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Design of a 150-megacycle Pocket Receiver for the BELLBOY Personal Signaling System

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A highly sensitive pocket receiver with a code-responsive signaling device has been designed for the 150-megacycle BELLBOY personal signaling system. Ten transistors in a single-IF, superheterodyne receiver circuit convert the FM signaling wave to produce excitation of a sound generator through a tuned reed selector circuit. Printed wiring and novel packaging techniques are employed to produce a receiver of acceptable size and weight. A rechargeable battery with provision for home charging or a primary battery is used for power supply.

A discussion of design problems and an analysis of circuit performance is included. Sensitivity sufficient to signal in a 20-microvolt per meter field is achieved.

I. INTRODUCTION

This paper will describe the electrical and physical features of the 55A radio receiver and certain associated apparatus, which were designed for use in BELLBOY personal signaling systems operating in the 150-megacycle common carrier band of frequencies. The receiver is pocket-sized and provides, in effect, an extension of the telephone bell to the customer's pocket so that he may be alerted while away from his office, home, or base location. An incoming signal, bearing the customer's specific code, triggers the receiver. The receiver then emits a continuous tone, in response to which the customer calls his base telephone to receive his message, or responds in some other prearranged manner.

The requirements and applications of this service have been covered in a previous paper.[1] In the present paper, discussion is concerned with the requirements placed on size, cost, and performance of the receiver, and the various circuit and equipment features which were used to achieve these ends. Major problems encountered in both the electrical and mechanical design are discussed in some detail, and an analysis of the circuit performance is included.

The 55A radio receiver is a ten-transistor superheterodyne circuit packaged in a molded plastic case. It has a self-contained antenna and is powered by a battery mounted in a detachable case. When a rechargeable battery is used, a charger is provided, which will accept the battery case and permit the battery to be charged by placing the assembly in any convenient 117-volt ac outlet.

II. OBJECTIVES

To meet system objectives for personal signaling service, the receiver must be able to respond to a calling signal when hand-held or pocket-borne, when located within or outside of buildings, whether some distance from or close to the transmitter site, and in many and varied environments. The receiver must therefore be very sensitive. It must also possess good stability against temperature variations, against shock and vibration of transportation or handling, and against normal drift in voltage of the battery source.

In addition to the above general requirements, the following performance objectives were set on the receiver:

(a) The receiver should be designed to permit reception on any assigned channel in the frequency range from 152.51 to 152.81 megacycles.*

(b) The receiver should respond to a carrier frequency which is frequency-modulated with three audio-frequency tones, simultaneously applied, each at a deviation of 1.3 kilocycles. Each receiver must respond to only one combination of tones sent out from the base transmitter. (In a fully loaded system, 3200 useful codes[1] are derived from the combinations of the three out of thirty-two available tone frequencies in the range from 500 to 1000 cycles.)

(c) The local oscillator of each receiver must possess a frequency stability of ±0.0005 per cent, or better. (The base transmitter frequency is maintained to ±0.0001 per cent, or one part per million.)

(d) The receiver must respond to this specified wave for any environmental field strength between 26 and 100 db above one microvolt per meter.

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* The actual receiver is capable of being tuned to frequencies somewhat beyond this range, but performance in such circumstances would be subject to restrictions, especially regarding occupancy of the image frequency band.

(e) With 30-kc channel spacing, the receiver must have a selectivity of at least 80 db against an adjacent channel carrier.

(f) All requirements should be met in an ambient temperature range from 50 to 110 degrees F.

(g) Radiation from the receiver must meet requirements of Part 15 of the FCC rules governing restricted radiation devices. For the frequencies of interest in this receiver, these requirements are: the field due to the 75-mc local oscillator must not exceed 50 μv/m at a distance of 100 feet. The field due to the 150-mc conversion frequency must not exceed 100 μv/m at a distance of 100 feet.

(h) In addition to the FCC requirements, radiation from the receiver must not be strong enough to cause the sensitivity of a second similar receiver at 5 feet distance to be reduced by more than 6 db.

(i) The receiver should operate from a self-contained, rechargeable battery with provisions for home charging. The receiver should operate without recharging the battery for at least 10 hours. As an alternate the receiver should operate from a disposable battery, which should provide at least 75 hours of operation before replacement.

(j) The signaling sound output of the receiver, when it is carried in an inside pocket, should be clearly audible in a reasonably strong noise environment.

The needs of the customer, as well as economic considerations, affected the design of the receiver package. To suit the customer, who must carry the receiver, it needed to be as small and light as possible, and attractive as well. It was required to be completely self-contained, with no appended antenna or battery box. However, the cost and ease of manufacture, as well as reliability in operation and ease of repair, are factors which tended to place a limit on the smallness and compactness of so complex a unit. Naturally, the final design represents an economically feasible compromise between these opposing influences.

Such objectives naturally posed very difficult design problems. The premium on small size and weight limited the available power from the battery. Therefore, to obtain a suitable interval of service before recharge, the current drain of the receiver had to be minimized. Also, the size and number of circuit components had to be kept small, which called for utmost simplification of the circuits.

III. ELECTRICAL DESIGN FEATURES

3.1 *General Circuit Description*

The selectivity and sensitivity requirements dictated the choice of a superheterodyne circuit with at least one low intermediate frequency. In the early work, conventional approaches using either a crystal filter or an electromechanical filter were explored, but the complexity and large number of components involved seemed contradictory in the face of space and cost limitations. Therefore a less conventional solution involving a single, very low intermediate frequency was adopted.

The circuit of the receiver is considered for convenience of discussion as consisting of the following major parts: RF circuits, IF circuits, discriminator, reed circuit and sound oscillator. These sections will be described briefly, referring to the circuit schematics, Figs. 1 to 4.

The RF circuit (Fig. 1) consists of the antenna, two RF amplifier stages, the RF mixer, and the local oscillator. Shielding is indicated by the broken lines. The output of the mixer is the 6-kilocycle IF, which is delivered to the IF amplifier. The first IF stage is included within the shielding of the RF compartment. In the IF circuits (Fig. 2), the input signal is amplified by one transistor amplifier, passed through a low-pass filter which acts as the IF filter, and is then amplified by two more IF amplifiers. The fourth IF stage is operated as a limiter. This stage is an overloaded amplifier which, for medium to strong signals, produces a square-wave-like output. This output is delivered to the discriminator (FM detector), shown in Fig. 3. The audio output from the discriminator is passed on to the reed circuits (Fig. 4). Here the tone content is amplified to a strength sufficient to operate the tuned armatures of the reed selector units.[2] Only when the signal contains the proper code will all three reeds be simultaneously stimulated. In that case, a circuit through the reed contacts delivers an impulse to the sounder circuit, which triggers it into oscillation. This causes an audio transducer to emit a continuous tone which signals the customer. To stop the audio sound output, the user must operate a miniature pushbutton, which then resets the circuit and places the receiver in readiness for the next call.

3.2 *IF Plan*

While the use of a single conversion and the low (6-kc) intermediate frequency in this receiver was a practical solution to the space and cost problem, it brought with it an interesting set of associated problems, some advantages and some disadvantages. One advantage was that the IF filter became a simple low-pass structure, inexpensive when compared to an electromechanical or crystal bandpass filter which would be required for a higher IF. Also, the IF amplifier could be designed to use relatively inexpensive alloy junction transistors. From an interference standpoint, the single, low IF remains an advantage only as long as its lone image response falls in an unoccupied space in the spectrum. The

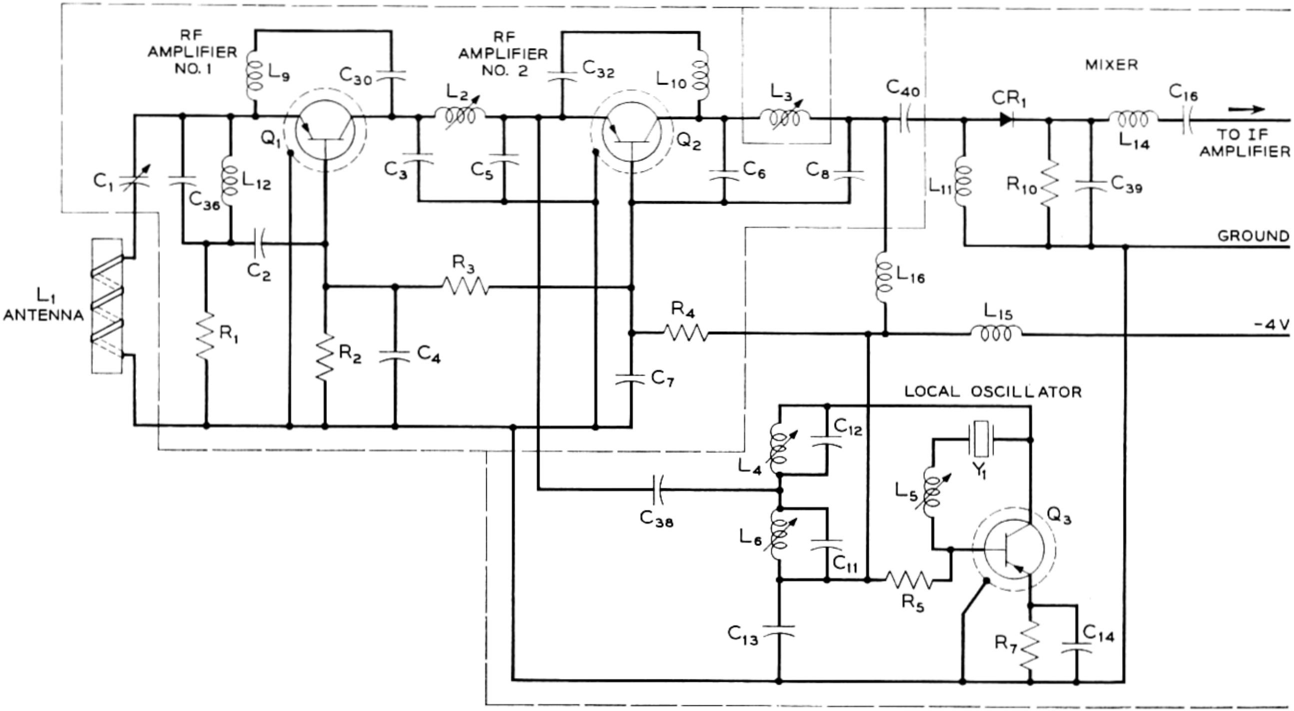


Fig. 1 — RF circuits.

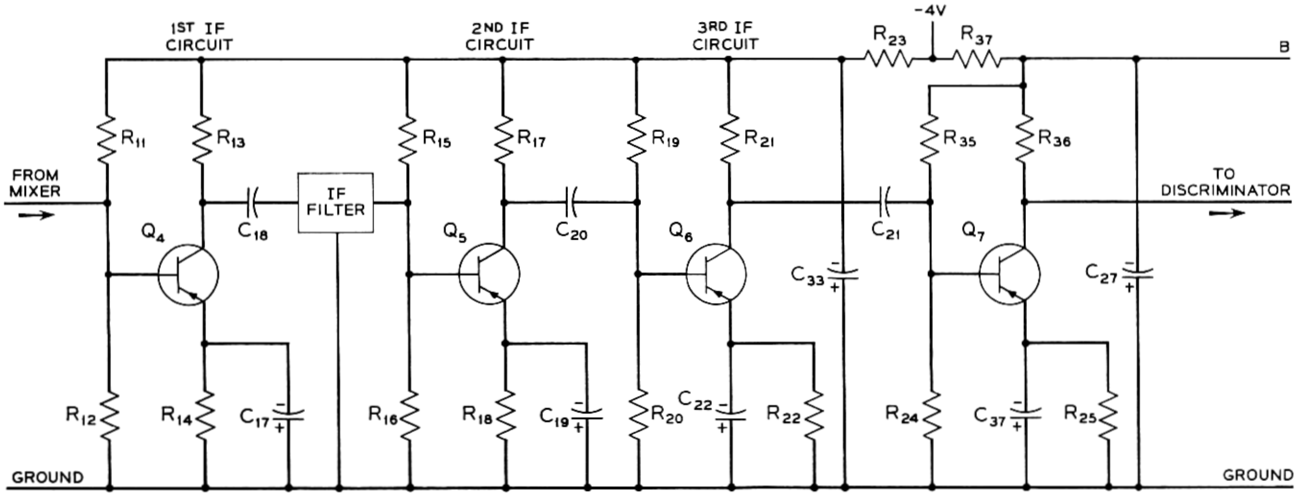


Fig. 2 — IF circuits.

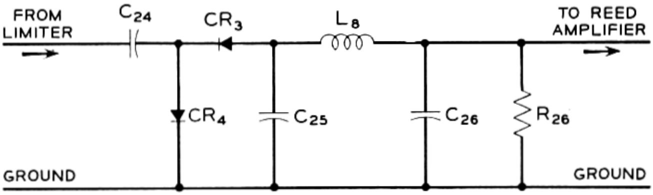


Fig. 3 — Discriminator.

choice of the 6-kc IF frequency was predicated on the assumed use by this service of one of the common-carrier mobile channels. Thus the image frequency, which is spaced 12 kc from the received carrier, falls within a channel width of ±15 kc (see Fig. 5).

Conventional superheterodyne receivers, with intermediate frequencies considerably higher than that used herein, obtain image rejection by means of RF selectivity. Such selectivity eliminates thermal noise contributions in the vicinity of the image frequency. Since no rejection of the image frequency exists in this design, a 3-db penalty in the noise figure must be accepted.

Another disadvantage of the low IF comes about from $1/f$ noise[3] modulation in the high-frequency beating oscillator. This noise modulation, characterized by sidebands which are strongest in the vicinity of the oscillator frequency, is detected by the mixer and appears as extraneous noise energy in the IF amplifier. In receivers employing higher intermediate frequencies, the $1/f$ noise modulation is less significant.

Because the frequency of the local oscillator is so close to the incoming signal frequency, no attenuation of the oscillator frequency is achieved in the RF amplifier tuned circuits. Therefore, the opportunity for spurious outputs of oscillator energy via reverse transmission through the amplifier is greater than would exist if the IF were considerably higher in frequency. This can produce interference in other nearby receivers as discussed in the next section.

To include the necessary sidebands of the intermediate frequency, and at the same time to attenuate the signaling tone frequencies, the IF amplifier was designed to cut off frequencies below 2 kc (Fig. 6). The discriminator output filter was designed to attenuate the IF residue above 2 kc. In the crossover region near 2 kc, the tandem gain of the IF amplifier and the reed amplifier remained sufficient to require very careful control of these characteristics to avoid instability due to inadvertent over-all feedback.

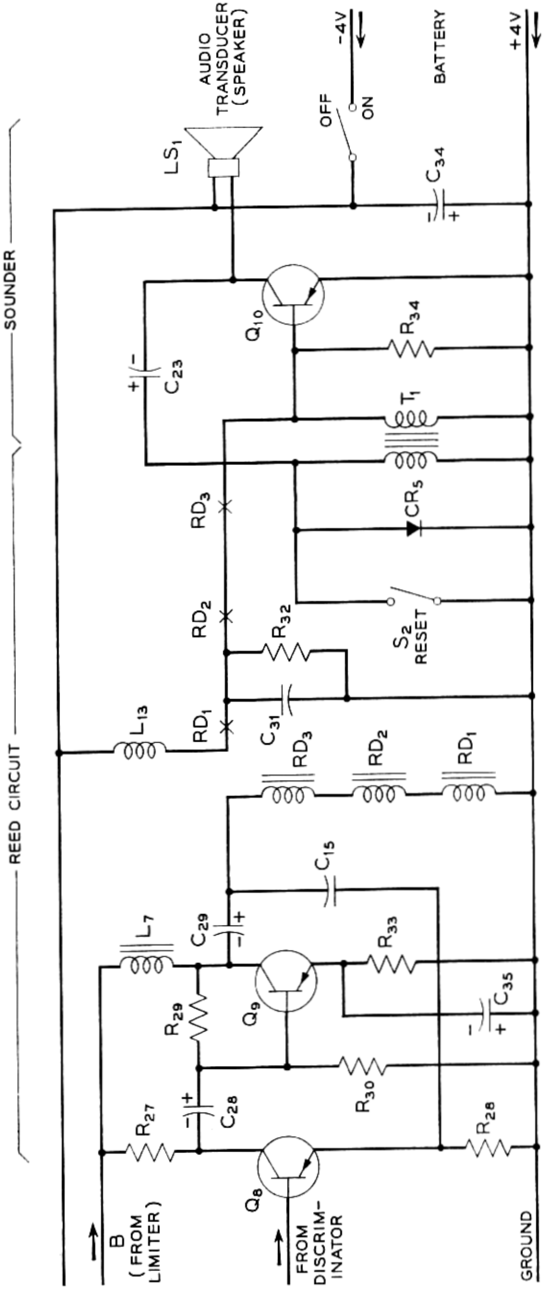


Fig. 4 — Reed circuit and sound oscillator.

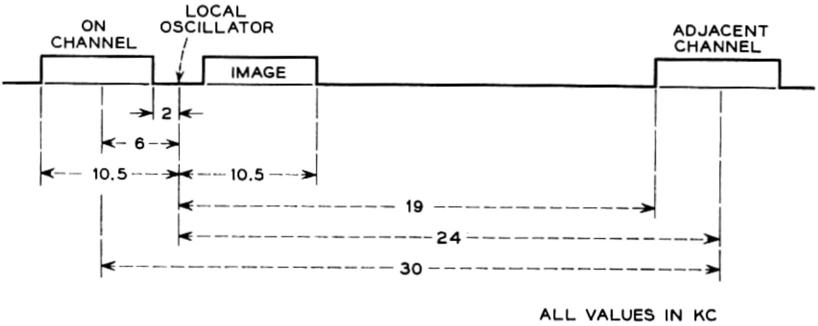


Fig. 5 — RF channel spectrum.

3.3 *Frequency Stability*

As many as twenty base transmitters may be used in a large metropolitan area to provide the required coverage. To prevent the generation of beat tones in the receiver, which might interfere with signaling, the frequencies of base transmitters are held to an accuracy of one part per million (±0.0001 per cent).[1]

Although oscillator radiation from the receiver has been kept within the stated requirements, there may be instances (as when two customers meet in conversation) in which a beat due to the difference of two local oscillators will occur in the mixer stages of each. If this beat is high enough in frequency it will be transmitted through the IF, causing de-

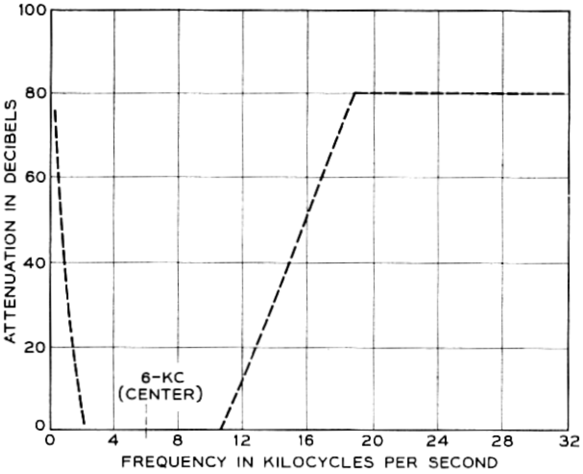


Fig. 6 — IF response requirements.

sensitization. If it is too low to pass through the IF, it may still be carried to the reeds as a tone modulation on the desired signal. In this latter case, if its frequency coincides with that of one of the three reeds, it could conceivably cause false signaling in response to any code containing the other two reed frequencies.

In an attempt to maintain these beat frequencies below the IF transmission band, the oscillators are adjusted within ±125 cps at the factory. The crystals maintain this frequency within ±600 cps of the original adjustment throughout the temperature range +10 to +45 degrees C. If the temperature coefficients are oppositely signed, it would then be possible for two such oscillators to differ by as much as 1450 cps at some temperature within the range. In addition to this, if two crystals did not enter service at the same time, an aging factor could add to or subtract from this difference. Thus, it is evident that desensitization due to direct feed into the IF is possible. However, it is considered improbable that the deviations due to extreme temperature, opposite-signed coefficients, and age difference would all add during a chance meeting of two customers.

In considering the probability of false signaling due to a beat within the reed frequency range (500 to 1000 cps), it is necessary to remember that each of the three reeds responds only to an extremely narrow frequency band (about 1.2 cps). Thus the probability of the beat falling into one of these slots is indeed small. Since such interference also depends on the coincidence of a number of low probability factors, it is not expected to be a serious field problem.

The positioning of the IF signal in the band of transmission defined by the filter and the low frequency cutoffs of the amplifier is affected by all deviations of the oscillator and transmitter combined. Thus the total of all such deviations, including the peak deviation due to modulation, ideally should be contained within the IF transmission bandwidth. This bandwidth is approximately 8.5 kilocycles.

TABLE I

Cause of Deviation	Max. Range
Base Transmitter:	
Oscillator (tolerance ± 0.0001%)	0.3 kc
Peak modulation (deviation ±3.9 kc)	7.8 kc
Receiver:	
Temperature (±4 ppm between 10°C and 45°C)	1.2 kc
Crystal aging (±5 ppm first year)	1.5 kc
Total	10.8 kc

Table I lists the factors involved in determining the required receiver IF bandwidth.

If we add the inaccuracy of the initial setting of the oscillator frequency, which is held within ±125 cps, it is obvious that peaks of modulation may often be in danger of spilling outside the IF transmission bandwidth. Fortunately, peak modulation due to the addition of three sinusoidal tones occurs only a small percentage of the time. Thus these peaks may be degraded without serious loss of signaling sensitivity.

Experiments have been performed in which the frequency has been deliberately moved off-center in the IF band. By this means it has been demonstrated that a displacement of ±1.5 kc produces less than 2-db degradation of signaling sensitivity.

3.4 *Battery Considerations*

The limitation on space and weight was one of the most serious factors in the choice of a suitable battery. A 3-cell, nickel-cadmium battery supplies about 3.7 volts and possesses the advantage that it can be recharged on a routine basis. For this purpose a simple home charger is provided, which may be supplied to the customer by the telephone company. A mercury battery with a nominal voltage of 4 volts is also available. This battery will provide service for about two weeks of average usage, before replacement.

Because of the limited battery capacity, circuits were required which provided the necessary gain with the lowest possible power drain. Special circuit designs were evolved, in some cases, to accomplish these objectives. For example, it was determined early in the development that greater gain in the RF circuits, for a given dc power input, could be obtained by operating the two diffused-base, germanium transistors in series from a dc standpoint, rather than in parallel.

Although the receiver is already in commercial service, development is continuing to improve the characteristics and life of the rechargeable battery. The outcome of this development may necessitate modifications in the battery case and also in the charger.

3.5 *Power Level Diagram*

Fig. 7 shows a block diagram of the receiver and an associated graph giving the power level in dbm of both signal and noise at significant points through the circuit. The noise is shown for the absence of signal. The signal is shown for the just-operate condition of the reeds, and the signal powers given at the reed driver amplifier (RDA) input and output

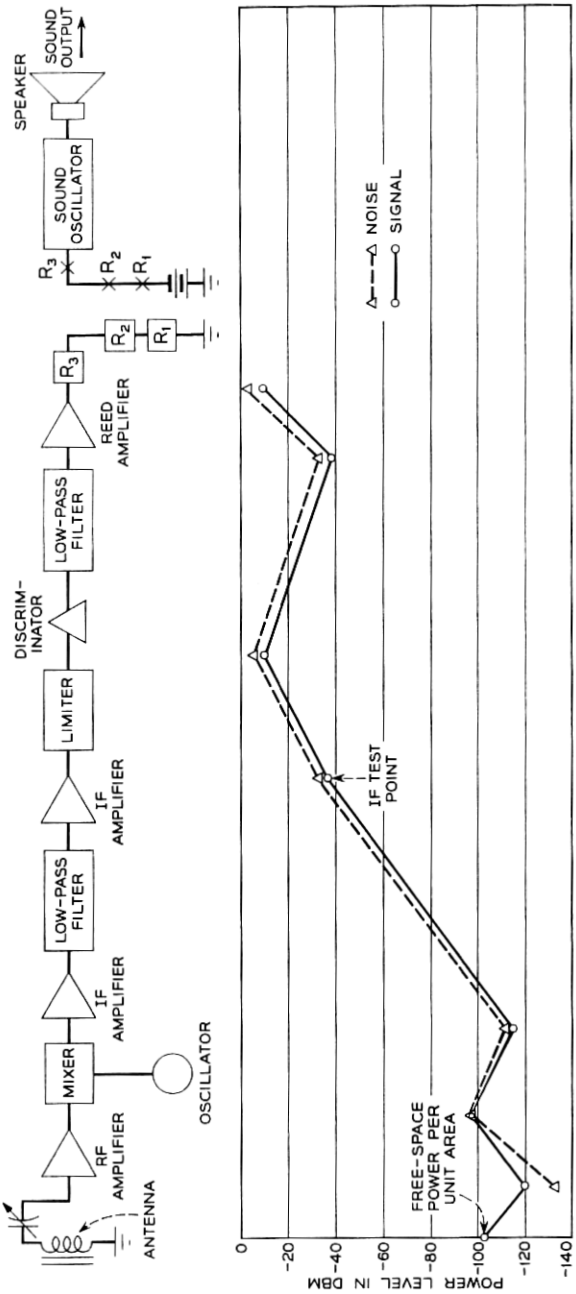


Fig. 7 — Receiver power level diagram.

are those for one of the three signaling tones. The signal values shown prior to the discriminator are for the power in the RF and IF wave regardless of modulation.

A readily measured reference is the level at the IF test point, where a signal-to-noise ratio of about -2 db exists for the just-signaling condition.

The levels in the early sections of the receiver are based on measurements of the IF amplifier gain, on laboratory measurement of the RF gain available in circuit jigs, and on computed values of noise at the RF input. The method of constructing the level diagram fixed the mixer output on the basis of measurements at IF, and the mixer input on signaling sensitivity input data and the measured value of RF gain. The difference between mixer input and output indicates 18-db conversion loss. The difference between signal-to-noise ratios at the first RF input and at the IF test point indicates a noise figure of 15 db, which agrees reasonably well with the result of the noise figure analysis to follow.

A signal level point is provided at the left of the chart showing the power per unit area in space carried by a signal wave whose field strength is at the required value, i.e., 26 db above 1 microvolt per meter. This is derived in the discussion of antenna effectiveness to follow.

3.6 *Noise Figure Analysis*

Since there is no image rejection, the available RF noise power must be calculated in a bandwidth twice that of the IF. For 8.5-kc IF bandwidth, therefore, the RF noise bandwidth is 17 kc. The available noise power (at 290 degrees Kelvin) is

$$\begin{aligned} P_n &= KTB \\ &= 1.38 \times 10^{-23} \times 290 \times 17 \times 10^3 \times 10^3 \text{ mw} \\ &= 6.8 \times 10^{-14} \text{ mw} \\ 10 \log P_n &= -131.7 \text{ dbm.} \end{aligned}$$

The input impedance of the RF amplifier transistor is determined by measurement from data in Fig. 9, which will be discussed later in connection with the neutralization of the RF stages. This impedance is

$$Z_i = 25 + j38.6.$$

Data on typical receivers indicated that the RF power input to this impedance required to cause 3-db increase of the energy measured at IF stage 3 output was approximately

$$P_s = -117.5 \text{ dbm}.$$

Assuming no further change in the signal-to-noise ratio at points beyond the IF test point, the difference in db between P_n and P_s is the noise figure

$$F_t = -117.5 - (-131.7) = 14.2 \text{ db}.$$

This correlates with the 15-db change in signal-to-noise ratio which appears between the RF input and the IF test point on the level diagram. Measured noise figures on a few sets ranged from 11 to 14 db.

The noise figure results from contributions of excess noise in each of the earlier stages of the receiver. The importance of each contribution is shown by the well-known formula[4] for over-all noise figure,

$$F_t = F_1 + \frac{F_2 - 1}{A_1} + \frac{F_3 - 1}{A_1 A_2} + \cdots$$

in which F_1, F_2, F_3, etc. are noise figures for the successive individual stages, and A_1, A_2, etc. are the power gain ratios of the successive individual stages.

Assume $A_1A_2 = 23$ db, which is the gain of the two RF stages shown on the level diagram, and assume that the individual stage gains, A_1 and A_2, are equal. Then

$$A_1 = 14.14 \text{ (power ratio)}$$
$$A_1A_2 = 200 \text{ (power ratio)}.$$

Also assume F_1 and F_2 are each 8 db or a power ratio of 6.3.

Then, for $F_t = 14.2$ db (or 26.3 power ratio), the contribution of the remainder of the set may be calculated:

$$26.3 = 6.3 + \frac{5.3}{14.14} + \frac{F_3 - 1}{200}.$$

Solving, we get

$$F_3 = 35.9 \text{ db}.$$

It is thus apparent that the third term, containing the noise figure of the mixer, is the heaviest contributor to the over-all result. About 18 db of this is due to the conversion loss, as indicated on the level diagram. A considerable amount is attributed to the noise figure of the diode. Another very considerable portion is the result of $1/f$ noise modulation carried by the local oscillator energy.

Although, in the above discussion, no stage beyond the mixer was considered, there is at least a noticeable contribution from the first IF transistor which may be harmful if not controlled.

3.7 *Antenna Effectiveness*

The antenna effectiveness is largely dependent on which way the receiver, or the person wearing it, is facing relative to the transmitter. As has been noted by Mitchell and Van Wynen,[1] the presence of the human body provides gain in some orientations, while in others it provides shielding, resulting in rather severe loss. Antenna effectiveness, averaged over all orientations, is a useful criterion.

According to Schelkunoff and Friis,[5] the effective area of a receiving antenna is the ratio of the maximum power received at its terminals from a linearly polarized wave, to the power per unit area in the wave. Thus

$$A = (240\pi P_r/E^2)$$

where

A = Effective area of the antenna in square meters.
E = Field intensity of the wave in microvolts per meter.
P_r = Power received by the load connected to the antenna terminals.

A receiver of average sensitivity will signal satisfactorily in a field of +26 db relative to 1 μv/m averaged over all orientations (or 20 microvolts per meter).

Thus

$$E = 20 \times 10^{-6} \text{ volt per meter.}$$

As shown on the level diagram, assume the signaling power to be -120 dbm at the antenna output, or

$$P_r = 1.0 \times 10^{-15} \text{ watt.}$$

Thus the effective area of the antenna, when worn on the body and averaged for all orientations, is

$$A_{av} = \frac{240\pi(1.0 \times 10^{-15})}{400 \times 10^{-12}}$$

$$= 1.886 \times 10^{-3} \text{ square meter.}$$

The effective area of a half-wave dipole antenna is

$$A = 0.13\lambda^2.$$

For 150 mc,

$$\lambda = 2 \text{ meters and}$$

$$A = 0.52 \text{ square meter.}$$

Therefore the gain of the receiver antenna averaged over all orientations, with respect to a half-wave dipole, is

$$G_{\mathrm{av}} = 10 \log (0.001886/0.52) = -24.4 \text{ db}.$$

Some experimental information showed that, on the average, the gain at optimum orientation with respect to the field is about 6.8 db above the average gain. Thus

$$G_{\max} = -24.4 + 6.8 = -17.6 \text{ db (at optimum)}.$$

Note that the power per unit area carried by the wave is

$$\begin{aligned} W &= \frac{E^2}{240\pi} = \frac{400 \times 10^{-12}}{240\pi} \\ &= 0.053 \quad 10^{-12} \text{ watt} \\ &= -132.8 \text{ dbw} \\ &= -102.8 \text{ dbm}. \end{aligned}$$

This point is plotted as antenna input power on the level diagram, Fig. 7.

A number of other antenna types were tested in the course of the development. The present design is probably not as great in effective area as some other configurations which were tested. It was adopted in preference to types which produced undesirable coupling of the antenna to other circuits of the receiver, resulting in instability, and other types which suffered detuning due to body presence.

3.8 *RF Neutralization*

Partial neutralization of the RF amplifier transistors was accomplished by providing an inductor between emitter and collector of the common-base amplifier, as shown in Fig. 1.

From a statistical analysis based on a modest sample of transistors in the early stages of production, element values were assigned to an equivalent circuit of a typical transistor. This network is shown in Fig. 8(a). Fig. 8(b) shows Z_F as the neutralizing element applied. This network is resolved in Fig. 8(c) into two parallel networks N_1 and N_2.

The y-parameters of these two networks were calculated and a well-known theorem of matrix algebra was applied. This states that each of the y-parameters of the combined network is equal to the sum of the corresponding parameters of the two component networks. Applying this, the feedback parameter (Y_{12}) for the combined network was computed in terms of the neutralizing element (Z_f) and equated to zero. Solving,

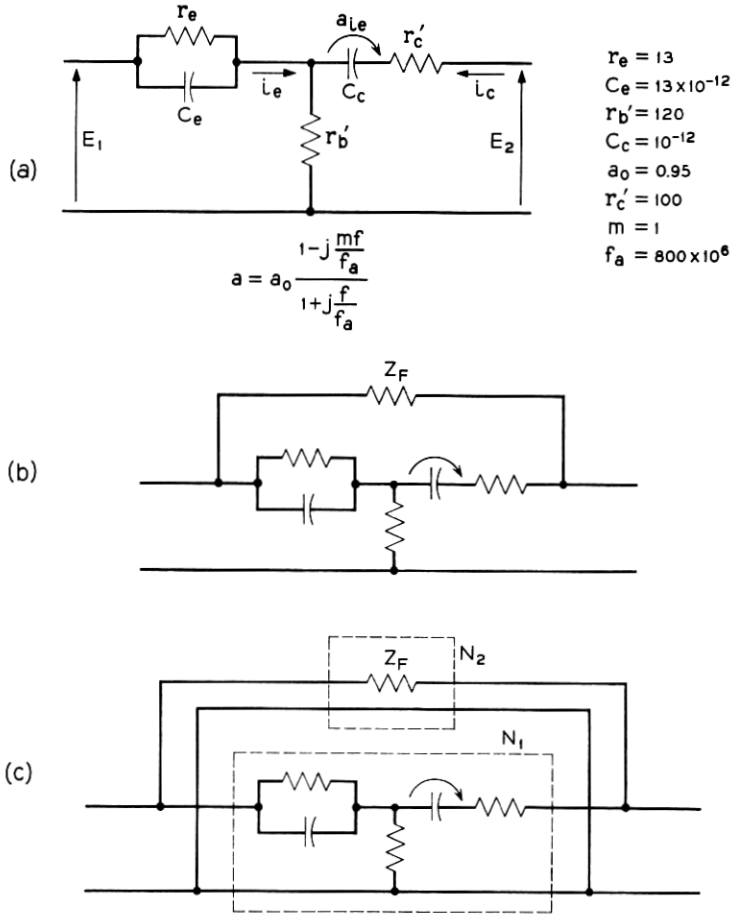


Fig. 8 — (a) Assumed equivalent circuit for RF amplifier transistor; (b) assumed equivalent circuit with neutralizing impedance added; (c) component networks used in analysis of neutralization.

the admittance $(1/Z_f)$ required for perfect neutralization was found to be

$$(1/Z_f) = -0.002155 - j0.000873.$$

This represents a coil of reactance $+j1142$ ohms in parallel with a resistor of -463 ohms connected between emitter and collector. Since a negative resistance is impractical in this circuit design, the coil alone was used to give only partial neutralization.

By taking into account the capacitance of the inductor and its mounting, very good agreement was found between the computed value of inductance and the value which was found to be most effective by experiment.

Results of impedance measurements of the input and output of an amplifier stage which employed a transistor of median characteristics, according to the above-mentioned analysis, are shown in Figs. 9 and 10. The test circuits are shown on the figures. These show that in each case the use of the neutralizing coil ($L_N = 0.68$ μh) has little effect on the measured value of reactance, but the variation of resistance is considerably improved. It is to be noticed that the measuring terminals, in each

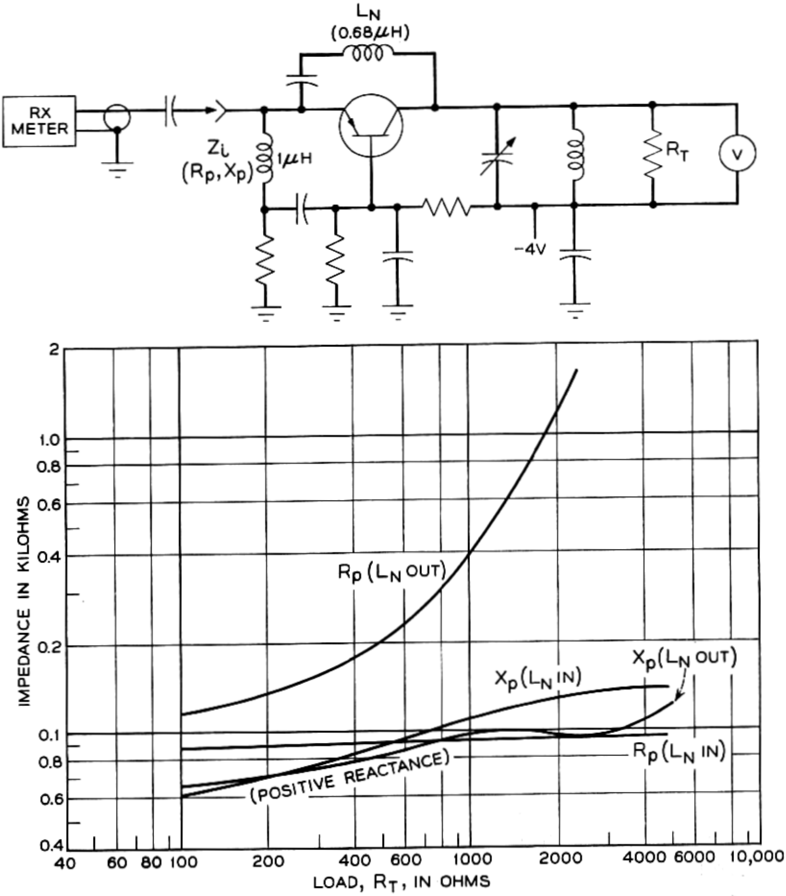


Fig. 9 — RF amplifier, neutralization effect on input impedance.

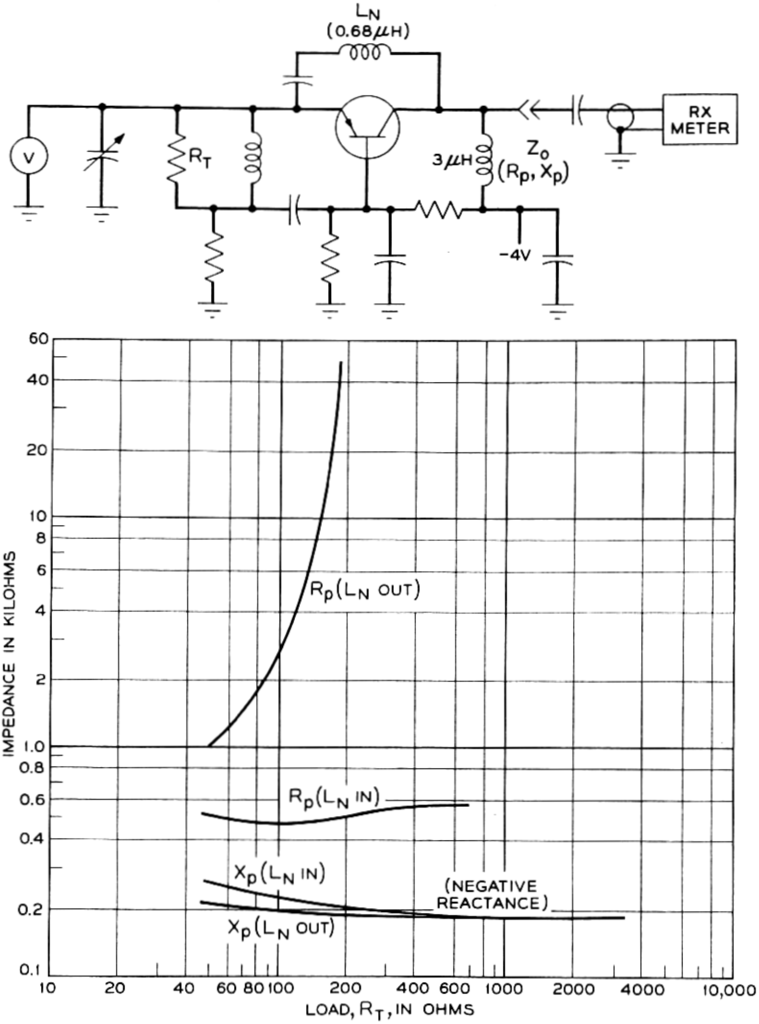


Fig. 10 — RF amplifier, neutralization effect on output impedance.

case, are shunted by a choke, whose reactance is included in the measured values together with circuit strays.

It is interesting to compare the measured values of input impedance with those calculated for the "median" transistor from its equivalent circuit. The calculated impedance is

$$Z_i = 25 + j38.6$$

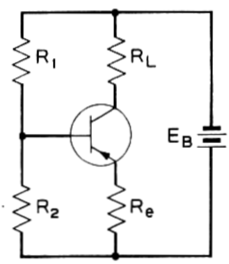
which corresponds to 85 ohms resistance in parallel with $+j55$ ohms reactance. From the curves, assuming 500 ohms load, the values are 89 ohms in parallel with $+j82$ ohms reactance.

3.9 *Bias Stabilization*

For uniformity of performance with variations due to ambient temperature, battery voltage, and the normal tolerances on components, some stabilization of the transistor bias is necessary. The design must accommodate the difference in battery voltage between the mercury battery (4 volts) and the standard nickel-cadmium rechargeable battery (3.7 volts). Since neither battery affords a surplus of energy to be consumed in biasing circuits, only a modest degree of stabilization was possible.

The general principles of bias stabilization are treated in many texts on transistor circuit design: for example, in Chapter 6 of Shea.[6] The basic bias circuit used widely in the 55A receiver is shown in Fig. 11. The effect on the collector current (I_c) of the variations of the saturation current (I_{co}) due to temperature, is designated as a factor S, which it is desired to minimize. The best stability is thus achieved when the emitter resistor (R_e) is made as large as feasible and the parallel combination of R_1 and R_2 is made as small as feasible.

Fig. 12 shows the bias circuit used in the RF stages, where the transistor currents are connected in series. An emitter resistor (R_1) stabilizes the current of the first transistor, while the base bias voltages of both transistors are fixed by the resistor chain R_2, R_3, and R_4 across the battery. The factor S for the first transistor is estimated to be about 4.5. The first collector current which is stabilized to this degree is auto-



$$S = \frac{dI_c}{dI_{co}}$$

$$S = \frac{k}{k-\alpha}, \text{ WHERE } k = 1 + \frac{R_e}{R_2} + \frac{R_e}{R_1}$$

$$k-\alpha = 1-\alpha + \frac{R_e}{R_2} + \frac{R_e}{R_1}$$

FOR GOOD VALUES OF α, $1-\alpha \doteqdot 0$

$$S \approx \frac{1+\frac{R_e}{R_2}+\frac{R_e}{R_1}}{\frac{R_e}{R_2}+\frac{R_e}{R_1}} = 1 + \frac{1}{\frac{R_e}{R_2}+\frac{R_e}{R_1}}$$

$$\therefore S \approx 1 + \frac{R_x}{R_e}$$

IN WHICH,

$R_x = R_1$ IN PARALLEL WITH R_2

Fig. 11 — 55A receiver — bias stabilization, single stage.

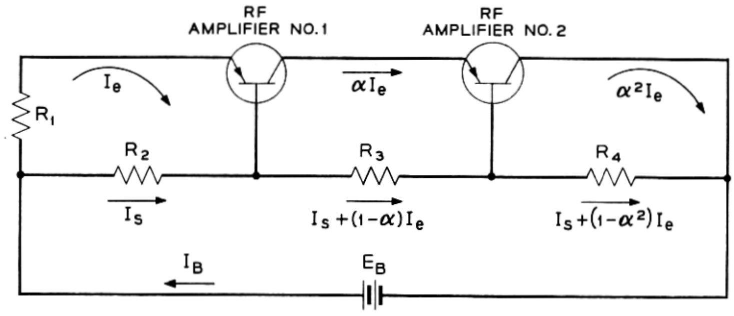


Fig. 12 — 55A receiver — RF amplifiers transistor bias circuit.

matically the emitter current of the second transistor. Thus, we might say that the emitter current of the second RF transistor is stabilized by the output resistance of the first transistor, which is relatively high.

On the basis of Fig. 11, the factor S for the IF amplifier stages is about 9.5. This poorer stabilization of the IF stages is in part compensated for by the fact that the IF transistor characteristics are carefully controlled, particularly with respect to I_{co}. Temperature variation tests showed that satisfactory stability has been attained.

3.10 *Semiconductor Devices*

In the design of this receiver, advantage was taken of the best available semiconductor devices, and in fact, the demand created through this application has had considerable influence on the characterization of the devices used. To meet the requirement of small size of the receiver, it was necessary to miniaturize the encapsulation of the transistors and diodes.

Gold-bonded germanium diodes are used both in the mixer and in the discriminator.

A set of seven germanium alloy junction transistors, coded as the 28A transistor, is used in the IF amplifier, limiter, reed amplifier and sound oscillator stages. These are mechanically and electrically the same as the WE 17A transistor but individually identified as to the range of the parameter h_{fe} (beta). Although each set uses the full range of beta found in normal 17A production, by the identification it is possible to install the low-beta and high-beta transistors in the stages which can benefit most from these characteristics.

The RF transistors (WE 26A), when connected in the common-base amplifier circuit, are capable of about 12 db per stage gain. These transistors are designed to maintain this characteristic at the low values of collector-to-base voltage which result from operating the two RF amplifiers in series.

IV. CIRCUIT DESCRIPTION

The following sections will describe the circuit in some detail, making use of the Figs. 1 to 4, which together form a complete schematic of the receiver.

4.1 *RF Section*

Fig. 1 shows the radio frequency circuits of the antenna, the two RF amplifiers, the mixer, and the local oscillator.

The self-contained antenna is a "loop-stick" type, consisting of about $2\frac{1}{2}$ turns of copper ribbon wound in a helix on a high-Q ferrite core 2 inches long and $\frac{3}{8}$ inch in diameter.

The inductance of the antenna winding is tuned to series resonance by a variable capacitor (C_1), connecting to the input of the first RF amplifier stage. Since the input of the transistor is shunted by a capacitor (C_{36}), the transistor is tapped across a portion of the capacitive branch of the resonant antenna mesh.

The RF amplifier stages consist of two diffused-base pnp transistors (WE 26A) in a common-base configuration. The coupling networks between the two transistors and between the second transistor and the mixer provide the necessary impedance transformations. The inductors are self-supporting coils which are tuned by manually stretching and compressing their length by use of an insulated pick inserted through openings provided in the shield around the RF circuits. The ratio of the two capacitance values in the pi networks determines the transformation ratio.

As discussed earlier, partial neutralization is accomplished by a fixed inductor in series with a dc blocking capacitor, connected from emitter to collector of each transistor. Neutralization is required to minimize interaction of tuning of the antenna, interstage, and mixer circuits. It also minimizes leakage of local oscillator energy to the antenna.

The amplified RF signal is combined with the second harmonic of the 75-megacycle, crystal-controlled, local oscillator* in the mixer diode (CR_1) to produce the intermediate frequency as the difference between these two frequencies. The second harmonic energy from the local oscil-

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* At the start of this development, a 150-megacycle crystal with the required stability was not considered to be feasible.

lator is capacitively fed to the emitter of the second RF amplifier transistor. It is then amplified simultaneously with the signal before being impressed on the mixer diode. The shunt capacitor (C_{39}) which follows the mixer diode provides RF ground, which causes the full RF voltage to be developed on the diode. Series inductor L_{14} passes to the IF amplifier the difference frequency that is developed on the mixer load resistor (R_{10}).

The method used here, which derives the second harmonic directly from the oscillator and amplifies it to a value suitable for mixing, possesses advantages over the direct injection of the 75-megacycle oscillator frequency into the mixer. The latter method would require third-order mixing, with inherently greater conversion loss than is achieved by the present method, which involves second-order mixing. Another advantage of the circuit used is that the 75-megacycle energy radiated from the receiver is more effectively attenuated.

A quartz crystal, oscillating on the fifth overtone in the 75-megacycle range, is used with a WE 26A diffused-base transistor to form the local oscillator circuit. The circuit may be thought of as a common-emitter amplifier in which the crystal provides a feedback path from collector to base. A slug-tuned coil (L_5) in series with the crystal is used to set the frequency.

The collector-to-emitter impedance of the oscillator consists of two resonant meshes. One (L_4 and C_{12}) is resonant near 75 megacycles while the other (L_6 and C_{11}) is resonant near 150 megacycles. The voltage developed across the latter is fed to the injection point on the second RF amplifier.

This type of oscillator possesses inherent $1/f$ noise modulation[3] which is apparently a function of the individual transistor, and is particularly troublesome because of the low value of the intermediate frequency. The resistor (R_7) between emitter and ground provides feedback which reduces the noise modulation to within tolerable limits. This resistor is bypassed at RF.

4.2 *IF Section*

Fig. 2 shows the schematic circuit for the three stages of IF amplification and the limiter stage. All four stages are similar, using alloy junction transistors in the common-emitter configuration with bias stabilization as shown in Fig. 11.

Filtering in the IF amplifier is controlled primarily by the package filter, which appears on the schematic as a block between the first and second IF stages. This is a low-pass filter with the ground terminal common to input and output. The filter cuts off at approximately 10 kilocycles.

Although the filter is a low-pass network, the over-all transmission of the IF amplifier exhibits a bandpass characteristic (Fig. 6). The low-frequency cutoff of about 2 kc is caused by the blocking capacitors between transistors.

The limiter is operated as an overdriven amplifier. Because of the high gain developed in the preceding stages, even the no-signal noise experiences a small degree of amplitude limiting in this stage. Thus any signal which rises out of the ambient noise is limited in this stage. Stronger signals are limited in progressively earlier stages.

4.3 *Discriminator*

Fig. 3 shows the discriminator circuit, which converts the FM IF signal into the original tone frequencies of the coded signal. It is seen to be a form of rectifier circuit using diodes with the load connected through a low-pass output filter. The circuit configuration resembles that of a voltage doubler rectifier. This circuit also bears a strong resemblance to that of a "storage counter" described in the literature.[7]

The low-pass output filter provides a cutoff of about 2 kc, in order to prevent the passage of the IF to the following stages. The filter has essentially zero loss to the recovered signal tones whose frequencies lie between 500 and 1000 cycles per second.

It is not necessary for the applied signal to be limited for this discriminator to function, but it may simplify understanding if the applied IF signal is considered to be a square wave whose frequency varies according to the modulating wave form.

The output capacitor (C_{25}) is continually charged by the rectification of the IF wave and discharged by current flow through the load resistor (R_{26}). The output filter separates C_{25} and C_{26} at the IF, but effectively connects them in parallel at the signal frequency. Therefore the charge is shared at the slower rate, and the rate of discharge is in effect determined by a time constant, $(C_{25} + C_{26})R_{26}$.

Referring to the input of the discriminator circuit, it is seen that a positive pulse will cause the shunt diode (CR_4) to conduct while the series diode is non-conducting. Thus, the series input capacitor (C_{24}) is charged at a rate dependent on its capacitance value multiplied by the effective resistance of the diode (CR_4). This rate is made high by choice of a small value of capacitance, so that approximately full charge is reached during the positive half-cycle of the IF wave.

Upon the reversal of the input wave, the shunt diode becomes nonconducting and the series diode (CR_3) conducts. Because of the voltage reversal, the stored charge on C_{24} adds to the drive voltage, and assists in charging the output capacitor (C_{25}). The measure of charge delivered to the output capacitor is determined by the change in the quantity stored on C_{24} during the cycle. Since the charge on C_{24} becomes completely reversed from its initial value, to a nearly equal but oppositely poled value, the net charge delivered to the load capacitor is nearly twice the maximum charge stored on the input capacitor.

The time constants of input capacitor charge and output capacitor discharge are chosen so that, for the unmodulated IF carrier, the output voltage on the load resistor (R_{26}) stabilizes at about half its maximum possible value.

During modulation, the intermediate frequency varies at the signal rate from its unmodulated value (6 kc) to a maximum value (near 10 kc) and then to a minimum value (near 2 kc). When the frequency increases, the increments of charge are delivered to the load capacitor (C_{25}) more rapidly and the output voltage therefore rises. Similarly, when the IF frequency decreases, the increments of charge arrive less frequently, and the output voltage falls because of the drain to a lower value. Time constants are chosen to allow these variations to follow the signal wave frequency.

4.4 *Reed Circuit and Sound Oscillator*

Fig. 4 shows the circuits of the reed amplifier stages, the reed selectors and the sound oscillator. The output from the discriminator is applied to a two-stage transistor amplifier using the transistors Q_8 and Q_9 in common-emitter configuration. The first of these transistor amplifiers gets its base bias from the rectification of the discriminator, combined with the base current flowing in the load resistor of the discriminator. A resistor (R_{28}) biases the emitter of this amplifier and provides bias stabilization, and at the same time furnishes the impedance across which feedback is introduced from the output of the second amplifier (Q_9). This second amplifier is biased on both base and emitter in the same manner as the IF amplifiers. The three windings of the reed selectors (RD_1, RD_2, and RD_3) forming the load are coupled by a blocking capacitor (C_{29}) which keeps the direct current from saturating the cores of these selectors. The capacitor C_{15} provides negative feedback, effective at the IF frequencies. This provides stability against IF regeneration and reduces noise without reducing the reed frequency gain.

The sound oscillator circuit uses a transistor oscillator whose positive feedback is accomplished through a transformer (T_1). This couples the collector back to the base of the transistor (Q_{10}). When the reed selectors are quiescent, the oscillator is also at rest. When a signal is received which causes all three reeds to respond, the simultaneous operation of their contacts causes an impulse to be applied to the base of the oscillator transistor. This impulse is amplified and returned through the transformer to the base in proper phase to start a buildup of oscillation. Once started, the oscillation continues regardless of the excitation of the reeds. The hearing-aid type transducer which is the load of the oscillator gives forth an audible tone which alerts the customer. The customer may then stop the oscillation and reset the circuit for further signaling by simply closing the reset switch (a miniature pushbutton-type). Capacitor C_{31} and resistor R_{32} are connected to ground from a point between the contacts of RD_1 and RD_2. These furnish a reservoir of charge whenever RD_1 is energized, so that if RD_2 and RD_3 become simultaneously energized there will be adequate pulse energy to set off the sounder oscillator. A diode (CR_5) across the primary of the feedback transformer (T_1) is polarized to absorb impulses caused by mechanical shock and thus diminish the probability of false signaling due to this cause. However, the receiver is automatically triggered when the receiver is first energized. This serves as an indication of the condition of the battery, since the oscillator will not function with a discharged battery.

V. TEST METHODS AND TECHNIQUES

5.1 *The Testing Problem*

In most other FM receivers such as, for example, those used in mobile telephone service, the receiver is tested as a unit without connection to its antenna. Test requirements are based on magnitudes or frequencies of energy applied to the input terminals of the receiver. Similarly, in such applications the efficiency of the antenna is determined by its energy yield into a standard terminating impedance, when the antenna is immersed in a standard strength of radio field.

In the development stages of the 55A pocket receiver, these same approaches were followed. Field measurements were made in which antennas of various types were compared with a half-wave dipole and with each other by connecting them through a transforming device to the input of a field strength measuring set. Also, the sensitivity, selectivity, and noise figure of the receiver were tested by connecting the appropriate test generator to the emitter input of the first RF amplifier through a suitable coupling transformer.

While these methods were useful in giving relative results, their absolute significance was always in doubt. The antenna, when connected to a cable leading to a field strength set, experiences a field which is distorted by the coupling to that cable. Also, it is then difficult to evaluate it in its true relation to the human body. Furthermore, the tests on the receiver were always in doubt because of the difference between the input coupling used and that which exists in the normal connection to the antenna in the assembled set.

To overcome these uncertainties, a method was devised by which the assembled receiver could be bench tested as a complete unit in a suitable test jig. These results were then correlated with the field performance of the receiver when carried normally by a person.

5.2 *RF Circuit Tuning*

The RF amplifiers are tuned with the local oscillator disabled by operation of a switch on the test jig. This switch places an RF ground on the collector of the oscillator transistor. As a result of a signal coupled to the antenna, rectified current flows in the mixer diode, and is measured across the diode load resistor (R_{10}). The antenna capacitor (C_1) and the interstage tuning coils (L_2 and L_3) are then adjusted to maximize this current.

5.3 *Local Oscillator Adjustments*

With no signal input to the antenna, and with the oscillator operating, the rectified current of the mixer diode is a measure of the injection of local oscillator energy. This is brought to final adjustment by varying the slug position in the coil (L_6) of the oscillator circuit. A coarse adjustment of the injection is available in the initial alignment by selecting the value of the oscillator emitter resistance (R_7).

The local oscillator may be adjusted to the correct frequency by the slug of the coil (L_5) which is in series with the crystal.

5.4 *Calibration of Test Jig*

Considerable discussion of signaling sensitivity and the field tests which were made to measure it is given in the paper by Mitchell and Van Wynen.[1] Signaling sensitivity is defined as the field in db above one microvolt per meter required to just trigger the receiver. A number of receivers whose sensitivity had been tested under free field conditions were used to calibrate the test jig. Thus the voltage from the modulated signal generator to the input of the jig, which is needed to produce triggering, could be interpreted in terms of the free field strength. In this way, meaningful measurements of signaling sensitivity are made in the jig setup for aligning the receivers in the laboratory, or in production.

5.5 *Noise Measurement*

By means of the jig, an rms type voltmeter may be connected to the IF test point at the collector of the third IF transistor. This measures the no-signal noise voltage at the test point. When a signal is supplied to the antenna coupling coil, the energy required to cause a 3-db increase in the voltage at the test point is a measure of sensitivity, which is related to noise figure as discussed elsewhere. Oscilloscopic observations at the IF test point show qualitatively the fact that neither the input to double the energy nor the input of modulated signal required for triggering is visible as a change from the random noise pattern. This shows qualitatively the fact that triggering occurs even for signal levels commensurate with the average noise in the IF band, or lower, as is indeed shown on the level diagram. Thus signals strong enough to produce limiting and FM quieting are not essential for the operation of the receiver. This is to a large extent an advantage derived from the exclusion of much of the noise energy by the very sharp frequency response of the reed selectors.

It is interesting to note that even after FM demodulation and band limiting by the 2-kc low-pass filter, the noise lies in a band nearly 2000 times greater than the bandwidth of a reed (about 1.2 cycles).

VI. MECHANICAL DESIGN

6.1 *General Features*

The mechanical design of the 55A receiver was influenced strongly by the inclusion of several required features. The receiver was designed to enable the customer to recharge and change batteries easily and to enable the telephone company to insert the reed selectors without the use of tools. It was necessary to include a changeable number card which could be exposed for viewing, but which would automatically remain hidden from view during normal operation of the receiver. The on-off switch and the audio transducer were placed in the top end of the receiver for optimum accessibility and audibility, respectively, when the receiver is pocket-borne. Moreover, it was necessary to reconcile such seemingly incompatible objectives as small size and reliability, light weight and ruggedness, and low cost and high performance. Obviously, at the outset of the mechanical design, it was not possible to set absolute values on all these objectives. The design became a problem in optimizing, and the realistic approach of making the receiver as small, light, and inexpensive as possible, consistent with high performance, reliability, and ruggedness, was taken. It was necessary to refrain from "gilding the lily," performance-wise, even if this penalized size or weight only slightly. For in the final analysis, if the receiver were incapable of being carried in a pocket, its market would diminish.

The receiver contains an antenna, thirty-eight capacitors, thirty-three resistors, four diodes, fifteen inductors, ten transistors, one transformer, one crystal unit, three reed selectors, one audio transducer, two switches, and one filter (which itself contains three inductors and five capacitors), all mounted on a 4.85 × 2.24-inch printed wiring board. The printed wiring substrate is $\frac{1}{16}$-inch thick epoxy glass. This material was selected, rather than the less expensive and more commonly used XXXP phenolic substrate, because of its superior mechanical and electrical properties.

6.2 *Circuit Layout and Shielding*

The circuitry was laid out in a smooth, logical pattern, so that the mechanical flow from top to bottom is in the same sequence as the electrical flow. As shown in Fig. 13, the antenna is at the top of the receiver. In sequence toward the bottom, the antenna is followed by the RF amplifier, RF mixer, local oscillator, IF amplifier and limiter, discriminator, reed circuit, and battery. The audio transducer is placed against the top of the receiver case where it will be most easily heard by the customer. The reed selectors are placed near the bottom of the circuitry, adjacent to the battery. Removal of the battery case uncovers a number card, which, upon its removal, in turn uncovers an access port through which the reed selectors may be inserted or extracted.

The RF amplifiers, oscillator, and first IF amplifier are contained in a three-compartment copper enclosure so that portions of these circuits are shielded from each other and from the remainder of the circuitry. The can cover, not shown in Fig. 13, is soldered into place, and the can is soldered to a "ground plane" on the printed wiring board. Ground planes run on both sides of the printed wiring board, covering as much area as possible. This minimizes the ground circuit impedance, reduces the coupling between ground paths, and contributes to the stability of the circuit.

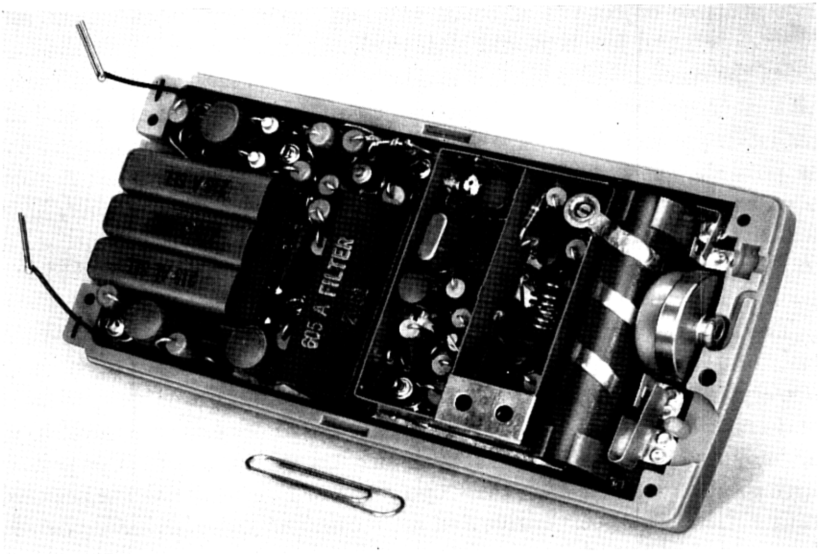

Fig. 13 — Layout.

6.3 *Space Conservation*

Space was conserved on the printed wiring board by using miniaturized components and by mounting all axial-lead components perpendicular to the printed wiring board. In some instances, where the tops of several components were electrically common, the lead of one component was bent into a common bus, which was connected to the tops of all the components in the group, thus eliminating land areas and further conserving board space. This arrangement is shown in Fig. 14. Although

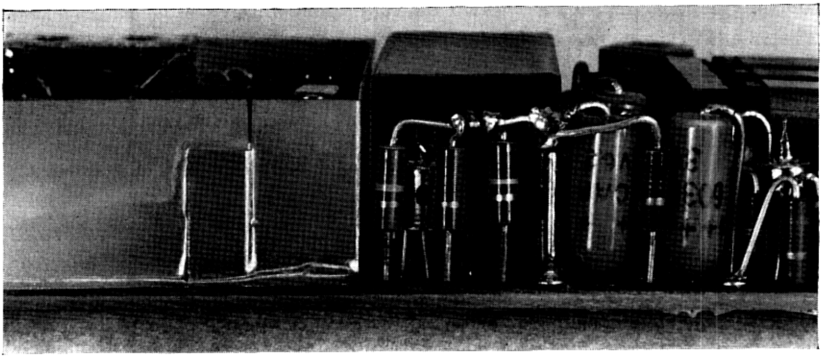

Fig. 14 — Component wiring for space conservation.

conductor spacings and widths were made as large as possible, for maximum board reliability, space considerations necessitated basing the printed wiring pattern on minimum path width, spacing, and land area diameter of 0.030, 0.040, and 0.075 inch, respectively.

6.4 *Case Design*

The operational requirements had a direct bearing on the design of the receiver case. The case consists of three main parts — two dish-shaped covers, which enclose the circuitry, and a battery case. These are shown in Fig. 15. The battery case is designed to accommodate a nickel-cadmium rechargeable battery. The battery case is a plug-in unit, and enables a discharged battery to be unplugged from the receiver, battery case and all, and inserted into a battery charger which, in turn, plugs directly into a 117-volt ac wall outlet. If necessary, a fully charged battery, in another battery case, can be plugged into the receiver for uninterrupted service. For special circumstances, a battery case designed to accommodate a nonrechargeable mercury battery is available.

The battery case is equipped with nickel-silver prongs which mate with contacts in the receiver case. The battery is equipped with slotted nickel tabs as shown in Fig. 16. Connection between the battery and the nickel-silver prongs is effected by means of screws which fasten the battery tabs to an extension of the nickel-silver prongs. The battery tabs and the connecting screws are located off-center with respect to the battery. This allows the battery to be inserted into the battery case only if it is properly oriented. Furthermore, the receiver case is designed so that the

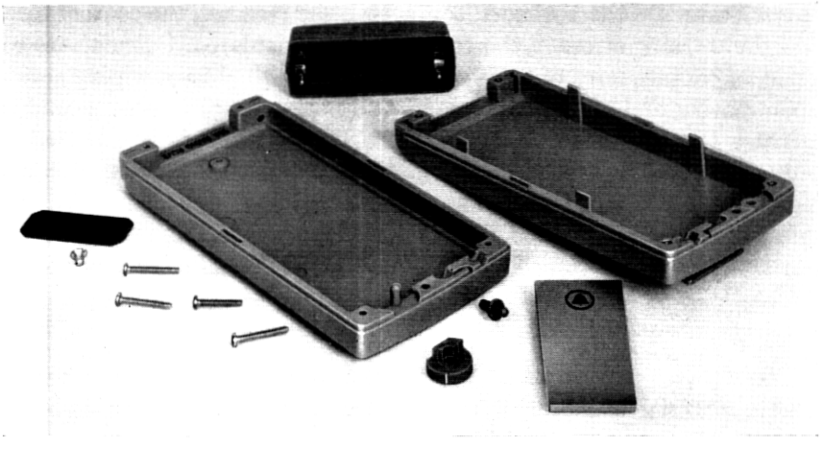

Fig. 15 — Case parts.

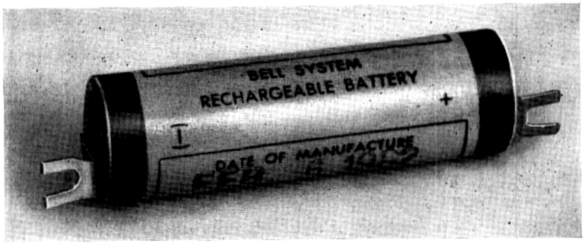

Fig. 16 — Battery.

prongs of the battery case can make contact with the circuitry only if the battery case is properly oriented. This series of orienting devices render it virtually impossible to inadvertently damage a receiver with an improperly oriented battery.

6.5 *Contact Design*

The mating contacts in the receiver were designed for minimum space consumption. They are made of extra hard spring-tempered nickel-silver wire, and are in the shape of the letter U. They are housed in cavities in the wall of the receiver case in a manner which permits the battery contacts to be inserted, through holes in the receiver case, into the mouth of the U. The cavities in which they are housed are large enough to permit the contacts to float into proper alignment with the pins of the battery holder. Connection is made to the circuitry by means of flexible jumper wires. The U-shaped contacts are shown in Fig. 17.

To be assured of reliable electrical contact between the prongs of the battery case and the U-shaped contacts in the receiver, the contact force and the working stress in the contacts were calculated. Calculations revealed a contact force of 0.460 lb. The contacts produce a wiping action upon mating and exert this force at two points. These features tend to increase the reliability of the electrical contact, and it is expected to provide trouble-free service. Calculations indicated a maximum working stress of 67,000 psi in the spring. Inasmuch as this is less than the safe working stress, 80,000 psi, for the nickel-silver alloy of the spring contact, it can be assumed that the spring will not lose its properties.

6.6 *Materials and Special Features*

The receiver case is molded of an acetal resin. This is a tough thermoplastic material which exhibits a high resistance to abrasion and cold flow. The battery case is molded of nylon, also a thermoplastic material

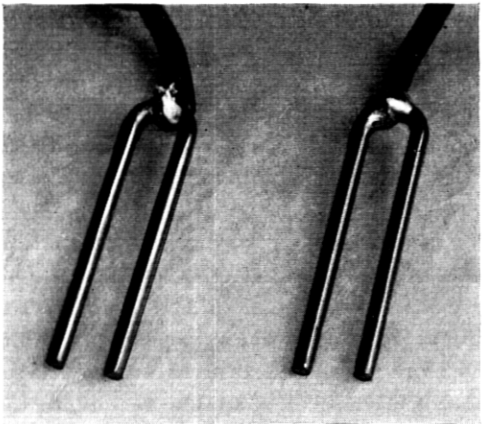

Fig. 17 — Contacts.

with excellent bearing properties. These properties were used to advantage in the design of the fastening device which permits the battery case to be snapped onto or off from the receiver case. The snap mechanism is molded as an integral part of the battery case and the receiver case, and obviates the need for hardware of any kind. A cross-sectional view of the snap is shown in Fig. 18.

The battery case was subjected to 20,000 snap-on-snap-off cycles. The pull-off force dropped from an initial value of seventeen pounds to a final value of nine pounds. This drop in pull-off force is not judged to be serious, since even the lower value is considered adequate to hold the battery case securely in place. It is estimated that the average customer will recharge his battery once a day. At this rate, 20,000 on-off cycles

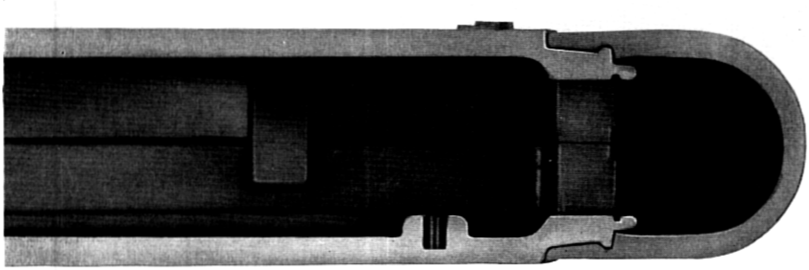

Fig. 18 — Snap fastener of case.

will not be achieved for over fifty years. For customers who are unable to exert the necessary force to unsnap the battery holder, a coin slot is provided, permitting the customer to pry it off with minimum exertion.

When carried in a pocket or on a belt, the receiver is held in place by means of a die-cast zinc clip. It has a brushed satin finish with the Bell System emblem depressed and colored dark blue. The clip is shown in Fig. 19.

A special switch, which is reliable, durable, compatible with printed wiring, and capable of blending harmoniously with the physical appearance of the receiver case, was designed. The switch contacts are a gold-silver-platinum alloy. They are welded to phosphor bronze flat springs, which are in turn mounted on the printed wiring board. The switch is actuated by a thumb wheel, which rotates on a molded axle protruding from the edge of the case. The thumb wheel is also molded of nylon and is designed with a protrusion which hits against the inner surface of the receiver case when the thumb wheel reaches either the "on" or "off" position. This device limits the rotation of the wheel and imparts a comfortable feel and a pleasant click to the switch. A model of this switch has been on life test in the laboratories for several months. As of the time of this writing, it has undergone over five million on-off cycles without any discernible degradation in performance. The switch is shown in Fig. 20.

Fig. 19 — Pocket clip.

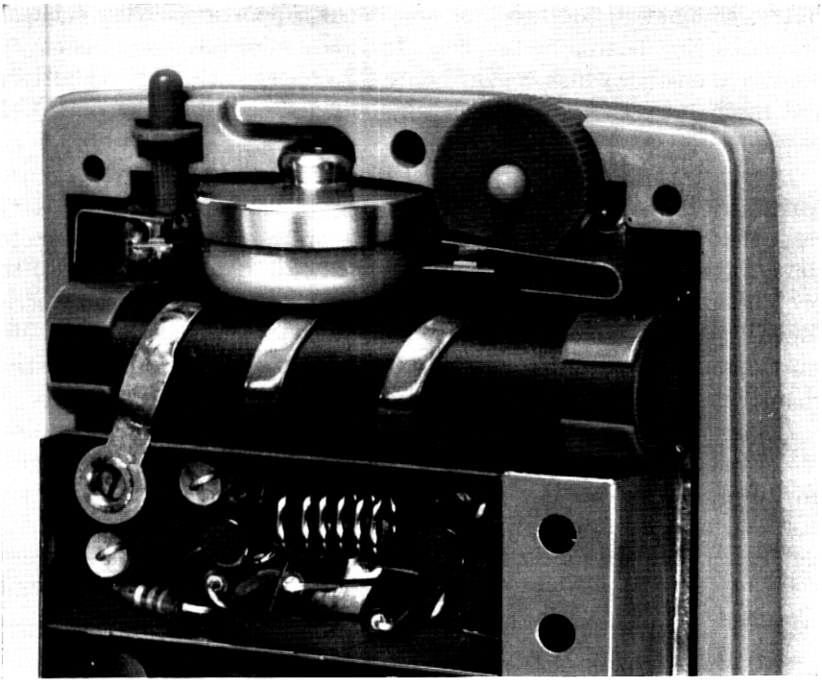

Fig. 20 — Switch.

6.7 *Battery Charger*

For normal use each customer is supplied with a cordless plug-in battery charger. The charger circuit consists of a diode rectifier, two resistors, and a neon indicator lamp. The circuitry is housed in a molded nylon case, which serves the dual purposes of case and structural support for the components. The charger plugs directly into a wall outlet — a feature which imposed two important restrictions on the design. The charger had to be made of nonflammable materials, and the "fall-out" torque — the product of the weight of the charger and the distance from the wall outlet cover to the center of gravity of the charger — had to be held to a low value. A fall-out torque not exceeding six inch-ounces was set as the design target, for it was judged that below this value the probability of a charger inadvertently falling out of a wall outlet would be negligible.

Nonflammability was achieved by specifying nylon for the housing. The inside of the housing is used as the structural support for the circuitry, eliminating the need for additional supporting media, such as printed wiring boards or brackets. In this manner, it was possible to produce a charger which weighed only 3.1 ounces, including the battery and the battery case, and which exerted a fall-out torque of only 1.45 inch ounces.

The battery case, containing the discharged battery, is disengaged from the receiver and plugged into the charger. The prongs in the battery case make contact with U-shaped contact springs, which are identical to those used in the receiver. The same system of orienting devices used to prevent insertion of an improperly oriented battery in the receiver is similarly used in the charger. The charger is equipped with a neon indicator lamp, which glows only when charging current is flowing. The charger is shown in Figs. 21 and 22.

The use of molded plastics contributed significantly to the realization of the objectives. The plastic parts are attractive, rugged, light in weight, intricately shaped and inexpensive. The case halves, in addition to serving as a closure, were designed with built-in functional refinements which eliminated the need for attached hardware in such places as the battery case snap, the switch axle, the speaker support, the pocket clip axle bearings, and the printed wiring board support. After tooling costs, these features are obtained virtually free of charge.

6.8 *Subjective Qualities*

The BELLBOY personal signaling receiver is a consumer product, to be worn on the person of the customer. Outwardly, the receiver was given a tailored appearance to satisfy the needs of the well-dressed customer. The appearance of boxiness was averted by adding barely discernible compound curves to the surface. These curves actually add slightly to

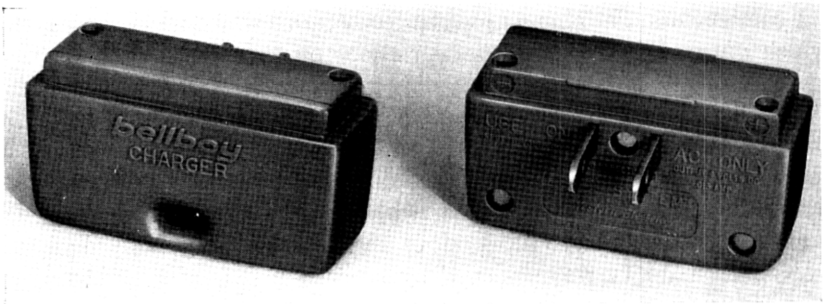

Fig. 21 — Charger.

Fig. 22 — Battery being charged.

the over-all dimensions of the receiver, but impart an appearance of elegance and compactness. The finished product, shown in Fig. 23, is $5\frac{7}{8}$ inches long, $2\frac{1}{2}$ inches wide, and $\frac{15}{16}$ inch thick, and weighs 11 ounces, including the battery.

The receiver case and battery case are different shades of gray, the battery case being the darker of the two. This not only adds to the appearance of the receiver, but avoids what would otherwise have been a troublesome color-matching problem which would have been manifest upon supplying replacement battery cases.

VII. CONCLUSION

In both the electrical and mechanical design of this receiver, emphasis has been placed on reliability in fulfilling service objectives and on convenience to the customer. In connection with the latter, the esthetic qualities essential to consumer acceptance have not been overlooked. The reactions of the consumer have been sampled by means of field trials

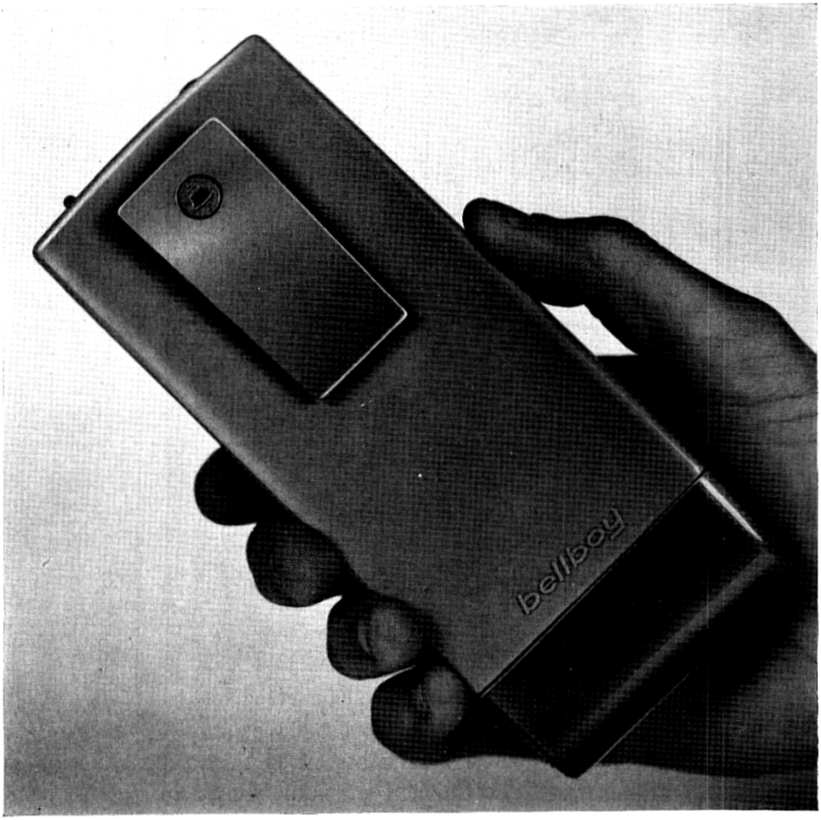

Fig. 23 — Finished product.

using development models. In the first commercial installation, which went into service at Seattle in April, 1962, the performance of the receiver has been satisfactory, and it is expected that additional installations will follow.

VIII. ACKNOWLEDGEMENTS

The receiver described in this paper is the result of the combined efforts of a number of people in several departments of Bell Telephone Laboratories, with the cooperation of members of the Western Electric Company at the Merrimack Valley Works. The authors, in presenting these results, acknowledge these contributions without attempting to give individual credit.

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