraints and a lack of manpower, a working model of the throw-away radio could not be completed. However, enough effort had been made to determine that it is feasible to develop a low cost,throw-away radio with reasonable performance. A preliminary cost estimate for the electronic components to build a single radio is $220, and the cost for a complete radio with case is estimated at $500 for a quantity of 5 to 10 thousand units. (See Appendix 1, Parts List and Cost Estimates.)

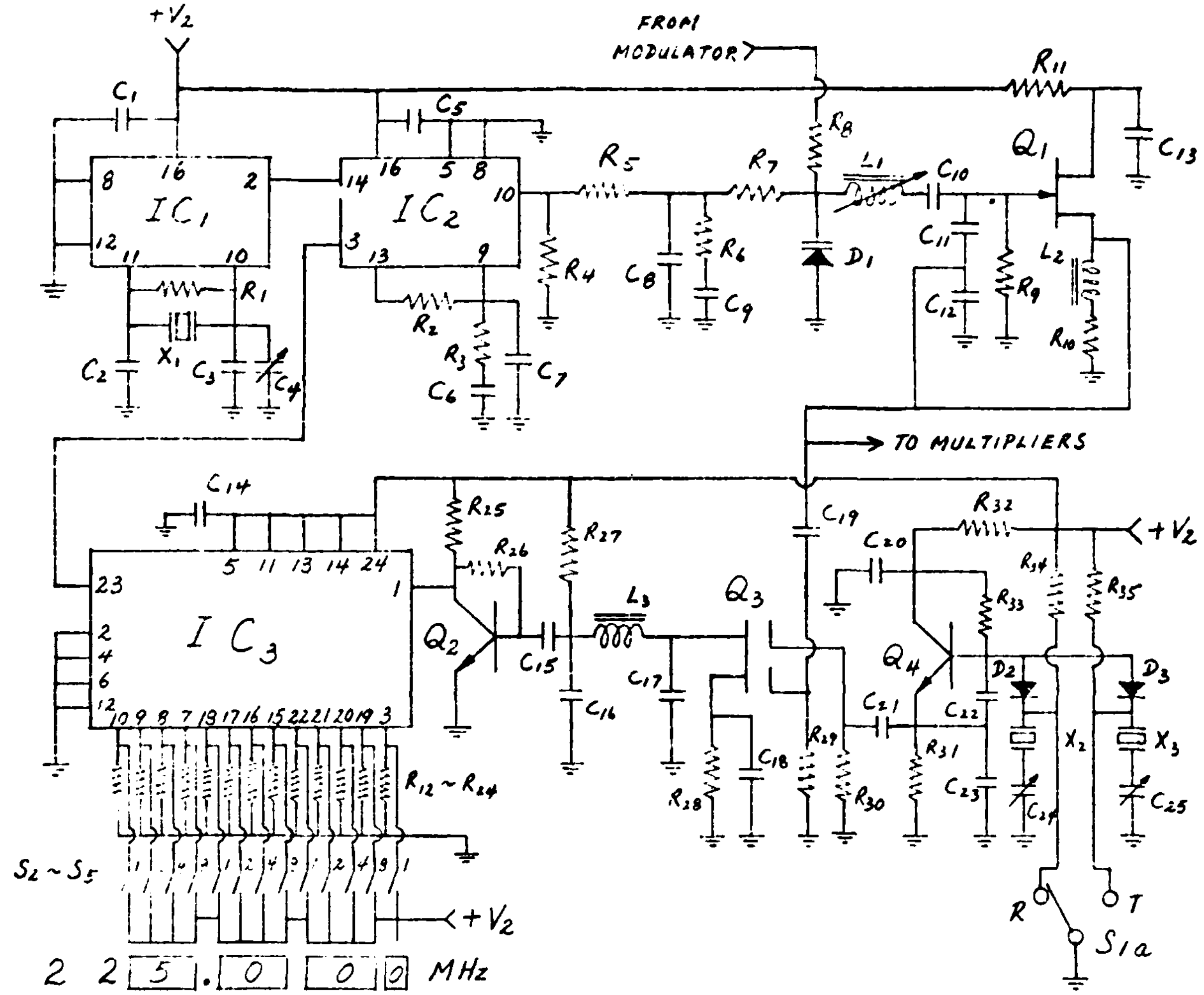

FIG. 4 SYNTHESIZER

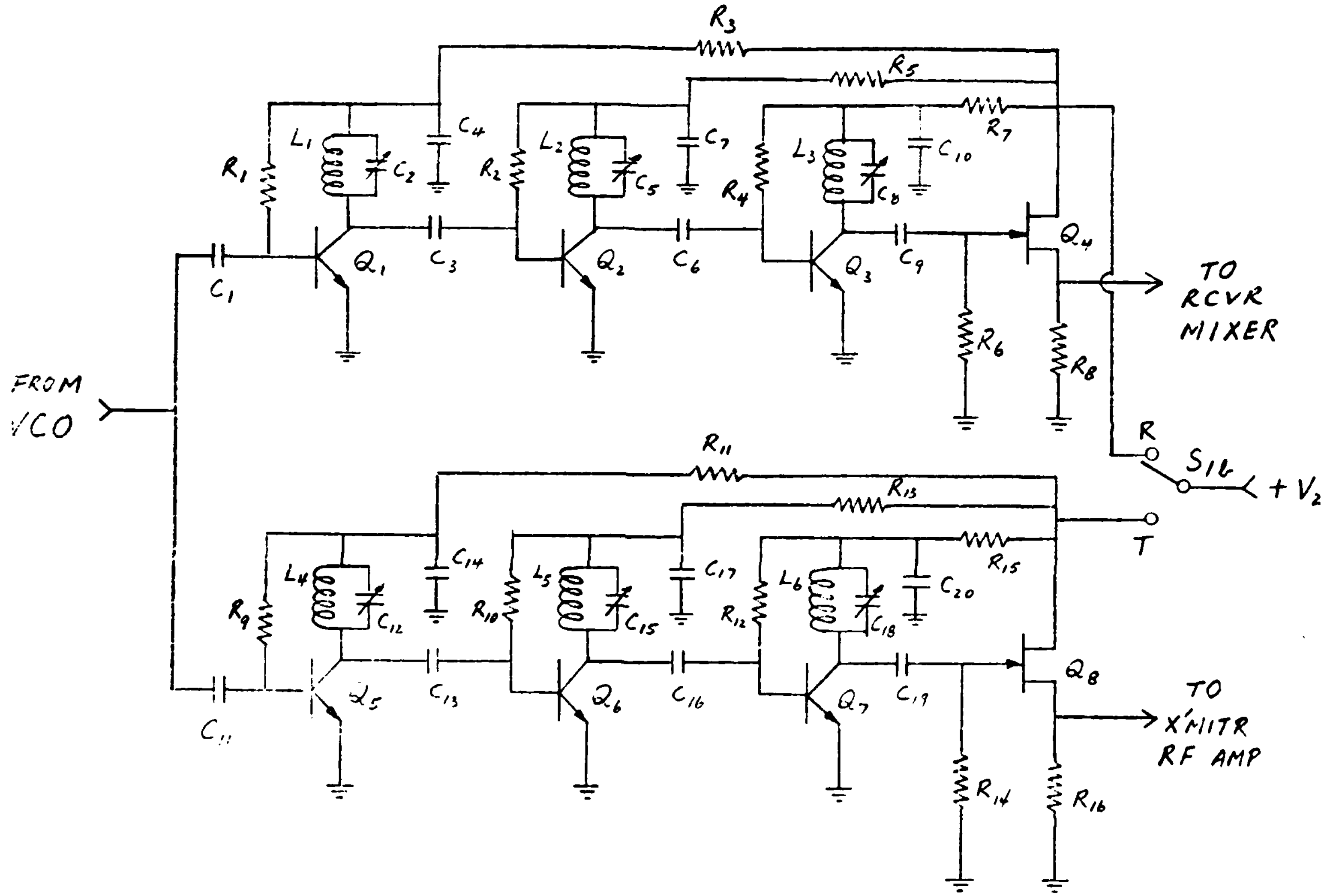

FIG. 5 MULTIPLIERS

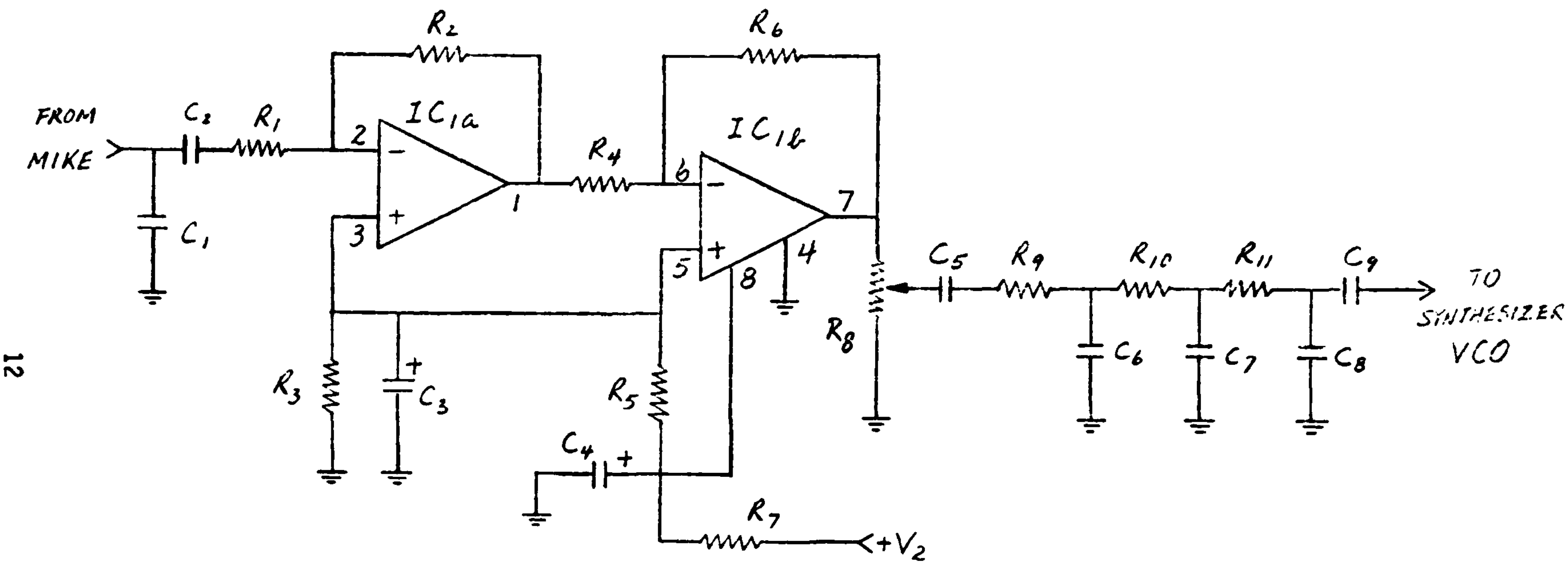

FIG. 6 MODULATOR

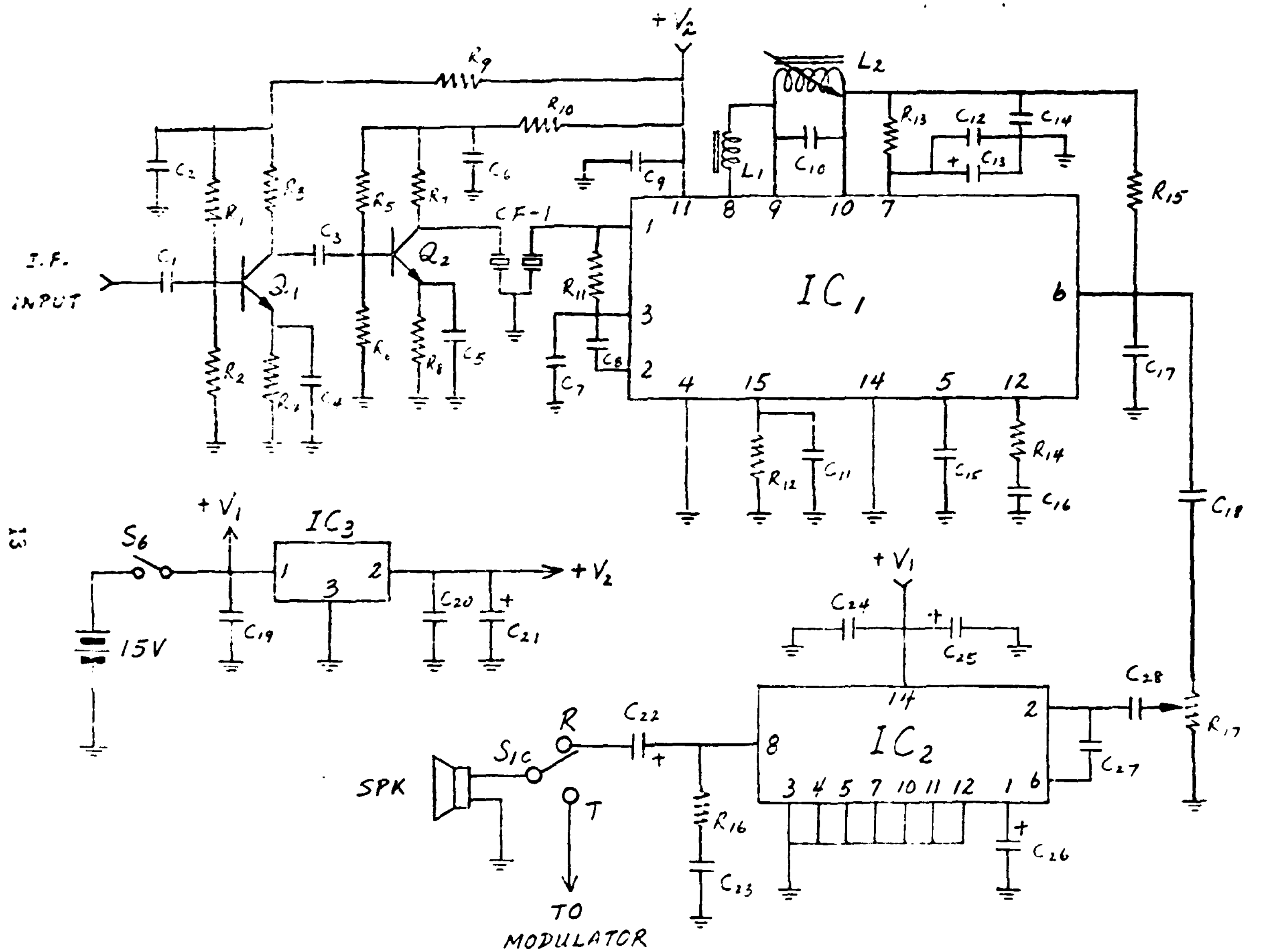

FIG. 7 I.F. & AUDIO AMPLIFIERS

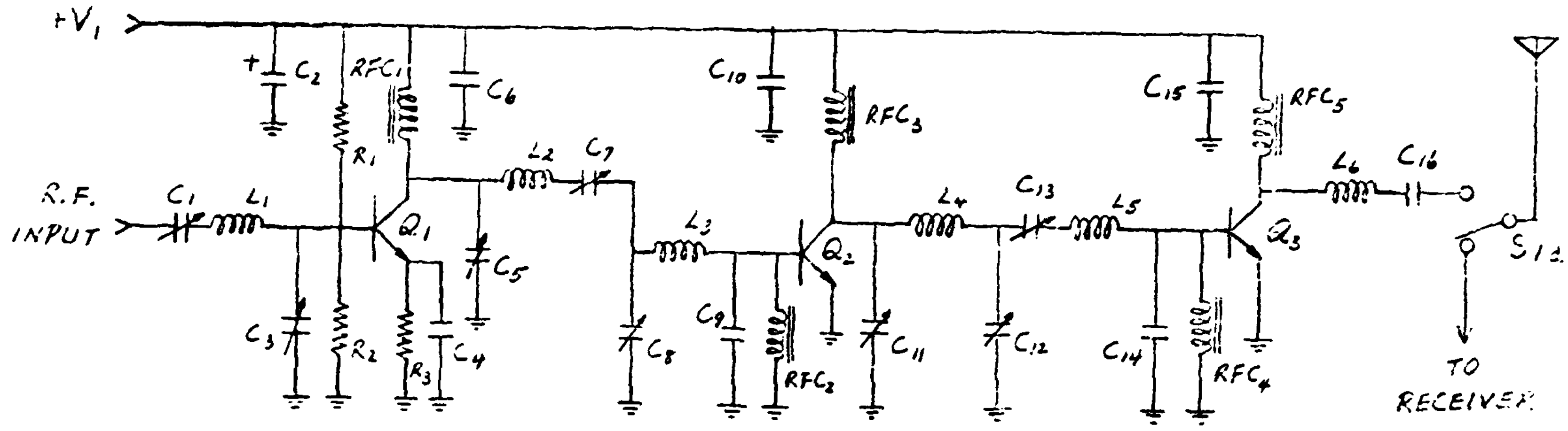

FIG. 8 TRANSMITTER AMPLIFIERS

APPENDIX 1

PARTS LIST AND COST ESTIMATES

(All costs are actual except where asterisked (*) which are estimates.)

SYNTHESIZER: (FIG 4)

IC_1	CD4060	Oscillator-divider	$1.68
IC_2	CD4046	Phase lock loop	1.99
IC_3	CD4059	Programmable divider	5.00
Q_1	3N128	FET	1.35
Q_2	2N3904	NPN Transistor	0.49
Q_3	40673	Dual gate MOSFET	1.75
Q_4	2N2857	NPN transistor	1.80
D_1	MV2112	Varactor diode	0.90
D_2	1N4148	Silicon diode	0.16
D_3	1N4148	Silicon diode	0.16
R_1	10M	¼W 5% carbon resistor	0.11
R_2	10K	¼W 5% carbon resistor	0.11
R_3	15K	¼W 5% carbon resistor	0.11
R_4	10K	¼W 5% carbon resistor	0.11
R_5	2.2K	¼W 5% carbon resistor	0.11
R_6	100K	¼W 5% carbon resistor	0.11
R_7	100K	¼W 5% carbon resistor	0.11
R_8	100K	¼W 5% carbon resistor	0.11
R_9	1M	¼W 5% carbon resistor	0.11
R_{10}	470	¼W 5% carbon resistor	0.11
R_{11}	100	¼W 5% carbon resistor	0.11

R_{12}	100K	¼W 5% carbon resistor	$0.11
R_{13}	100K	¼W 5% carbon resistor	0.11
R_{14}	100K	¼W 5% carbon resistor	0.11
R_{15}	100K	¼W 5% carbon resistor	0.11
R_{16}	100K	¼W 5% carbon resistor	0.11
R_{17}	100K	¼W 5% carbon resistor	0.11
R_{18}	100K	¼W 5% carbon resistor	0.11
R_{19}	100K	¼W 5% carbon resistor	0.11
R_{20}	100K	¼W 5% carbon resistor	0.11
R_{21}	100K	¼W 5% carbon resistor	0.11
R_{22}	100K	¼W 5% carbon resistor	0.11
R_{23}	100K	¼W 5% carbon resistor	0.11
R_{24}	100K	¼W 5% carbon resistor	0.11
R_{25}	3.3K	¼W 5% carbon resistor	0.11
R_{26}	220K	¼W 5% carbon resistor	0.11
R_{27}	2.2K	¼W 5% carbon resistor	0.11
R_{28}	270	¼W 5% carbon resistor	0.11
R_{29}	100K	¼W 5% carbon resistor	0.11
R_{30}	100K	¼W 5% carbon resistor	0.11
R_{31}	1K	¼W 5% carbon resistor	0.11
R_{32}	100	¼W 5% carbon resistor	0.11
R_{33}	3.3K	¼W 5% carbon resistor	0.11
R_{34}	100K	¼W 5% carbon resistor	0.11
R_{35}	100K	¼W 5% carbon resistor	0.11

C_1	0.01uF	Ceramic disc capacitor	$0.11
C_2	47pF	Ceramic disc capacitor	0.07
C_3	68pF	Ceramic disc capacitor	0.07
C_4	35pF	Trimmer capacitor	1.69
C_5	0.01uF	Ceramic disc capacitor	0.11
C_6	1uF	Tantalum capacitor	0.66
C_7	0.1uF	Tantalum capacitor	0.66
C_8	1uF	Tantalum capacitor	0.66
C_9	10uF	Tantalum capacitor	0.76
C_{10}	0.001uF	Ceramic disc capacitor	0.07
C_{11}	47pF	Ceramic disc capacitor	0.07
C_{12}	47pF	Ceramic disc capacitor	0.07
C_{13}	0.01uF	Ceramic disc capacitor	0.11
C_{14}	0.01uF	Ceramic disc capacitor	0.11
C_{15}	0.001uF	Ceramic disc capacitor	0.07
C_{16}	220pF	Ceramic disc capacitor	0.07
C_{17}	220pF	Ceramic disc capacitor	0.07
C_{18}	0.01uF	Ceramic disc capacitor	0.11
C_{19}	10pF	Ceramic disc capacitor	0.07
C_{20}	0.01uF	Ceramic disc capacitor	0.11
C_{21}	39pF	Ceramic disc capacitor	0.07
C_{22}	100pF	Ceramic disc capacitor	0.07
C_{23}	100pF	Ceramic disc capacitor	0.07
C_{24}	35pF	Trimmer Capacitor	1.69
C_{25}	35pF	Trimmer Capacitor	1.69

X_1	4.551111 MHz Crystal	$8.50
X_2	21.033333 MHz Crystal	6.50
X_3	22.222222 MHz Crystal	6.50
L_1	VCO Tuning coil	*2.00
L_2	15uH RFC	1.05
L_3	10uH RFC	1.05
S_1	4P2T push to talk switch	*3.00
S_2	BCD switch	1.95
S_3	BCD switch	1.95
S_4	BCD switch	1.95
S_5	BCD switch	1.95
TOTAL		$64.84

MULTIPLIERS: (FIG 5)

Q_1	2N2857	NPN transistor	$1.80
Q_2	2N2857	NPN transistor	1.80
Q_3	2N2857	NPN transistor	1.80
Q_4	3N128	FET	1.35
Q_5	2N2857	NPN transistor	1.80
Q_6	2N2857	NPN transistor	1.80
Q_7	2N2857	NPN transistor	1.80
Q_8	3N128	FET	1.35
R_1	220K	¼W 5% carbon resistor	0.11
R_2	220K	¼W 5% carbon resistor	0.11
R_3	100	¼W 5% carbon resistor	0.11
R_4	220K	¼W 5% carbon resistor	0.11
R_5	100	¼W 5% carbon resistor	0.11
R_6	100K	¼W 5% carbon resistor	0.11
R_7	100	¼W 5% carbon resistor	0.11
R_8	270	¼W 5% carbon resistor	0.11
R_9	220K	¼W 5% carbon resistor	0.11
R_{10}	220K	¼W 5% carbon resistor	0.11
R_{11}	100	¼W 5% carbon resistor	0.11
R_{12}	220K	¼W 5% carbon resistor	0.11
R_{13}	100	¼W 5% carbon resistor	0.11
R_{14}	100K	¼W 5% carbon resistor	0.11
R_{15}	100	¼W 5% carbon resistor	0.11
R_{16}	270	¼W 5% carbon resistor	0.11

C_1	270pF	Ceramic disc capacitor	$0.07
C_2	20pF	Trimmer capacitor	0.07
C_3	10pF	Ceramic disc capacitor	0.07
C_4	0.01uF	Ceramic disc capacitor	0.11
C_5	20pF	Trimmer capacitor	1.69
C_6	10pF	Ceramic disc capacitor	0.07
C_7	0.01uF	Ceramic disc capacitor	0.11
C_8	20pF	Trimmer capacitor	1.69
C_9	10pF	Ceramic disc capacitor	0.07
C_{10}	0.01uF	Ceramic disc capacitor	0.11
C_{11}	470pF	Ceramic disc capacitor	0.07
C_{12}	20pF	Trimmer capacitor	1.69
C_{13}	10pF	Ceramic disc capacitor	0.07
C_{14}	0.01uF	Ceramic disc capacitor	0.11
C_{15}	20pF	Trimmer capacitor	1.69
C_{16}	10pF	Ceramic disc capacitor	0.07
C_{17}	0.01uF	Ceramic disc capacitor	0.11
C_{18}	20pF	Trimmer capacitor	1.69
C_{19}	10pF	Ceramic disc capacitor	0.07
C_{20}	0.01uF	Ceramic disc capacitor	0.11
L_1	#25 AWG wire, 6 turns, 3/16" dia.		*0.05
L_2	#25 AWG wire, 2 turns, 3/16" dia.		*0.05
L_3	#25 AWG wire, 2 turns, 3/16" dia.		*0.05
L_4	#25 AWG wire, 6 turns, 3/16" dia.		*0.05

L_5	#25 AWG wire, 2 turns, 3/16" dia.	*0.05
L_6	#25 AWG wire, 2 turns, 3/16" dia.	*0.05
TOTAL		$25.30

MODULATOR: (FIG 6)

IC_1	LM1458	Dual op-amp.	$0.89
R_1	100K	¼W 5% carbon resistor	0.11
R_2	470K	¼W 5% carbon resistor	0.11
R_3	10K	¼W 5% carbon resistor	0.11
R_4	4.7K	¼W 5% carbon resistor	0.11
R_5	10K	¼W 5% carbon resistor	0.11
R_6	100K	¼W 5% carbon resistor	0.11
R_7	100	¼W 5% carbon resistor	0.11
R_8	10K	Trimmer potentiometer	2.00
R_9	15K	¼W 5% carbon resistor	0.11
R_{10}	15K	¼W 5% carbon resistor	0.11
R_{11}	15K	¼W 5% carbon resistor	0.11
C_1	220pF	Ceramic disc capacitor	0.07
C_2	0.01uF	Ceramic disc capacitor	0.11
C_3	10uF	Tantalum electrolytic	0.76
C_4	10uF	Tantalum electrolytic	0.76
C_5	0.47uF	Tantalum electrolytic	0.66
C_6	0.001uF	Ceramic disc capacitor	0.07
C_7	0.001uF	Ceramic disc capacitor	0.07
C_8	0.001uF	Ceramic disc capacitor	0.07
C_9	0.47uF	Tantalum electrolytic	0.66
TOTAL			$7.22

IF AND AUDIO AMPLIFIERS: (FIG 7)

IC_1	CA3189	I.F. amplifier	$3.75
IC_2	LM380	Audio amplifier	1.25
IC_3	uA78L08	Voltage regulator	0.61
Q_1	2N3904	NPN transistor	0.49
Q_2	2N3904	NPN transistor	0.49
R_1	68K	¼W 5% carbon resistor	0.11
R_2	39K	¼W 5% carbon resistor	0.11
R_3	820	¼W 5% carbon resistor	0.11
R_4	470	¼W 5% carbon resistor	0.11
R_5	68K	¼W 5% carbon resistor	0.11
R_6	39K	¼W 5% carbon resistor	0.11
R_7	820	¼W 5% carbon resistor	0.11
R_8	470	¼W 5% carbon resistor	0.11
R_9	1K	¼W 5% carbon resistor	0.11
R_{10}	1K	¼W 5% carbon resistor	0.11
R_{11}	3.3K	¼W 5% carbon resistor	0.11
R_{12}	10K	¼W 5% carbon resistor	0.11
R_{13}	10K	¼W 5% carbon resistor	0.11
R_{14}	470	¼W 5% carbon resistor	0.11
R_{15}	10K	¼W 5% carbon resistor	0.11
R_{16}	2.2K	¼W 5% carbon resistor	0.11
R_{17}	5K	Volume control with ON-OFF switch S_6	2.00

C_1	10pF	Ceramic disc capacitor	$0.07
C_2	0.01uF	Ceramic disc capacitor	0.11
C_3	220pF	Ceramic disc capacitor	0.07
C_4	0.01uF	Ceramic disc capacitor	0.11
C_5	0.01uF	Ceramic disc capacitor	0.11
C_6	0.01uF	Ceramic disc capacitor	0.11
C_7	0.01uF	Ceramic disc capacitor	0.11
C_8	0.01uF	Ceramic disc capacitor	0.11
C_9	0.01uF	Ceramic disc capacitor	0.11
C_{10}	47pF	Ceramic disc capacitor	0.07
C_{11}	0.01uF	Ceramic disc capacitor	0.11
C_{12}	0.01uF	Ceramic disc capacitor	0.11
C_{13}	10uF	Tantalum electrolytic	0.76
C_{14}	10uF	Tantalum electrolytic	0.76
C_{15}	2.2uF	Tantalum electrolytic	0.66
C_{16}	0.47uF	Tantalum electrolytic	0.66
C_{17}	0.01uF	Ceramic disc capacitor	0.11
C_{18}	0.01uF	Ceramic disc capacitor	0.11
C_{19}	0.01uF	Ceramic disc capacitor	0.11
C_{20}	0.01uF	Ceramic disc capacitor	0.11
C_{21}	10uF	Tantalum electrolytic	0.76
C_{22}	100uF	Tantalum electrolytic	1.00
C_{23}	0.1uF	Tantalum electrolytic	0.66
C_{24}	0.01uF	Ceramic disc capacitor	0.11
C_{25}	100uF	Tantalum electrolytic	1.00

C_{26}	4.7uF	Tantalum electrolytic	$0.66
C_{27}	0.01uF	Ceramic disc capacitor	0.11
C_{28}	0.01uF	Ceramic disc capacitor	0.11
L_1	22uH	Coil	1.05
L_2		Tunes with C_{10} at 10.7 MHz	*2.00
CF-1	10.7 MHz	Filter	5.00
Speaker		3" 8 ohm 0.1W	2.00
TOTAL			$29.29

R.F. AMPLIFIERS: (FIG 8)

Q_1	2N2857	NPN transistor	$1.80
Q_2	2N2857	NPN transistor	1.80
Q_3	MRF-207	RF power transistor	2.00
R_1	6.8K	¼W 5% carbon resistor	0.11
R_2	5.6K	¼W 5% carbon resistor	0.11
R_3	470	¼W 5% carbon resistor	0.11
C_1	20pF	Trimmer capacitor	1.69
C_2	10uF	Tantalum electrolytic	0.76
C_3	20pF	Trimmer capacitor	1.69
C_4	0.001uF	Ceramic disc capacitor	0.07
C_5	20pF	Trimmer capacitor	1.69
C_6	0.001uF	Ceramic disc capacitor	0.07
C_7	20pF	Trimmer capacitor	1.67
C_8	20pF	Trimmer capacitor	1.67
C_9	39pF	Ceramic disc capacitor	0.07
C_{10}	0.001uF	Ceramic disc capacitor	0.07
C_{11}	35pF	Trimmer capacitor	1.67
C_{12}	35pF	Trimmer capacitor	1.67
C_{13}	20pF	Trimmer capacitor	1.67
C_{14}	39pF	Ceramic disc capacitor	0.07
C_{15}	0.001uF	Ceramic disc capacitor	0.07
C_{16}	39pF	Ceramic disc capacitor	0.07

L_1	4 turns, #18 AWG wire, 3/16" dia.	*0.05
L_2	4 turns, #18 AWG wire, 3/16" dia.	*0.05
L_3	2 turns, #18 AWG wire, 3/16" dia.	*0.05
L_4	4 turns, #18 AWG wire, 3/16" dia.	*0.05
L_5	2 turns, #18 AWG wire, 3/16" dia.	*0.05
L_6	4 turns, #18 AWG wire, 3/16" dia.	*0.05
RFC_1	4 turns, #18 AWG wire on 1/8" ferrite bead	*0.50
RFC_2	4 turns, #18 AWG wire on 1/8" ferrite bead	*0.50
RFC_3	4 turns, #18 AWG wire on 1/8" ferrite bead	*0.50
RFC_4	4 turns, #18 AWG wire on 1/8" ferrite bead	*0.50
RFC_5	4 turns, #18 AWG wire on 1/8" ferrite bead	*0.50
TOTAL		$23.40

RECEIVER FRONT END:

Cost estimate based on anticipated complexity of the receiver front end.	*$20.00

MISCELLANEOUS:

Case	*$20.00
Antenna	*$10.00
PC board	*$ 5.00
Battery terminals, knobs, mounting hardware, etc.	*$15.00
TOTAL	$50.00

GRAND TOTAL:

Synthesizer	$64.84
Multipliers	25.30
Modulator	7.22
IF and Audio Amplifiers	29.29
R.F. Amplifiers	23.40
Receiver Front End	20.00
Miscellaneous	50.00
TOTAL	$220.05

All the component prices are for small quantity purchases. For small quantity purchases, the total component cost for the radio is estimated to be $220. For large quantity (5000 ~ 10000) purchases, the total cost for components can be expected to be reduced by 50%. This brings the component cost to $110. From previous experience with private industries, the final selling price can be estimated at four times the material cost. Therefore, the radio should be able to be purchased for less than $500 in large quantities.