NBS CIRCULAR 545

Subminiaturization Techniques for Low-frequency Receivers

UNITED STATES DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

Related Publications of the National Bureau of Standards

Printed Circuit Techniques Circular 468, 35 cents

. . . Printed circuits have emerged from the experimental stage to become one of the most practical new ideas for mass production of electronic devices. This book discusses methods of applying wiring and circuit components directly to an insulated surface, thus combining ruggedness with a high degree of miniaturization.

. . . Performance and application details are considered for such techniques as:

Painting	Vacuum Processes
Spraying	Die-Stamping
Chemical Deposition	Dusting

Applications and examples given include printed amplifiers, transmitters, receivers, hearing aid subassemblies, plug-in units, and electronic accessories.

. . . The book consists of ten chapters plus a bibliography covering processes, patents, applications, and other relevant matters. It is well illustrated with twenty-one halftones, eighteen line cuts, and five tables.

New Advances in Printed Circuits Miscellaneous Publication 192, 45 cents

. . . As a result of increasing interest in this rapidly developing electronic art, the Aeronautical Board's Aircraft Radio and Electronics Committee held a symposium under the technical supervision of the National Bureau of Standards. This book contains the proceedings of the symposium, which included twenty-two papers on the status, applications, and limitations of printed circuits.

. . . Papers presented by representatives of industry and Government laboratories cover such topics as:

Status of printed circuits	Imprinted circuit inlays
Printed resistors	Die-stamped wiring
Vitreous-enamel dielectric products	Typical commercial applications
Spraying techniques	Printed electronic components on glass, plastics, and other nonconductors
Mechanization of electric wiring	
Conductive silver preparations	
Trends in military communication	

. . . In its eighteen chapters the book contains, besides the symposium papers, a summary of the subject and a discussion of the important technical questions raised. Forty-three halftones and line cuts and ten tables amply illustrate and clarify the text.

UNITED STATES DEPARTMENT OF COMMERCE • Sinclair Weeks, *Secretary*
NATIONAL BUREAU OF STANDARDS • A. V. Astin, *Director*

Subminiaturization Techniques for Low-frequency Receivers

Gustave Shapiro

National Bureau of Standards Circular 545

Issued April 7, 1954

For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.
Price 50 cents

Foreword

The work covered by this report was carried out by the General Miniaturization Group, Engineering Electronics Section of the National Bureau of Standards, under the support of the Bureau of Aeronautics, Department of the Navy. This was the second phase of a continuing program for the development of miniaturization techniques applicable to airborne military electronic equipment.

Earlier Bureau work cited on page 1 covered miniaturization as applied to high-gain fixed-tuned intermediate-frequency strips in the very high-frequency band. This combines with the present work to provide practical engineering treatment of a wide variety of electronic miniaturization problems over the radio-frequency spectrum between 100 kilocycles and 100 megacycles.

The present work was carried out by a staff consisting of: Robert O. Stone, Welfred M. Redler, Joseph F. Brooks, Mark N. Upshur, Samuel Levinson, Frank S. French, Frederick J. Bakon, under the direction of Gustave Shapiro and the general cognizance of P. J. Selgin, Chief, Engineering Electronics Section.

A. V. Astin, *Director.*

Contents

Figures

SUBMINIATURIZATION TECHNIQUES FOR LOW-FREQUENCY RECEIVERS

Gustave Shapiro

A subminiature radio receiver, tuning from 190 to 550 kc, has been developed. Total volume of this 12-tube unit is 55 in^3. This compactness is made possible by 14 new components, including r-f inductors and i-f transformers, using high-temperature litzendraht wire, glass dielectric capacitors, tantalum electrolytic capacitors, and audio inductors wound with ceramic insulated wire. Design and fabrication techniques, which make this receiver adaptable to quantity production, are applicable to other miniature electronic devices.

1. INTRODUCTION

The development of subminiature techniques for low-frequency receivers represents a second phase of the electronic subminiaturization program sponsored by the Department of the Navy, Bureau of Aeronautics. The low end of the radio-frequency spectrum near 100 kc was to be investigated, as it was believed that this program would provide solutions for a major portion of the electronic subminiaturization problems that lay between 100 kc and 60 Mc. A receiver in the frequency range from 190 to 550 kc was chosen as the vehicle for presenting new, low-frequency, subminiaturization techniques. This frequency range is one of the more difficult in which to apply subminiaturization techniques because of the large capacitors and inductors required. Figure 1 illustrates the original receiving equipment (the R-23 A/ARC 5), a miniaturized version (the R-230 (XN-1)/ARR-21), and the subminiature version that resulted from this development.

In the first phase of the subminiaturization program* a 60-Mc, 11-tube, wide-band i-f strip, adaptable to mass production, was selected for development. With this high-frequency subminiaturization accomplished, it was desired to develop next subminiature components and techniques suited to the lowest radio frequencies likely to be encountered in practical communications equipment. By showing what can be accomplished in size reduction both at 60 Mc, where short interconnecting leads and low stray capacities are mandatory, and at a frequency two octaves below the broadcast band, where relatively large inductances and capacitances are involved, it has been demonstrated what may be achieved in the design of practical full-performance subminiature equipment between these extremes.

The 60-Mc i-f strip previously subminiaturized was a fixed frequency assembly. The present receiver represents a pioneer accomplishment in the subminiaturization of a complete continuously-tunable functional unit.

Although it was possible to carry over much of the know-how accumulated from the first phase of the program on miniaturization techniques for airborne electronic equipment, many new engineering problems were presented. The receiver was more complicated in that it was composed of such a variety of components, electromechanical devices, and types of circuits that it was not possible to apply a timesaving procedure that was used so successfully in the amplifier, whereby a single stage configuration with minor modifications was repeated throughout the entire unit. There were the additional problems not encountered in the radar-type i-f amplifiers, that of obtaining high-Q, high

* National Bureau of Standards Electronic Miniaturization, Final Report, #PB 100-949, Office of Technical Services, Department of Commerce, (Sept. 1949).

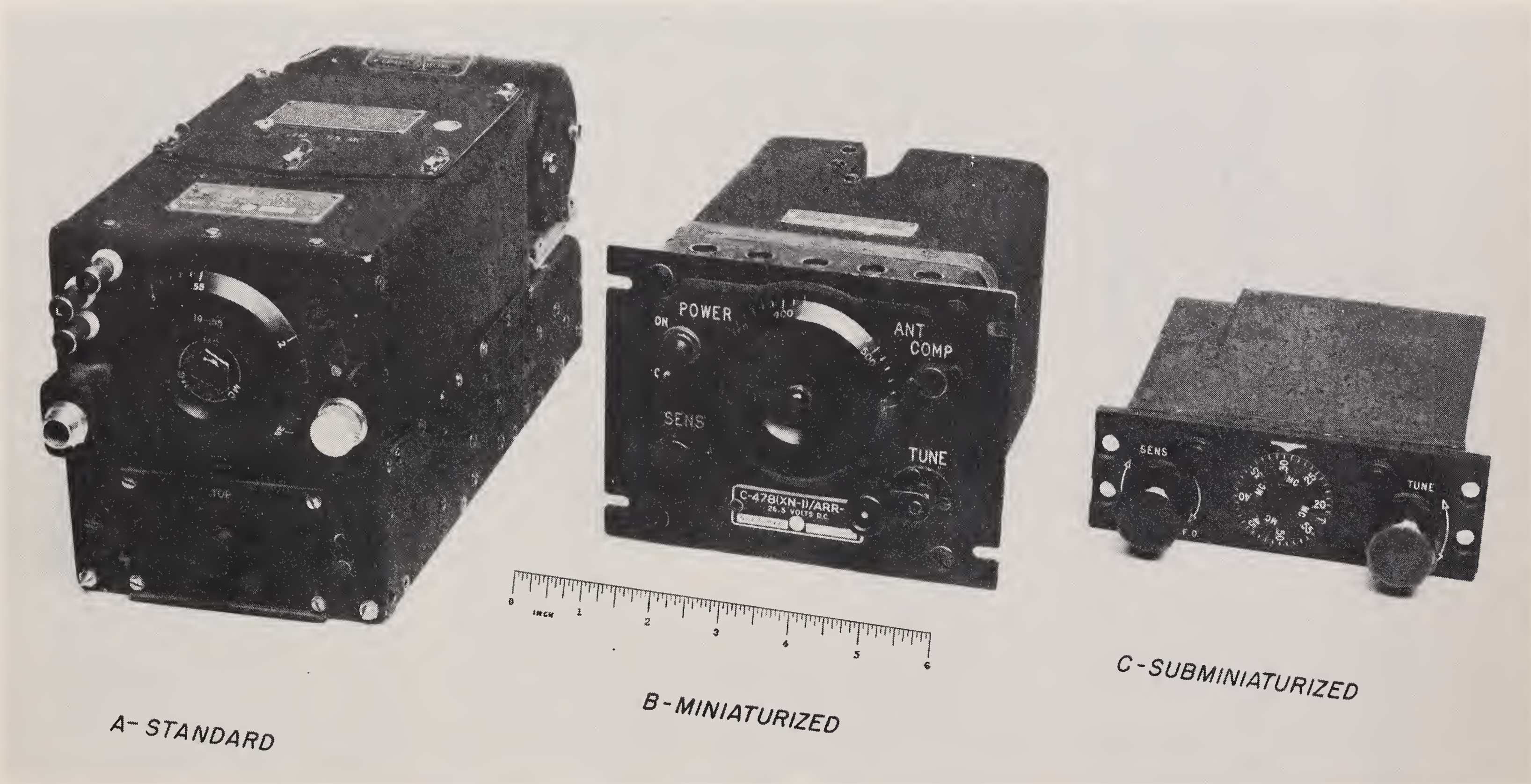


Figure 1. Comparison of low-frequency receivers.

temperature-resistant, compact tuned circuits so very necessary in communications equipment.

To achieve the degree of size reduction that was the goal of this development, it was necessary to abandon conventional methods for fabricating electronic equipment and to develop new ones. It is hoped that the components and assembly techniques that were employed will point the way to the evolution of new standard components and the adoption of new electronic-equipment assembly methods.

Where special components or unusual mechanical assemblies were required, these devices were designed so that the equipment manufacturer would be able to fabricate them and thereby free himself from an uncertain source of supply. A large percentage of the development time was spent in solving problems of this nature.

Some interesting observations may be made from table 1.

TABLE 1.

Equipment	Weight	Volume	Average density	Approximate panel height
	lb	in^3	lb/in^3	in.
R-23-A/ARC-5	8.938	300	0.0298	5.5
R-230(XN-1)/ARR-21 (Miniature)	7.625	150	0.0509	4.5
NBS range receiver	5.375	55	0.0978	1.875

Miniaturization has the effect of greatly increasing the density, because the volume is reduced faster than the weight. Aircraft console-loading specifications currently call for 1 pound per inch of panel. This figure will of necessity have to be increased a minimum of three times to accommodate this new type of equipment.

2. SPECIFICATIONS AND CIRCUIT DETAILS

The subminiature receiver was designed to meet the following specifications:

1. Tuning range from 190 to 550 kc.

2. A 135-kc, i-f amplifier.

3. Operation of all tube elements at 26 v dc.

4. Audio output power of 200 mw with zero signal output impedance not less than 300 ohms. (It was recognized that it might not be possible to realize 200 mw under these conditions, and that a smaller output power would probably be realized.)

5. A minimum of 60-db rejection to signals 5.7 kc or more from the center frequency.

6. A 6-db band not more than 2.8 or less than 1.9 kc in width.

7. Sensitivity such that a 5-μv input 30 percent modulated yields 50-mw audio output with a ratio of signal-plus-noise to noise of 6 db.

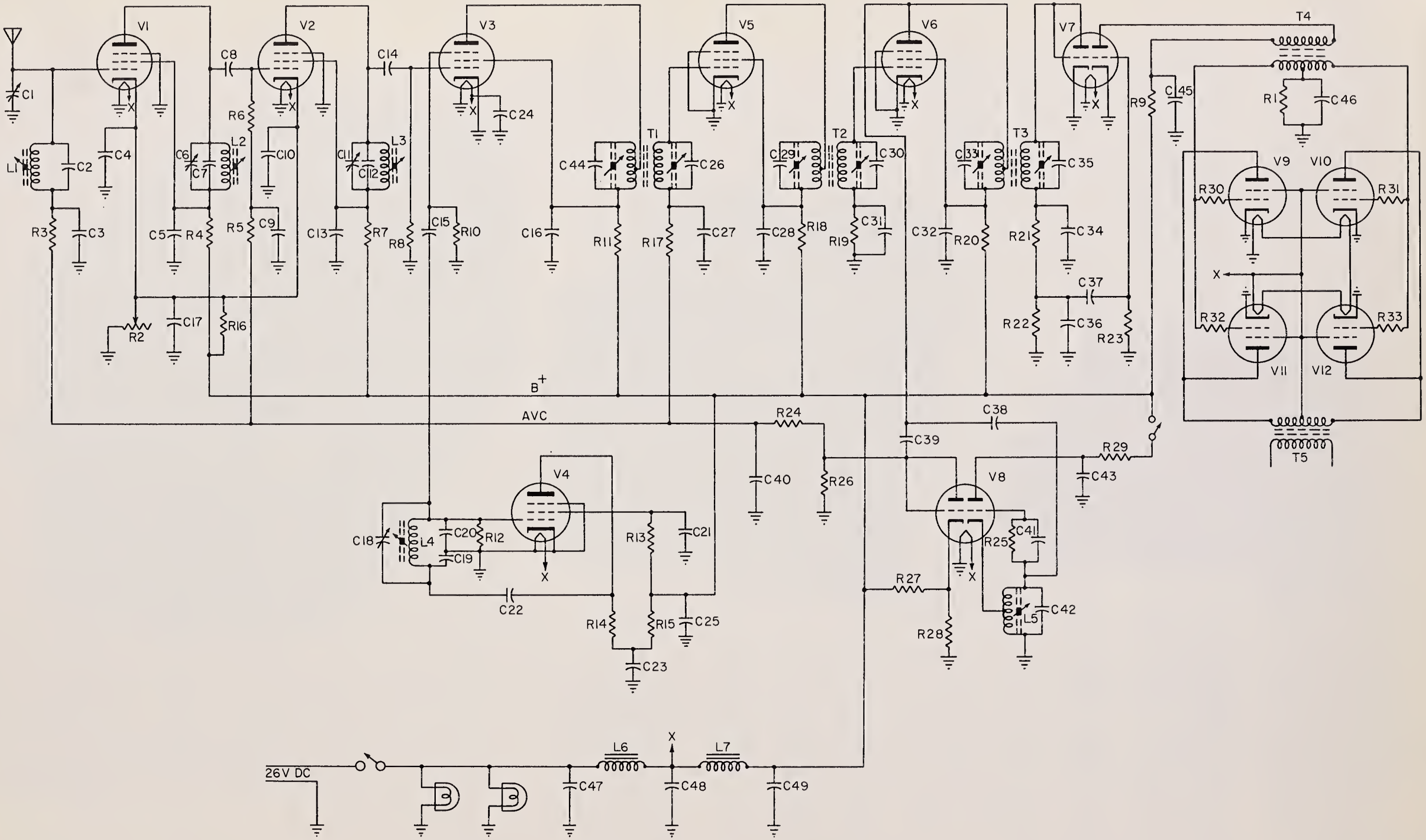


Figure 2. Receiver schematic diagram.

8. An unsealed antenna trimmer located on a surface other than the front panel.

9. A beat frequency oscillator and switch.

10. The entire receiver should be a sealed replaceable plug-in unit.

Figure 2 is a schematic diagram of the complete receiver. This receiver operates with 26 v on the screens, plates and heaters of all the tubes. Although the output tubes have 6.3-v heaters, four of them are connected in series so that they may be operated across the 26-v supply. There are a number of advantages in the use of 26 v rather than a higher voltage for the B supply. However, audio power in excess of 100 mw cannot be easily obtained from conventional tubes operated at 26 v, and existing special tubes designed for this class of operation are much too large. However, there was under development a 9-pin miniature tube that was expected to yield close to the desired output power, and the receiver was designed so that this tube could easily be included when it became available by utilizing a simple adapter unit. For the present, four 5902 pentodes with series-connected heaters are used in push-pull parallel to provide adequate output.

It appears at this time that a push-pull parallel transistor output-stage assembly could be employed to advantage. This assembly would be mounted on the exterior of the receiver proper and therefore would not be subjected to the internally generated heat. Since the present output stage of the receiver accounts for approximately 50 percent of the d-c power consumed, the use of such a transistor output stage should materially reduce the temperature rise of the equipment.

When operated in aircraft the output of this and its companion receivers are connected in parallel to a common-distribution line. Because this receiver is often left "on"even when no range signal is being received, it is important that it does not absorb too much of the audio power put into the distribution line by the other receivers. This requires that the impedance measured at the receiver output terminals be high when it is turned "on", but is delivering no audio power. A high zero-signal output impedance is best achieved by supplying fixed bias to the grids of the output stage. Consideration was given to deriving that voltage from the bias generated by the local oscillator. To do this would have required the use of a bulky audio-decoupling network to prevent the audio signal from frequency modulating the local oscillator. Cathode bias could not be used without seriously reducing the plate-supply voltage, which is barely adequate. In view of these considerations, a grid-leak bias supply, conventional for this type of low-voltage output stage, was used instead of fixed bias.

In favor of using a 26-v B supply are a number of considerations:

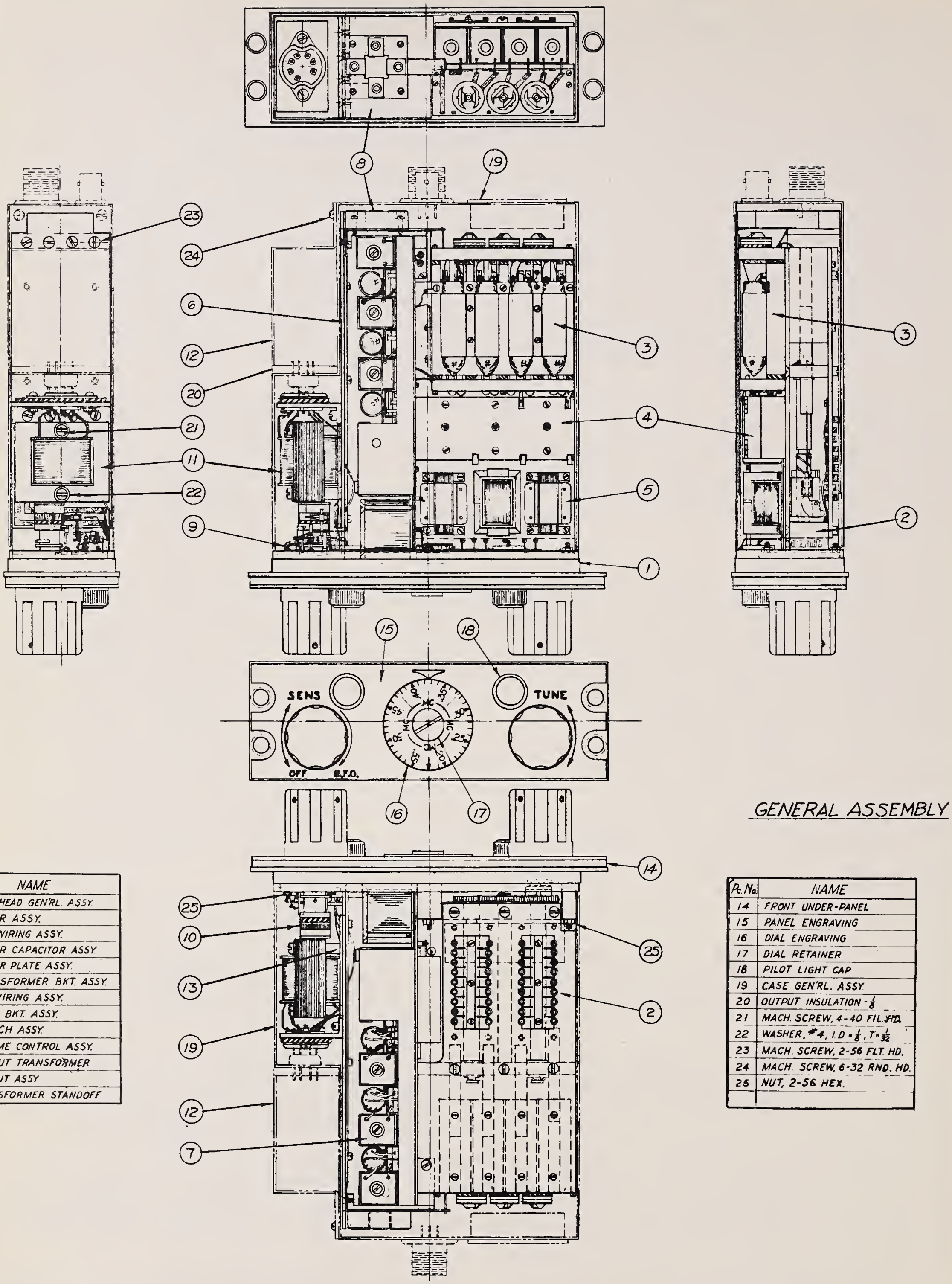
1. When used at high temperatures, the life of medium and high-K dielectric films, such as those used in capacitors, is a function of the capacitor voltage. With low voltages, thinner dielectric films could be used, and reasonable life could still be obtained.

2. The power dissipated in resistors is usually less if a low-voltage supply is used, so that resistors can be expected to last longer under these conditions. The low screen and plate dissipation of the tubes will materially reduce the equipment temperature.

3. It is possible to obtain commercial, high-temperature, tantalum electrolytic capacitors with very high capacities at these low operating potentials. For voltages in excess of 80 v these capacitors require several cells assembled in series, and as a result they become bulky.

4. The power supply necessary to furnish a high B voltage from a 26-v d-c primary source is bound to be much larger than the simple hash filter required in an equipment having 26-v operation throughout.

284541 O - 54 - 2



Pc. No.	NAME
1	BULKHEAD GEN'RL. ASSY.
2	TUNER ASSY.
3	R.F. WIRING ASSY.
4	FILTER CAPACITOR ASSY.
5	FILTER PLATE ASSY.
6	TRANSFORMER BKT. ASSY.
7	I.F. WIRING ASSY.
8	REAR BKT. ASSY.
9	SWITCH ASSY.
10	VOLUME CONTROL ASSY.
11	OUTPUT TRANSFORMER
12	OUTPUT ASSY
13	TRANSFORMER STANDOFF

Pc. No.	NAME
14	FRONT UNDER-PANEL
15	PANEL ENGRAVING
16	DIAL ENGRAVING
17	DIAL RETAINER
18	PILOT LIGHT CAP
19	CASE GEN'RL. ASSY.
20	OUTPUT INSULATION - $\frac{1}{8}$
21	MACH. SCREW, 4-40 FIL. HD.
22	WASHER, #4, I.D. = $\frac{1}{8}$, T = $\frac{1}{32}$
23	MACH. SCREW, 2-56 FLT. HD.
24	MACH. SCREW, 6-32 RND. HD.
25	NUT, 2-56 HEX.

Figure 3. Receiver assembly drawing.

In conventional receivers, i-f and r-f amplifier stages have either fixed or cathode bias. Slight differences of contact potential in tubes of the same type are ordinarily of little consequence because these small differences are masked by the tube bias. The 26-v plate supply makes these methods of biasing impractical because the required bias is of the same order as the grid contact-potential. Slight contact-potential variations in tubes operated under these conditions result in large performance variations. The grid-leak resistor method of biasing was chosen because of its self-regulating property which tends to minimize the effect of variations between individual tubes of the same type. A grid-leak value of 2 megohms was found to yield the best compromise between minimum circuit loading and tube stability.

Gain control is obtained by applying a cathode biasing potential to the r-f stages. Decoupling resistors in the cathode circuits of the gain-controlled tubes proved to be unnecessary because the gain control function is provided by a variable resistor common to the cathode circuits of two adjacent stages, which resistor introduces negative feedback. A bleeder resistor (R 16) was provided so that cut-off bias could be developed across the gain control rheostat.

It was necessary to connect the i-f tubes across only a portion of the i-f transformer primaries to avoid an excessive decrease in their Q due to the loading effect of the low plate impedance. The loading of the secondaries caused by the grid leak bias was found low enough to be ignored, thereby making it unnecessary to tap the i-f transformer secondaries.

Although the r-f inductor Q's are reduced by the plate loading of the tubes, they are sufficiently high so that they yield more than adequate rejection without being tapped. The normal unloaded Q of these permeability-tuned r-f inductors is fairly constant over the tuning range; therefore, the resonant impedance and gain that can be realized in each stage is greater at the low-frequency end of the spectrum than at the high-frequency end. The loading provided by the plate impedance of the tubes serves to reduce the Q, and consequently the resonant impedance and the gain at the low-frequency end. This is desirable as it contributes to a more uniform gain of the receiver over the tuning range. In spite of the reduction in Q at the low frequencies, spurious signals are still adequately rejected.

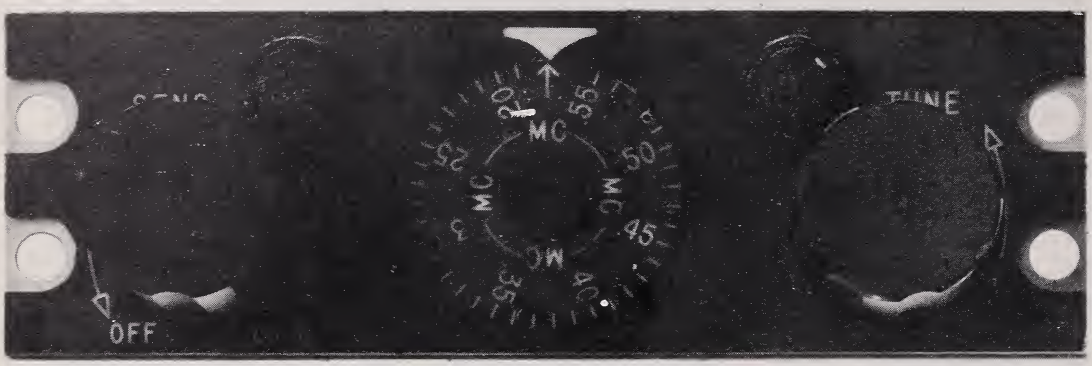
The receiver is made up of two r-f amplifiers, a mixer, a local oscillator, two i-f amplifiers, a diode detector, a beat-frequency oscillator, a delayed automatic volume-control diode, an audio amplifier, and four tubes in push-pull parallel in the output stage.

The r-f amplifiers, the i-f amplifiers, and the local oscillator tubes are type 5797, hard-glass-envelope, r-f pentodes designed for high temperature operation. Type 5908, having a soft-glass envelope, is used as a mixer. Two type 5798 hard-glass double triodes are used in this receiver. Of these the first serves as the audio amplifier and diode detector. The other performs the functions of beat-frequency oscillator and delayed automatic volume-control diode.

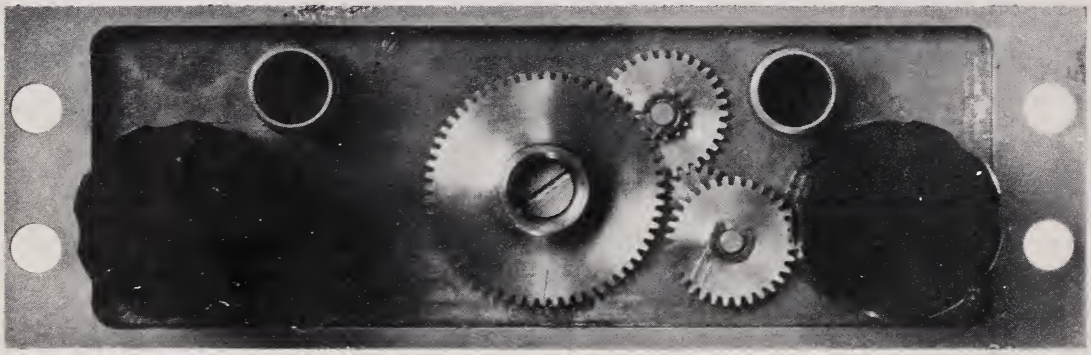
3. RECEIVER LAYOUT

The receiver, because of its small size, was made as a sealed replaceable, plug-in unit to be repaired only in central repair depots. At these depots the equipment could be repaired by subassembly replacement. The defective subassemblies could be repaired in due course. To realize this objective the receiver was made of a number of functional subassemblies. Not only is maintenance simplified by this subassembly structure, but production is made much easier by the natural breakdown into separate manufacturing operations. Figure 3 illustrates an assembly view of the complete receiver.

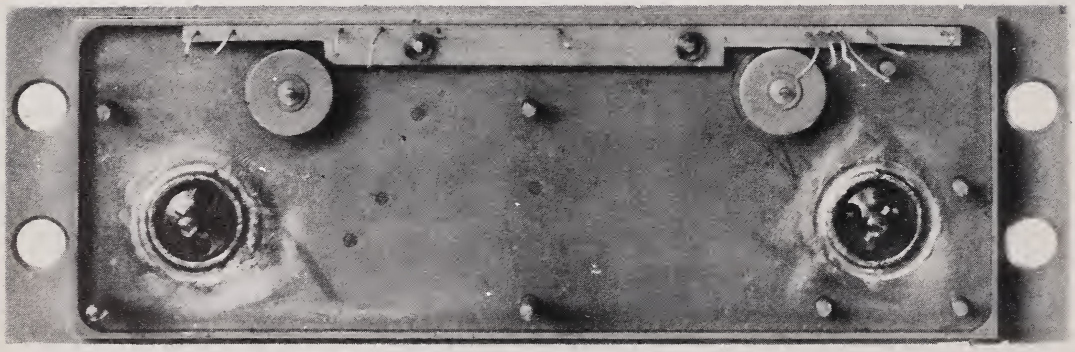
The portion of the receiver whose function most closely resembles that of the chassis is the steel front subpanel (fig. 4). This subpanel bolts to the console when the receiver is installed in the aircraft. The receiver subassemblies are



A — FRONT VIEW OF RECEIVER



B — FRONT VIEW OF RECEIVER WITH TOP PLATE REMOVED EXPOSING STEEL PANEL



C — REAR VIEW OF STEEL SUBPANEL

Figure 4. Receiver front panel.

fastened to this subpanel on the inside, and derive their mechanical support from it. Heat from the interior of the receiver is conducted through the metal structure supporting the subassemblies to the steel front subpanel, and thence to the metallic aircraft console. The outer or front surface of the steel front subpanel is recessed to contain a gear train that drives the tuning-dial indicator. The sealed pilot-light sockets and the knob rotary hermetic seals are soldered into this subpanel. The pilot-light sockets hold the nonmetallic front panel in place. This front panel embodies the edge lighting system recommended by aeronautical illumination engineers. The panel is two-ply, the inner ply being transparent lucite and the outer, melamine. Should the temperature prove to be too great for the transparent lucite panel, it could be replaced by a tempered-glass panel. The melamine facing in front of this glass panel could protect it from accidental blows.

Threaded steel studs are provided on the rear of the steel front subpanel to support the receiver subassemblies. The electrical assemblies behind the subpanel are in two sections, one to the right side, and the other to the left side of the subpanel. A number of Teflon-insulated conductors are fastened inside a silicone-glass laminate container and the entire wiring assembly is secured by two studs to the top rear of the subpanel. This wiring assembly interconnects the two sections of the receiver.

The console in which this receiver mounts accommodates panels with heights varying in increments of 3/8 in. Rather than waste space by using a 2 1/4-in. front panel, an unusual amount of engineering time was expended designing the equipment with a 1 7/8-in. panel. It would be highly desirable if installation engineers would review the physical structure of the mounting console with the consideration of lessening the 3/8-in. increments of panel-height now in effect. A possibility is a console with a slot and T-bolt securing means. This would eliminate all restrictions of panel heights other than that of a minimum height.

The limited area (1 7/8 in. high and 5 3/4 in. wide) allotted for the front panel turned the panel and tuning-dial design into major problems. To reduce the number of controls on the front panel, the power switch, the beat-frequency-oscillator switch, and the volume control are all actuated from the same control knob located on the left side of the panel. On the right side is the tuning knob. Centrally located in the panel is a 1 1/2-in.-diameter tuning dial. With a dial this small it would ordinarily be very difficult to use large figures. Fortunately, however, this receiver will be mounted beside the operator so that it is seen at an angle. This made it necessary to put the frequency markings radially permitting the use of larger and more readable figures.

Four threaded steel studs on the rear right side of the steel subpanel mount the r-f tuner mechanical assembly (fig. 5) which contains the r-f inductors and the slug deflecting mechanism. The r-f assembly, the power-line-filter capacitors, and the audio choke-transformer assembly are fastened to the top side of the r-f tuner assembly (fig. 6). These assemblies are all electrically interconnected. The audio choke-transformer assembly is connected to the end of the conductors on the right side of the steel subpanel. The transformer bracket assembly (fig. 7) and the power switch (fig. 8) are mounted next, after which the audio output transformer is wired into place (fig. 9). The i-f amplifier slides into place on the grooves provided for it in the vertical member of the r-f tuner mechanical assembly (fig. 10). Silvered steatite buttons recessed in this same vertical member of the r-f tuner mechanical assembly (fig. 5) make connection with contactor springs on the i-f amplifier printed plate, thereby connecting the i-f amplifier into the receiver circuit. The beat-frequency-oscillator switch is connected to a spring contact on the transformer bracket, the spring making contact with a button mounted on top of the beat-frequency-oscillator shielded compartment. A bracket that mounts the four-terminal socket on the rear of the receiver is next put in place by means of five screws (fig. 10). All but one of the connections to this plug are made automatically when the bracket is mounted. The remaining connection, the receiver input, must be soldered.

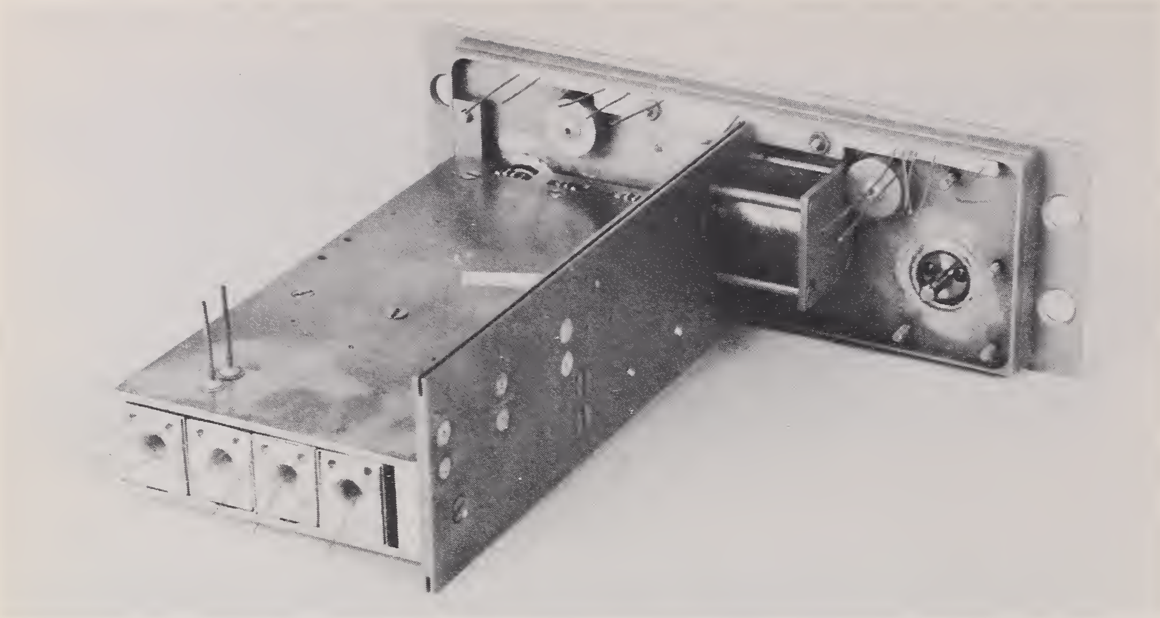


Figure 5. Tuning assembly mounted to front panel.

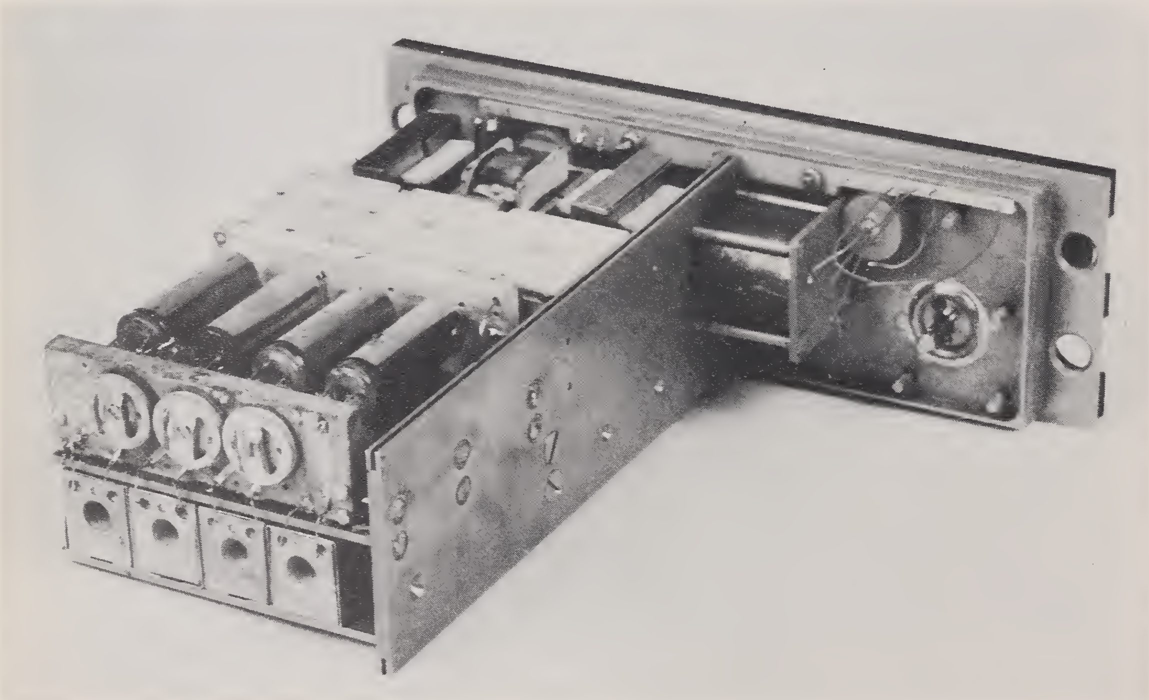


Figure 6. Receiver, partial assembly.

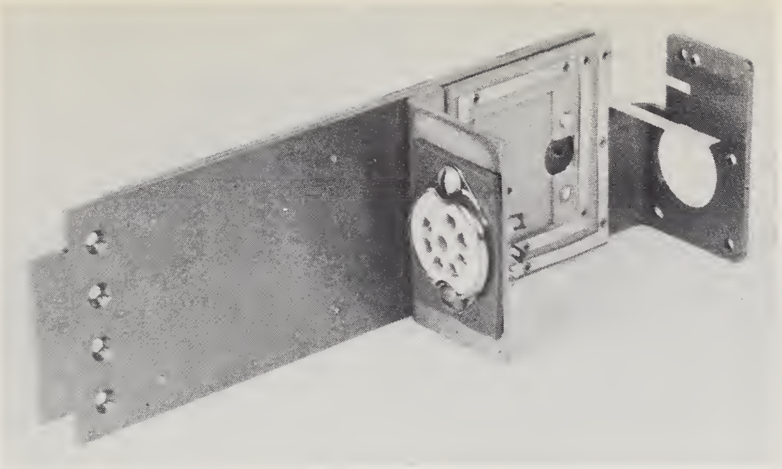


Figure 7. L-bracket assembly.

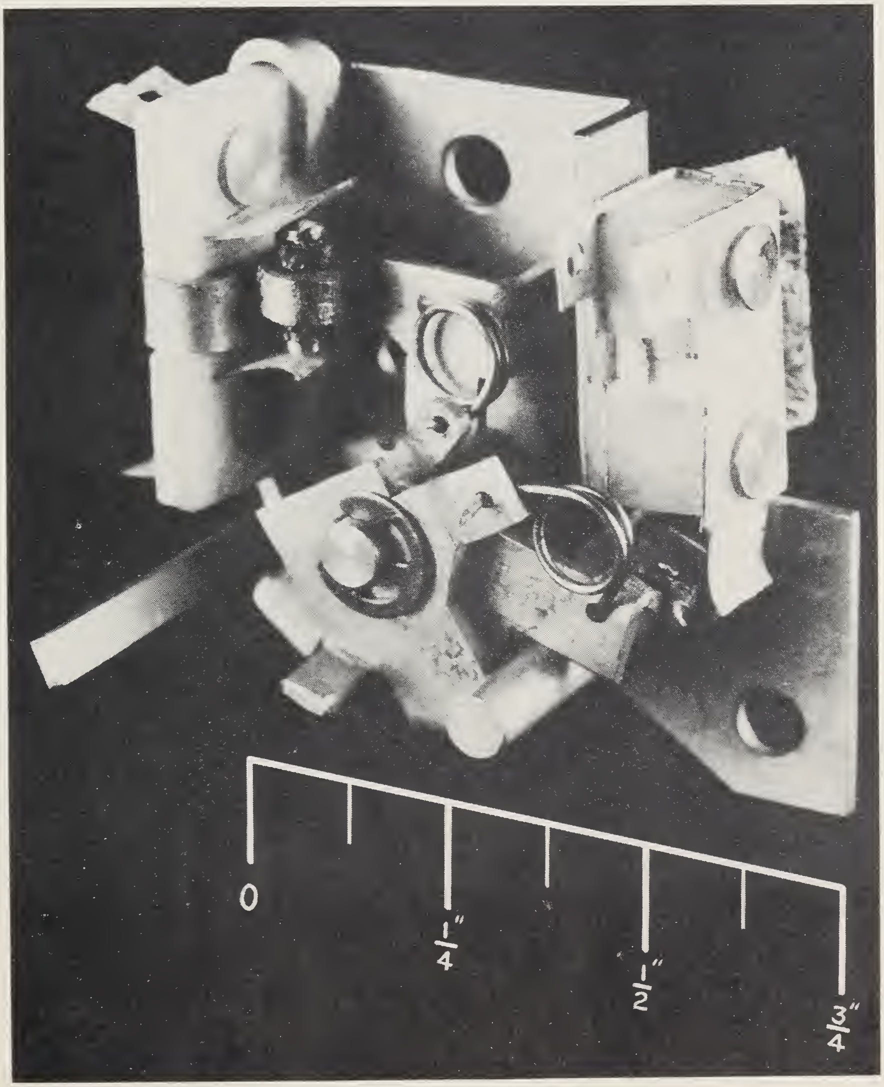


Figure 8. Multiple switch

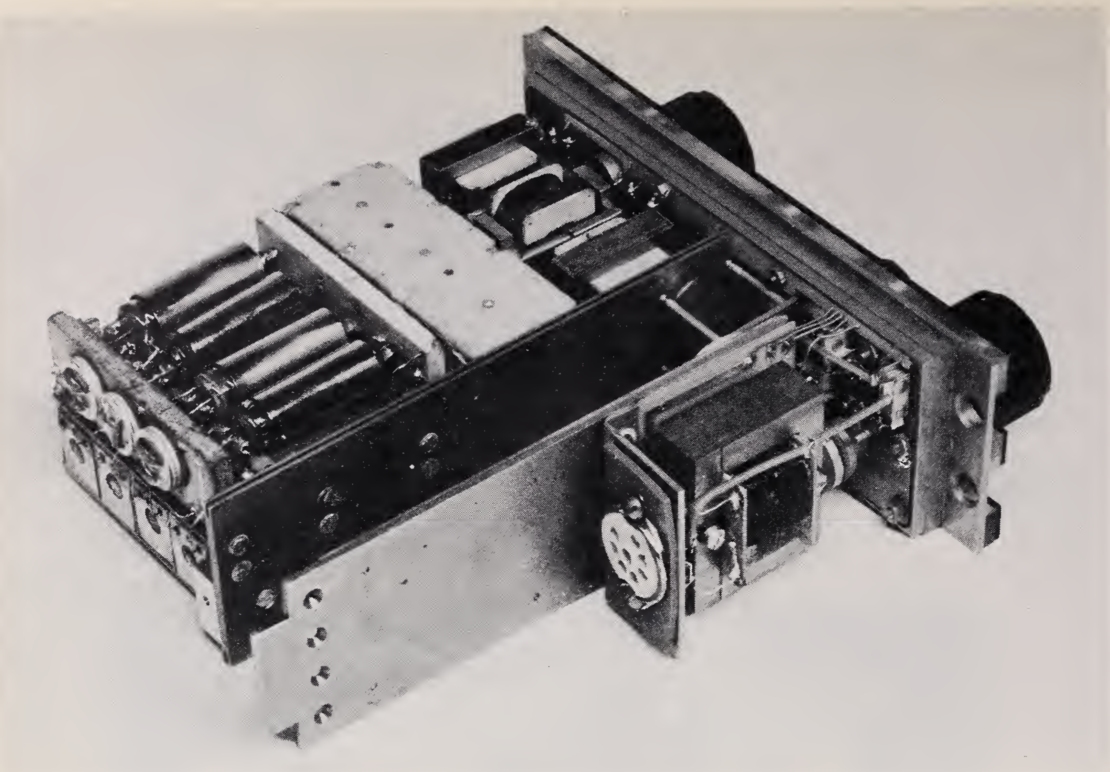


Figure 9. Receiver, partial assembly.

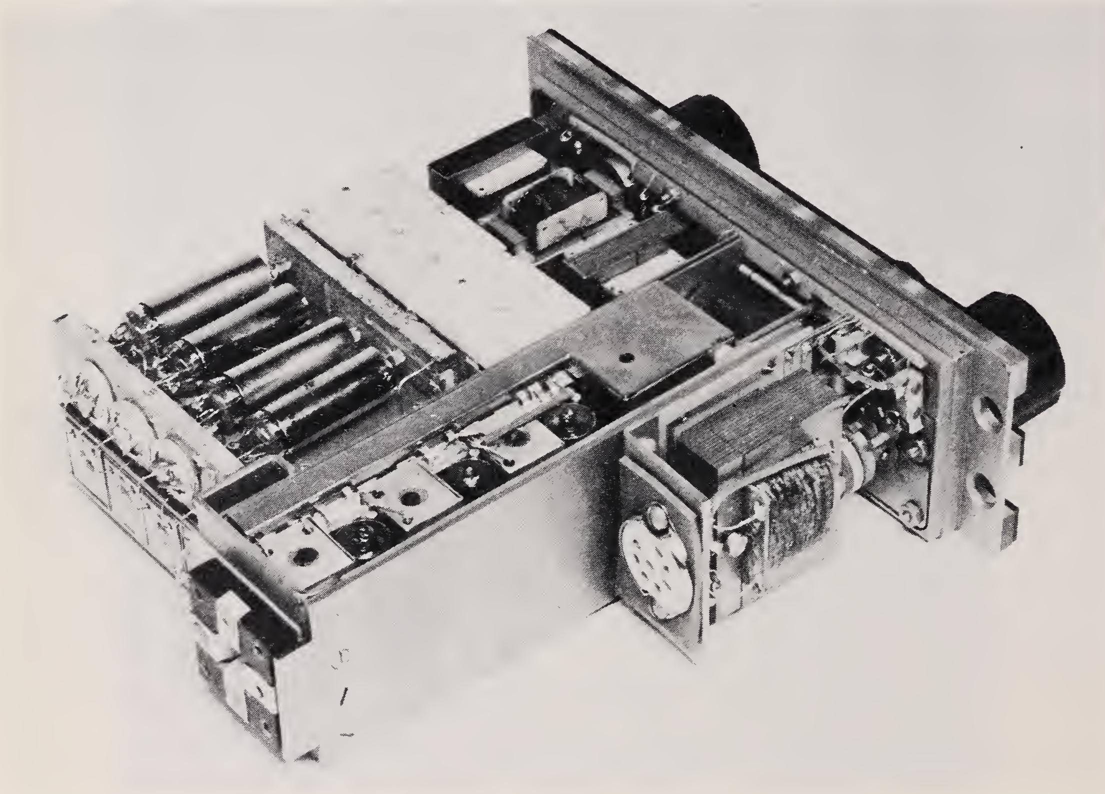


Figure 10. Top view of assembled receiver.

The case has been designed so that it may be hermetically sealed by soldering a strip of metal over the junction. The strip may be removed by unwinding with a key, similar to the method of opening a pressure-sealed coffee can. The rear left side of the case is recessed to accommodate the audio output tube assembly, The connections to the audio output tubes are made through a sealed 7-pin double-ended male plug which is soldered into the case. This plugs into a 7-pin miniature socket on the transformer bracket inside the case and into the audio output assembly on the outside of the case. Placing the output tubes on the outside of the case yields a distinct advantage from the standpoint of design flexibility, heat, dissipation and maintenance. As has been indicated, this assembly may be omitted and a 7-to 9-pin female adapter may be plugged into place for a single-envelope miniature output tube whenever it becomes available. The output tubes alone dissipate 12 w so that by locating this assembly outside the sealed enclosure, we materially reduce the operating temperature of the receiver proper and this very hot assembly can be replaced easily. A silicone rubber gasket placed between the output assembly and the case serves to prevent the entrance of moisture into the output tube assembly. The four output tubes are connected in push-pull parallel with 100-ohm parasitic suppression resistors in series with each grid. The tubes, resistors, and 7-pin female socket are all mounted to, and interconnected by a printed steatite plate. The tubes are inserted into counterbored holes; the leads are spread radially back into slots and soldered to the silver pattern. Spreading the leads back increases the distance between them and makes the soldering operation considerably easier. Each output tube has three cathode leads so that by removing two of them and properly designing the steatite plate it becomes impossible to incorrectly solder the tubes into place by faulty insertion. The metal output housing is provided with springs that press the tubes firmly in place. The steatite is secured between the tubes and the 7-pin socket, which in turn is screwed to a post in the metal housing. Thus, the steatite plate is permitted to float under spring pressure rather than be mounted rigidly. The entire output assembly plugs into place and is then secured by two screws.

The antenna trimmer-capacitor is mounted in the case and is externally adjustable. A gasket-sealed screw cover keeps the trimmer free of foreign materials.

4. CERAMIC-TEFLON INSULATED LITZ WIRE

In the frequency range over which this receiver operates it is desirable to use litz wire to achieve high-Q inductances. Because of the temperature requirements, commercially available litz wire is not satisfactory. It was thought that special litz wire could be woven from strands of ceramic or ceramic-Teflon-insulated magnet wire and then wrapped with glass fibres to furnish the over-all insulation. A number of wire manufacturers were contacted in an effort to arouse commercial interest in this special high temperature wire. It was found that not only was there a lack of interest regarding the manufacture of a special high-temperature litz wire, but few companies were interested in manufacturing even ordinary litz wire. It then became obvious that the equipment manufacturer would have to depend upon his own resources to produce ceramic-Teflon insulated litz wire. A machine for weaving conventional litz wire is both elaborate and expensive. Therefore, it was decided that the high-temperature ceramic-Teflon-insulated litz wire required for this receiver should be of the twisted variety, wherein a group of wires are twisted and then three groups twisted into the final bundle. For example, 6-strand litz would be composed of three 2-strand groups, 9-strand litz of three 3-strand groups, and 12-strand litz of three 4-strand groups. By making the final twist tight, it is possible to eliminate the over-all fabric wrap which in this case would have to be of glass fibre. A very simple machine was devised to accomplish this objective (see appendix A).

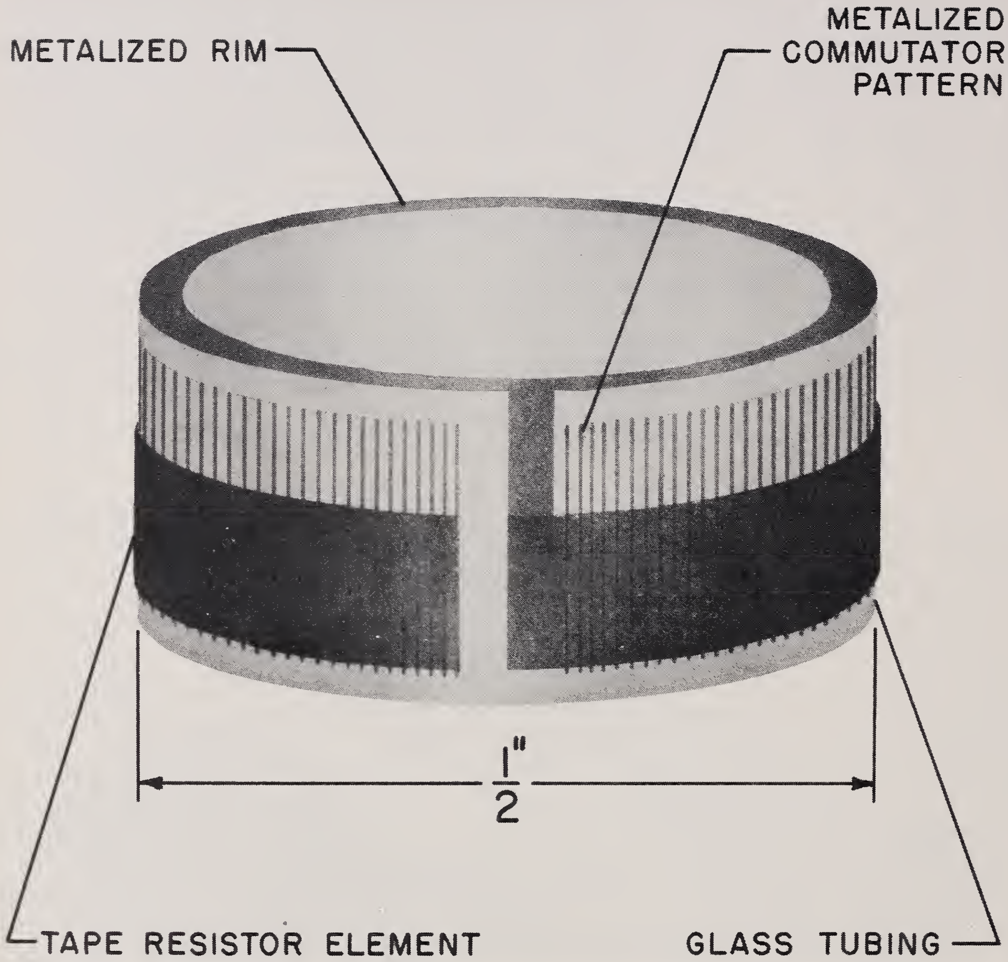


Figure 11. Gain control commutator.

5. GAIN CONTROL

Since there were no commercially available rheostats or potentiometers that met the space and temperature requirements of this receiver, a suitable gain control had to be designed. Two designs were considered practical for this application. Both utilized the tape resistor developed by the Components Development Group of the National Bureau of Standards. The first approach used an arc of silicone-bonded resistance tape baked on the surface of a 1/2-in. disk. The disk was mounted on the gain-control shaft and a stationary contact arm was used. One end of the tape was grounded throught the shaft. It was found that the initial contact resistance made it impossible to obtain a rheostat with low initial resistance. A number of methods that made use of the tape resistor with a graduated resistance coating were suggested. Though it was believed that a satisfactory and practical device could eventually result from such a scheme, the time required to accomplish this would probably have been excessive. It was considered advisable, therefore, to investigate the second variable-resistor scheme. This variable resistor also made use of a tape resistance element, but eliminated the direct contact between the wiping arm and the resistor element. A metallized cylindrical commutator provided this contact, and was chosen because it could be made with higher definition than a disk-shaped commutator.

The rheostat finally took the form of a Pyrex glass tube section 1/4 in. long and 1/2-in. outer diameter. An NBS tape resistance element was bonded to a conductive silver-paint commutator over 225° of the outer periphery (fig. 11). One end of the tape resistor is grounded through a silvered strip extending to meet a silvered ring (covering one end of the tube) which is mechanically grounded. The rheostat is mounted on a bushing at the top end of a cam shaft that operates the dual power switch. Sheet Teflon is used as a shim to mount the commutator concentrically. A silicone rubber washer mounted below the rheostat serves as a cushion to prevent breakage of the glass when the grounding washer is drawn up tightly. A fixed contact arm, which rides the commutator, was procured commercially.

The commutators are applied to a long glass tube by scribing axial lines on rings of air-dried conductive silver paint. The paint is applied by masked brushing or spraying and is air-dried while rotating to provide an even coating. The lines are scribed by a chisel-pointed stylus mounted in a gravity-loaded holder. Gravity loading provides a constant scribing pressure which compensates for nonuniformity of the glass tube. The lines are indexed with a large gear having the desired pitch (in this case a 92-tooth gear provided a definition of 122 lines per inch). Unwanted silver between the ends of the commutator is scraped off with a wide scribe, and the long tube is fired at 1,100° F. The tube is then cut into the 1/4-in. lengths, leaving margins at the top and bottom of each commutator. One end of each 1/4-in. length is silvered, and the grounding strip is painted on so as to make contact with it. The individual pieces are then refired, and the NBS tape resistors cured upon them.

In mass production, it is conceivable that special scribing template, with closely-spaced spring-loaded scribes located helically around the desired angle, could scribe all lines on one long glass tube simultaneously.

6. POWER-BFO SWITCH

Front panel space limitations required that the power switch and the beat-frequency oscillator switch each be separately actuated by the hermetically-sealed shaft of the gain control.

The two switches are incorporated in one assembly (fig. 8) and operated by two pins set at different levels and spaced about 90° apart in the bottom half of the rheostat bushing. The two cam followers (which also serve as stops) and their respective spring-loaded contact arms are all mounted on a common mast. The remainder of the parts are mounted on a stamped sheet-metal chassis either by riveting or by bending tabs. A long narrow projection of the chassis is bent up at 90° to serve as the standard for the contact arm of the volume control.

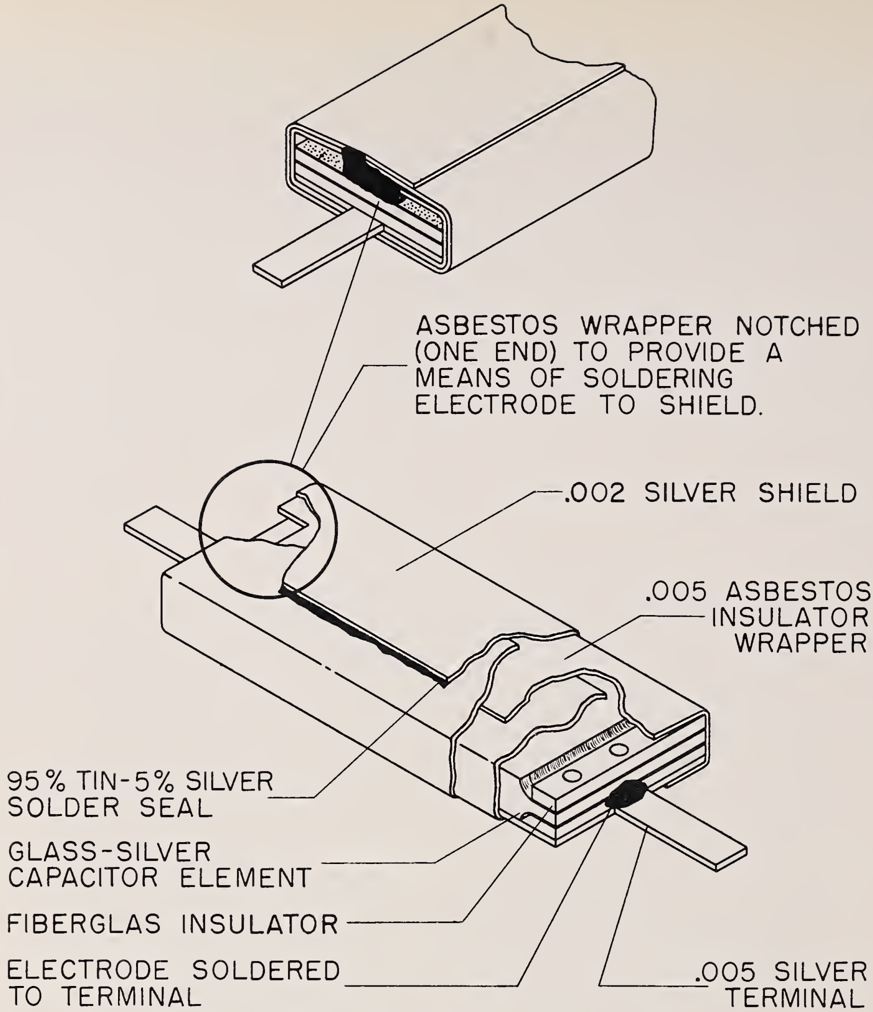


Figure 12. Capacitator fabrication steps

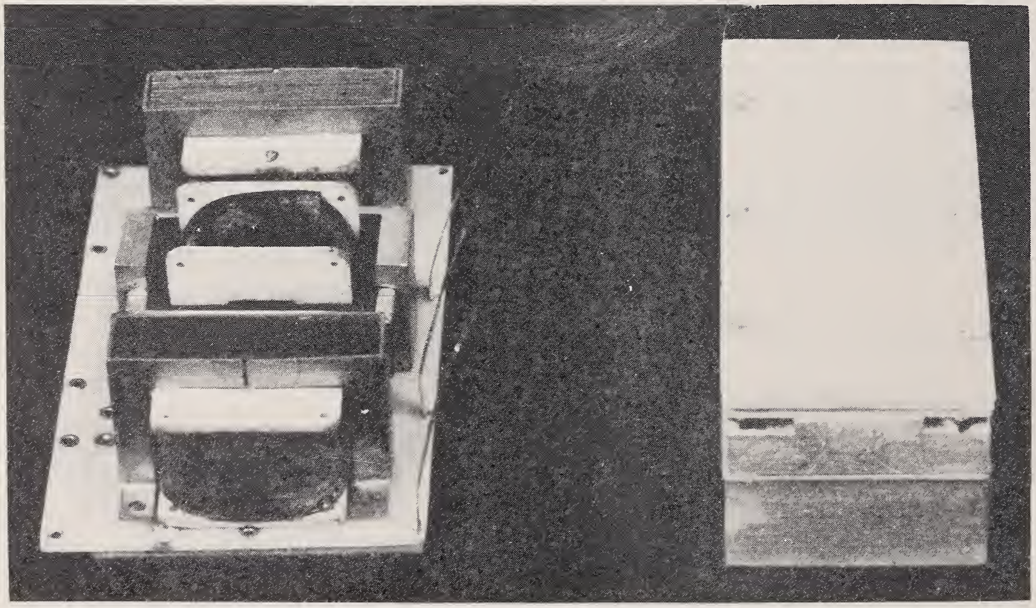


Figure 13. Line-filter components.

The assembly is designed so that the power switch is turned on at the beginning of a clockwise rotation of the volume-control knob. The BFO switch can be turned on by further turning the knob through 225 degrees. It will remain in its "on" position while the volume control is rotated counter-clockwise to an adjustment that will yield a comfortable volume level. Turning the volume control counterclockwise all the way will turn both switches "off". Each switch has positive snap-action wiping contacts.

This novel double switch occupies a space 25/32 by 13/16 by 13/32 in., or a volume of 0.26 $in.^3$, and will operate at temperatures as high as 200° C. It is lubricated with silicone grease and uses silicone-impregnated glass for insulators.

7. CAPACITORS

In the early stages of the development, the intent was to fabricate all capacitors from very thin, flat sections of high-K ceramic dielectric material. To obtain capacitors of the order of 0.015 µf with small volumes and desirable shape factors, it was necessary to obtain thin silvered wafers that could be stacked and housed in a rigid manner so that their inherent fragility could be overcome. However, experimentation with ceramic material was terminated in favor of the use of glass capacitors for this application. (See appendix B for information on the experimentation with the ceramic dielectric material).

Glass dielectric capacitors were developed by an industrial organization during the war. Electrical grade glass with a dielectric constant of 8.5 and a power factor of approximately .045 % is extruded as a ribbon 0.001 in. thick. Lengths of this ribbon are stacked and interleaved with aluminum electrodes. The stack is then sealed under heat and pressure, and the strips are cut up into individual capacitor units.

Originally, glass dielectric capacitors were developed to be mica-capacitor replacements and as such were furnished with wire leads in a package that resembled, in shape and size, conventional molded mica capacitors. Examination of those components revealed that a large percentage of the volume was wasted by thick glass end plates, which functioned to mechanically secure the wire leads. It was reasoned that by discarding the wire leads and end plates and substituting clip terminals, the capacitor's useful volume could be made a much greater percent of the package volume.

The desired capacitor package shape was set to match the conventional T-3 subminiature-tube shape. The width was set to a maximum of 0.400 in., the length to 1 1/4 in., and the height was determined by the thickness of the glass capacitor stack. In practice this package thickness was about 3/32 in. for a 0.015-µf assembly. The case was made of thin sheet metal, and could be either connected to one terminal or left floating. The terminals that emerge from each end of the capacitor assembly can be either individual terminals or a common one. The audio coupling capacitor (C37 fig. 2) was designed with a floating case with end terminals connected to opposite capacitor electrodes. The bypass capacitors have common end terminals connected to one electrode of the capacitor with the case connected to the other electrode. The double-end arrangement of the hot electrode for the bypass capacitors gives these capacitors some flexible features that should make them useful in a variety of assemblies. To make the terminals of a stack of capacitors easily accessible, the end terminals were brought out either on center or off center. In this manner, three capacitors could be stacked without limiting the accessibility of their terminals.

The basic capacitor elements, procured commercially, are fabricated from 0.001-in. thick glass dielectric ribbon. The electrodes are thin pieces of aluminum foil, spot welded in tinned clips, which function as the capacitor element terminals (left side of fig. 12). The capacitors have the maximum number of plates that may be used without encountering difficulties caused by the different coefficients of expansion of the aluminum and the glass. The high-potential electrodes are punched from 0.005-in. sheet silver. The two varieties are illustrated in figure 12. The left-hand electrode becomes a right-hand one when it is turned over.

One insulating piece of 1/64-in.-thick, silicone-impregnated glass cloth is cemented with silicone varnish to one side of one terminal of the basic capacitor element and another to the opposite side of the other terminal of the basic capacitor element. This prevents the basic capacitor elements from being shorted out by either the high-potential electrodes or the outer shield. The high-potential electrode is placed beside the capacitor element and soldered to one terminal. This assembly is then wrapped in an asbestos paper wrapper, which serves to insulate the high-potential electrodes from the outer shield. This paper is only 0.005 in. thick, and it is cut out to expose the capacitor terminal that must later be soldered to the outer shield (if the capacitor is to function as a bypass). A piece of 0.002-in. silver foil, that has been cut to size and has diametrically opposite tinned edges that overlap in assembly, is next wrapped around the asbestos paper wrapper and inserted into a sizing jig. This jig is constructed of metal and also functions as the passive electrode of a soldering machine. This soldering machine is made by modifying a conventional spot welder. As the outer shield is pretinned, no solder need be added in this operation. The outer shield is made the ground terminal by soldering it to the capacitor terminal that has been exposed by the cutout in the asbestos paper wrapper. Figure 12 illustrates the parts that are used in the assembly of the capacitors.

It is usually necessary to use capacitors as large as 0.5 to 1.0 μf to keep the line transients out of the receiver. The size of high-capacity glass dielectric capacitors for this function seemed to be out of proportion with the receiving equipment itself; hence tantalum electrolytic capacitors were used instead. Although many metals have good dielectric-film-forming properties, one of the properties in favor of tantalum-oxide film is its dielectric constant of approximately 11.5 as compared with aluminum films with dielectric constants of approximately 7.5. Tantalum foil, because its surface is inherently less smooth than other metals, tends to yield considerably larger capacities than other metal electrodes. Where extremely large capacities are required in very small spaces, good results may be obtained by using a porous tantalum electrode made with the methods of powder metallurgy. By properly selecting the particle size, compacting and sintering the powder to achieve the desired porosity, a very large effective surface area may be obtained in proportion to weight and volume. Tantalum is not subject to corrosion and can be employed in most acid electrolytes except hydrofluoric acid. Processing the tantalum capacitor is a painstaking task and requires extreme cleanliness to prevent contamination. The tantalum capacitors used in this receiver were supplied by a commercial company, and use sulphuric acid as an electrolyte. They are characterized by good low-temperature performance. The cell cases are made of silver-plated steel. Sealing is achieved by spinning metal over a Teflon gasket. Because of the pressure built up by the electrolyte and because of the tendency for Teflon to deform, it is necessary for the tantalum capacitor gasket-sealed cells to be placed under spring pressure when the cells are to be operated at temperatures approaching 200° C. These cells were sealed in a steel jacket and contained the required spring. These jackets, however, were so dimensioned that it was impossible to conveniently package 3 of the 4 capacitors required in this receiver. A special capacitor block was designed (fig. 13) to house the 3 individual cells required for the power filter. To keep the height of this block small, Belleville washers were designed to replace the original springs. Because the only other function this block serves is to retain any possible electrolyte seepage, it was unnecessary for it to be solder-sealed. Instead, a Teflon gasket seal was used.

The capacitors used to resonate the r-f and i-f inductors are washer-shaped punchings. These could be made from silvered sheets of either mica or ceramic. As mica sheets were on hand, the capacitors were made of mica to hasten the completion of this development. A production version of this receiver should use capacitors of ceramic with the proper temperature compensating characteristics.

8. ROTARY HERMETIC SEALS

The receiver was designed to be hermetically sealed. It was necessary therefore to use some mechanism that would transmit the rotation of the knobs to the interior without breaking the seal. Although rotary hermetic seals of the gasket type have been developed, all of them depend upon a critical relationship between the rigid surfaces that ride on the gasket and the character of the gasket material. All such seals, which have been developed in the past and have proved satisfactory, use gasket materials that function best at moderate operating temperatures. Therefore, it was decided that the rotary seals should be of the true hermetic type without gaskets.

There are various magnetic-clutch systems and other systems in which reciprocating motion is converted to rotary motion through a bellows. These systems are invariably bulky, complex, limited in angular rotation, or they suffer very severely from backlash. One engineering company has developed a seal that appears to be the most practical for this application to date. This seal is designed on the wobbling-bellows principle. A rotary motion is transformed into a wobbling motion, transmitted through a bellows seal, and then converted back to rotary motion. Unfortunately, this seal is quite bulky, and were it to be housed in a receiver interior, it would occupy an amount of room completely out of proportion to its function.

Because this receiver would be operated by aircraft personnel who would in all probability wear gloves, it was highly desirable that the knobs be large. This line of reasoning suggested housing the bellows-type seal inside the hollow knobs, rather than in the receiver proper. The first knob so designed consisted of a commercial wobbling-bellows-type rotary seal from which the outer casing had been removed and replaced by a knob-shell. After a few of these knobs were built to practical machining tolerances, it was found that the backlash was much greater than in the original wobbling-bellows-type rotary seal. A second knob was designed, which did not increase the backlash of the original seal. In this second design the shell of the seal was left on and turned concentrically with its shafts. The hollow knob was placed over the entire assembly. This second design is the one included in the final version of the receiver. The knob shells are aluminum with a black anodized finish. If a redesign of this equipment is attempted, it might be wise to look into the possibility of using a nonmetallic shell to keep the knob temperature low. Although it is the best of the true rotary hermetic seals available, the wobbling-bellows seal is far from ideal. The inherent backlash of the units is objectionable, even though 9 revolutions of the knob are required to tune through the range. Because the tuning knob drives the tuning-dial gear train directly, backlash through the knob affects the tuner, but not the tuning dial. Some backlash was intentionally introduced between the knob gear and the tuning-dial gear to permit the dial to follow the tuner more accurately, and reduce the dial error due to knob backlash.

9. RADIO-FREQUENCY MAGNETIC SHIELDS

A distinct effort was made to limit the r-f inductors to approximately the same shape and size as the i-f transformers, so that similar shield cans and magnetic shielding structures with the same cross section could be used. The diameter of the i-f and r-f inductors was established at 3/8 in. It was then necessary to determine the minimum magnetic shielding to isolate effectively the inductors from the "shorted turn" effect of the copper shield, which tends to lower the inductance and Q of the inductors.

The magnetic materials normally used over the range 100 to 1,000 kc are powdered iron materials. Tuning slugs and magnetic sleeves (3/8 in. ID by 21/32 in. OD by 1 1/2 in. long) were available, and were used in the initial tests. Sleeves of various sizes were made from these cylinders, and tests were conducted to determine the magnetic-shielding efficiency of different wall thicknesses by comparing the results obtained with and without a continuous 5-mil copper shield surrounding the sleeves. The results are illustrated in figure 14 and may be summarized as follows:

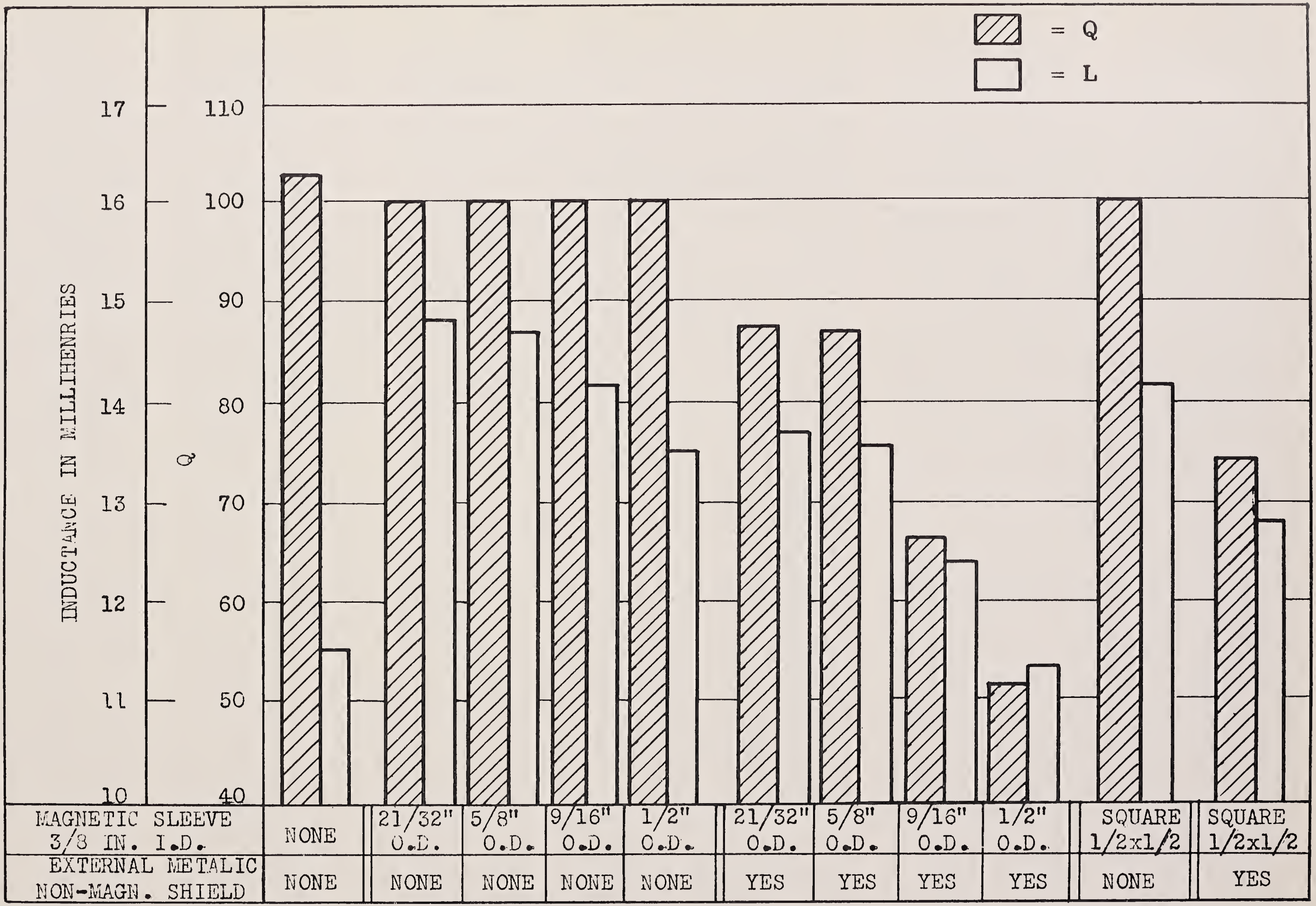


Figure 14. Magnetic-shielding comparisons.

1. The increase of coil inductance and the efficiency of magnetic shielding were a function of the sleevewall thickness.

2. The presence of all sleeves caused a slight reduction of inductor Q even when no copper shield was used.

3. The presence of the metallic shields reduced the coil inductance and Q with the least change occurring for the thickest sleeve walls.

4. The square sleeve provided appreciably more magnetic shielding than did the cylindrical sleeve with the same outside diameter.

5. The effectiveness of magnetic shielding provided by the 1/2 by 1/2-in. square sleeve fell between that provided by the 9/16-in. diameter and the 5/8-in. diameter round sleeves.

The 1/2-in. square sleeve was adopted as the best compromise between size and magnetic shielding.

10. RADIO-FREQUENCY MAGNETIC MATERIALS

During the development of the r-f inductors, high-temperature magnetic ferrites, with higher permeabilities than those of the powdered iron cores, became available. Tests showed that they yielded inductors with more constant Q than did powdered-iron cores. The higher permeability of the ferrite compared with that of powdered iron permits a greater tuning range with a given displacement, or a smaller displacement for the same tuning range (fig. 15).

A comparison of Q variation with frequency for inductors using powdered iron and ferrite cores is made in figure 16. The Q variations of the same inductor from 190 to 550 kc for powdered-iron slugs and ferrite slugs were 105 to 64 and 77 to 68, respectively.

Although magnetic ceramic materials, such as ferrites, have been available for some time, the Curie temperatures of most commercially available materials were below 200° C, the required performance temperature. A commercial corporation has recently made available some ferrites having a Curie temperature much higher than 200° C. Tests were performed using a toroidal inductor to determine some of the properties of an early ferrite body as a function of temperature (fig. 17). These ferrites were found to have higher permeabilities and provide better Q's than comparable powdered-iron materials. Inasmuch as ferrites are known to saturate easily, tests were conducted to determine their change of permeability when subjected to magnetizing forces of the order that arises when tube plate currents flow through r-f and i-f inductor windings. The effect was found to be negligible. Although there are many suppliers of magnetic ceramics, only one has been located who will furnish bodies with Curie temperatures in excess of 200° C. Table 2 illustrates the properties of some of these bodies.

Ferrite B material was used in this receiver because of its low-temperature coefficient of initital permeability (0.04%/°C). After the r-f inductors had been designed, they were tested for thermal drift. The inductors using ferrite cores showed an inductance variation of + 1/2 percent to - 1 1/2 percent from 25° to 200° C. A similar test with a powdered-iron core showed a drift of over 10 %. The characteristics of the powdered-iron core changed permanently at 200° C.

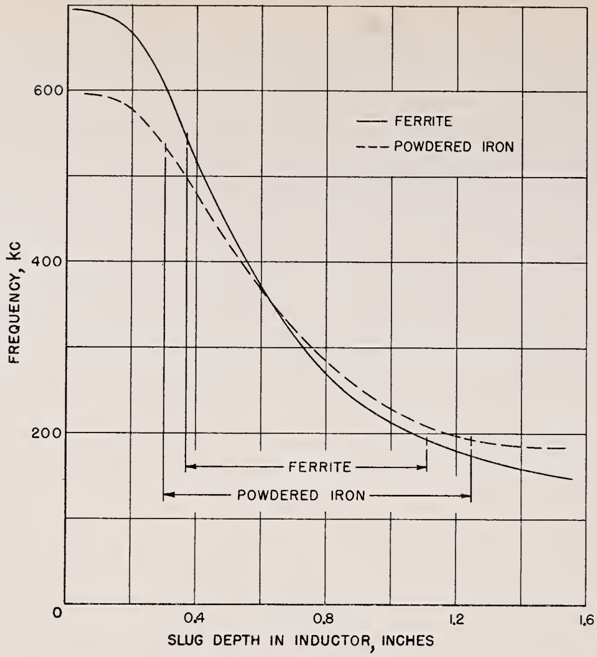


Figure 15. Permeability-tuning curves.

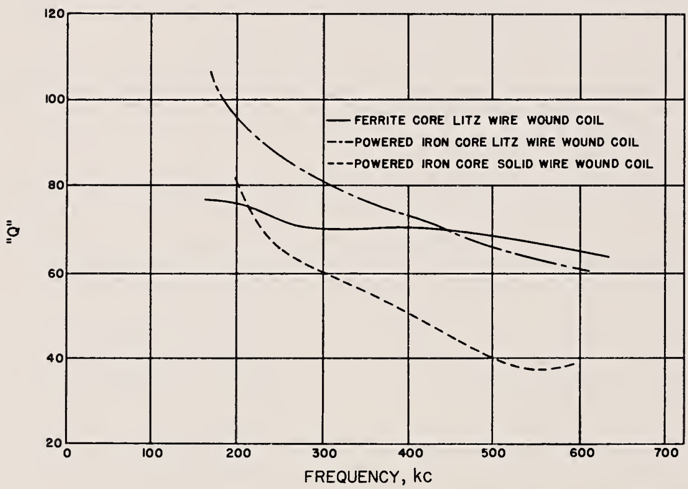


Figure 16. Core-comparison curves.

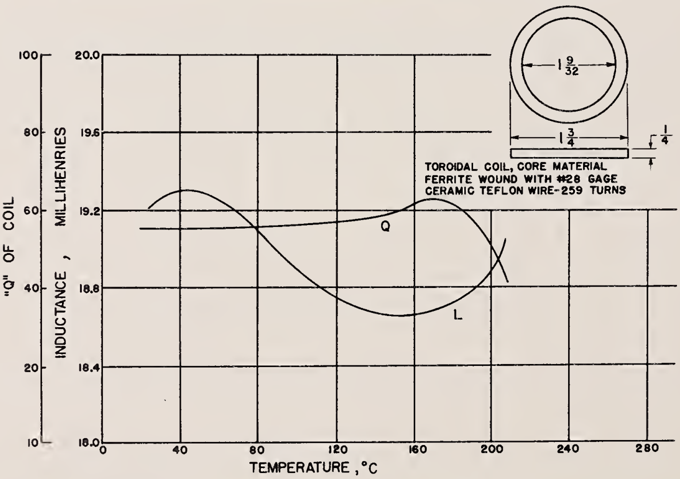


Figure 17. Temperature characteristics of an early ferrite sample.

TABLE 2. Type of ferrite material

Property	Unit	A	B	C
Initial permeability at 1 mc/sec	- - - -	15	95	220
Maximum permeability	- - - -	97	183	710
Coercive force	Oersted	3.7	3.0	2.1
Residual magnetism	Gauss	615	830	2700
Saturation flux density	Gauss	840	1900	3800
Curie point	° C	280	260	330
Temperature coefficient of initial permeability	%/° C	0.65	0.04	0.4
Volume resistivity	Ohm-cm	1×10^9	2×10^5	2×10^3
Loss factor at:				
1 mc/sec	- - - -	- - - -	0.00016	0.00007
5 mc/sec	- - - -	0.0004	0.0011	0.0008
10 mc/sec	- - - -	0.0005	- - - -	- - - -

11. RADIO-FREQUENCY INDUCTORS

The conclusion was reached early in this project that the r-f assembly should be permeability tuned using the antenna capacity as part of the resonating capacity of the r-f input tank for best efficiency. This permitted close coupling of the antenna and receiver input with consequent maximum efficiency. It was also believed that the r-f assembly could be made smaller if permeability tuning were used.

An inductor wound of commercial 11/41 litz wire was tried. Its Q varied from 105 to 60 over the tuning range of 190 to 550 kc. This wire, however, was not suitable for use at 200° C. After some unsuccessful efforts to find a commercial source of high-temperature litz wire, the machine described in appendix A that twists a form of litz wire from ceramic-Teflon insulated magnet wire, was designed and constructed. The r-f inductors were wound with 9-strand ceramic-Teflon insulated litz wire and the i-f transformers with 3-strand ceramic-Teflon-insulated litz wire.

Several methods of inductor construction were tried. Inductors were wound on a preformed bobbin composed of an asbestos tube with steatite separators between the pies, giving a neat and sturdy construction. There was an appreciable increase in Q when going from 1 to 3 pies. Beyond three pies, the Q did not increase enough to justify the more complex construction. The Q of the inductors finally used varies from 73 to 65.

The r-f and oscillator inductors each consisted of three layer-wound pies on an asbestos paper tube. The pies were separated by steatite spacers containing two small holes through which buses of No. 26 solid wire were threaded. The inductor-winding connections are easily made to these buses. One end of each bus connects to the washer-shaped inductor-resonating capacitor; the other end provides an interconnection between the inductor and the r-f electrical assembly.

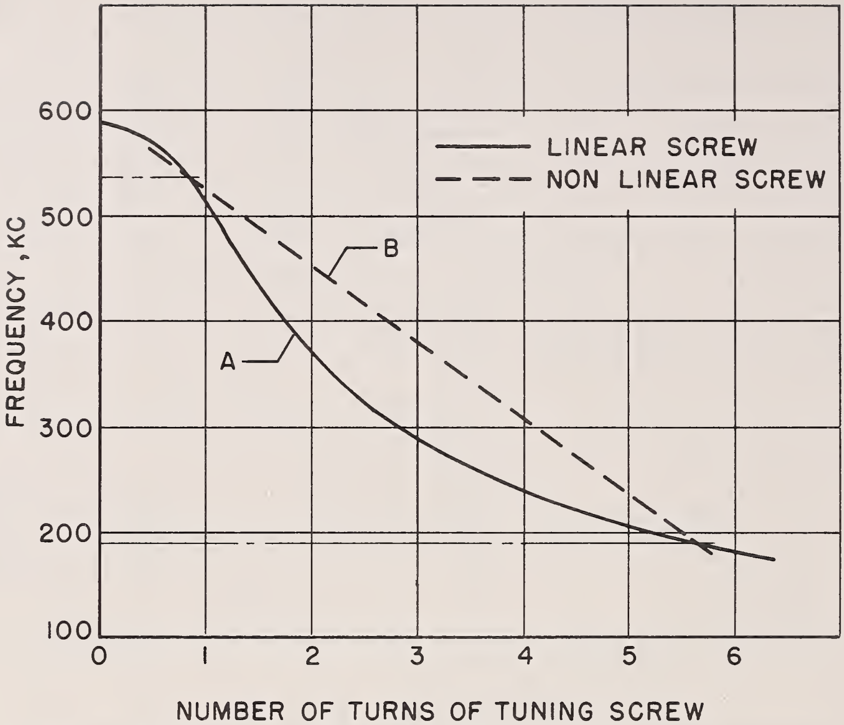


Figure 18. Frequency versus rotation of tuning screw.

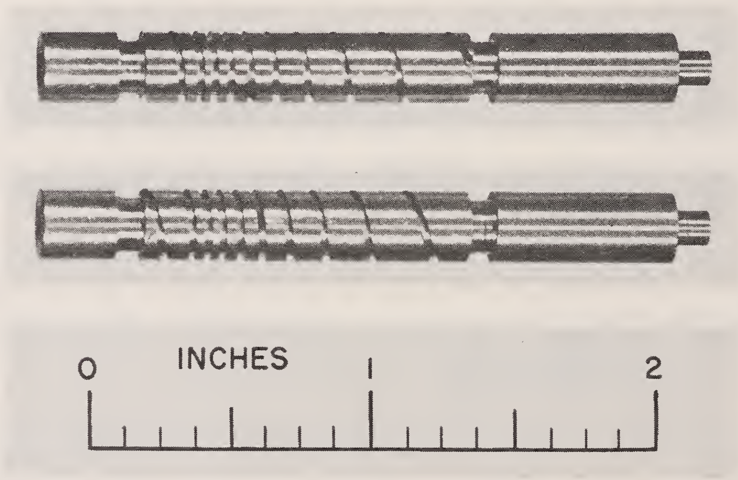


Figure 19. Nonlinear-pitch screws.

The r-f inductor assemblies differ only in the value of the resonating capacitors. The local oscillator-inductor assembly has two capacitors mounted on the end of the inductor. These capacitors are series-connected, with the common point grounded to provide a capacitive tap for the Colpitts-type local oscillator.

Each r-f inductor assembly is mounted in a sleeve of ferrite B material, which in turn is enclosed in a cadmium-plated copper shield. A 1/16-in.-thick metal strip, drilled and tapped for two 0-80 screws, provides means for mounting the inductors.

The resonating capacitors are made up of stacks of paralleled silvered-mica washers, housed in steatite cups and mounted at the ends of the inductors. The holes in their centers permit the tuning slugs to enter the inductors. The silvered pattern of the mica washers is not circular but C-shaped. This prevents them from behaving like shorted turns inductively coupled to the inductors, thereby lowering the inductor Q's. The silvered patterns are so arranged that no mica washer pattern will short the gap of the adjacent one. This shorted-turn effect can be very serious because of the tight coupling caused by the presence of the tuning slugs inside both the inductors and the capacitors.

The entire inductor assemblies are held compressed by silicone-rubber washers that rest against the capacitor cups.

12. LINEAR TUNING DIAL

The tuning dial of this equipment was required to be as linear as possible, so that operating personnel could read it with maximum ease. This was especially desirable in this receiver since its tuning dial was considerably smaller than that usually found on military equipment. In order to achieve a linear dial presentation for a multilayer permeability-tuned inductor, the inductors are usually wound with a variable build-up so that there are more layers of wire on one portion of the inductor form than on another. The procedure for arriving at the proper build-up form factor for the inductor is usually empirical. Such an inductor assembly, however, has waste space created by those sections containing few layers of wire, which from a miniaturization standpoint is undesirable. The fact that these inductors had to be wound with ceramic-Teflon-insulated litz wire provided another reason for ruling out this conventional linearizing method. The slippery texture of the ceramic-Teflon-insulated litz-wire surface makes it impossible to wind variable build-up inductors with any degree of uniformity and reproducibility, because of the tendency for the wires to slip and slide when wound in a sloping lay.

It has been suggested that this problem might be approached through the use of a tuning slug with variable cross-section areas down its length. Because the difficulties of reproducing and quality-controlling such slugs is apparently beyond the present technology of the inductor-slug fabricators, this approach was ruled out also.

The inductance required for these inductors was sufficiently large to preclude the winding of single-layer solenoids with a variable pitch, as is usually done in high-frequency applications.

It was argued that a suitable solution would consist of winding the r-f inductors uniformly and displacing the slug nonuniformly. In this manner, the familiar S-shaped tuning curve of a permeability-tuned inductor (fig. 18, curve A) could be compensated for (fig. 18, curve B). There are many ways for accomplishing this objective, but most of these are rather complex and space consuming. The simplest and least space-consuming mechanism for accomplishing a nonlinear displacement is a screw with a nonlinear pitch (fig. 19).

The idea of a nonlinear screw drive for permeability-tuned inductors is not particularly novel. The difficulties in achieving the required nonlinearity and the expense of fabricating small quantities of these screws have prohibited the adoption of this idea in the past. A device for producing these screws efficiently and economically was invented as part of this development (see appendix C).

13. RADIO-FREQUENCY AMPLIFIER CIRCUIT

The major problems encountered in the r-f circuit are as follows:

1. Because the grid-to-plate capacity of the subminiature r-f pentode used is greater than that of the equivalent octal or miniature-tube types lower stable gains per stage may be realized.

2. Small size, high-Q components are difficult to realize.

3. All components must be able to withstand high temperatures,

4. With the plates of the tubes operating at 26 v, the low output impedance of the tubes tends to deteriorate the tuned-circuit Q's.

Because of the low-output impedance of the r-f pentodes, it was intended that the interstage inductors would be tapped so that the tubes would not load the tuned circuits excessively. It was found, however, that the resonant impedance and Q of the unloaded r-f tuned circuits varied considerably with frequency. In general, the circuit Q's and resonant impedances were higher at the lower frequencies.

When untapped inductors were used as part of the interstage networks, the loading effect of the tubes tended to minimize variations of the tank resonant impedance and caused the Q to vary in such a manner as to equalize the r-f selectivity over the tuning range.

Because tuning is accomplished by varying the inductance of the r-f tuned circuits, the capacitive reactance, hence the resonant impedance, rises at the low-frequency end of the band for a constant Q. If the Q's of the inductors increase at the low-frequency end of the band, as occurred with the tapped inductors, the resonant impedance rises even more.

In the case of the untapped inductors, however, the constant plate impedance of the tubes maintains the resonant impedance of the tuned circuit relatively constant. This tends to equalize both gain and band width over the entire band. For this reason, and because in the case of the tapped inductor the loss in gain far overshadowed the simultaneous increase in selectivity, the untapped r-f inductor was used in the tuned circuit.

It was expected that the use of grid-leak bias, dictated by the 26-v operation of the tubes, would load the tuned circuits. However, the high value of grid-leak resistance (2 megohms) restricted this loading to negligible proportions.

As one r-f amplifier stage would have yielded marginal spurious-signal rejection, two stages were used to provide a conservative design. This was more desirable from a stability standpoint also, because it was then possible to operate each stage with lower gain.

To obtain satisfactory Q's between 190 and 550 kc, it was necessary to wind the r-f inductors with ceramic-Teflon-insulated litz wire described elsewhere in this report. The original intention was to use 9/44 wire; however, it was discovered that 3/42 ceramic-Teflon-insulated litz wire gave adequate performance when three tuned circuits (2 r-f stages) were employed. Inasmuch as 3/42 ceramic-Teflon-insulated litz wire was used in the i-f section, the use of 3/42 litz in the r-f section made for economy in production. The r-f inductors, in their final form, were wound with 3/42 ceramic-Teflon-insulated litz wire in three layer-wound pies. The overall structure, including the sleeve and shield, was 1/2 by 9/16 by 1 1/2 in.

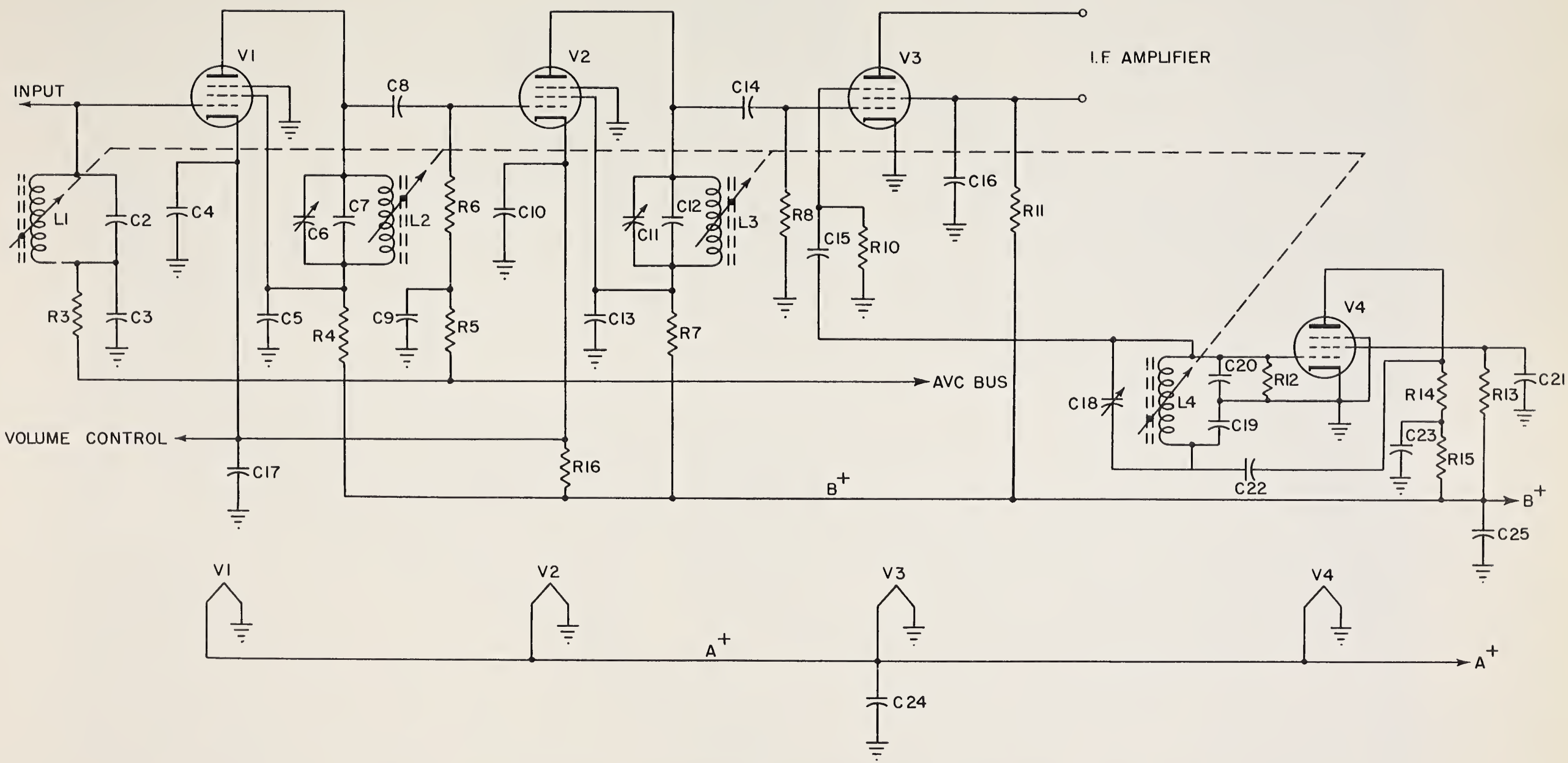


Figure 20. Radio frequency amplifier schematic diagram.

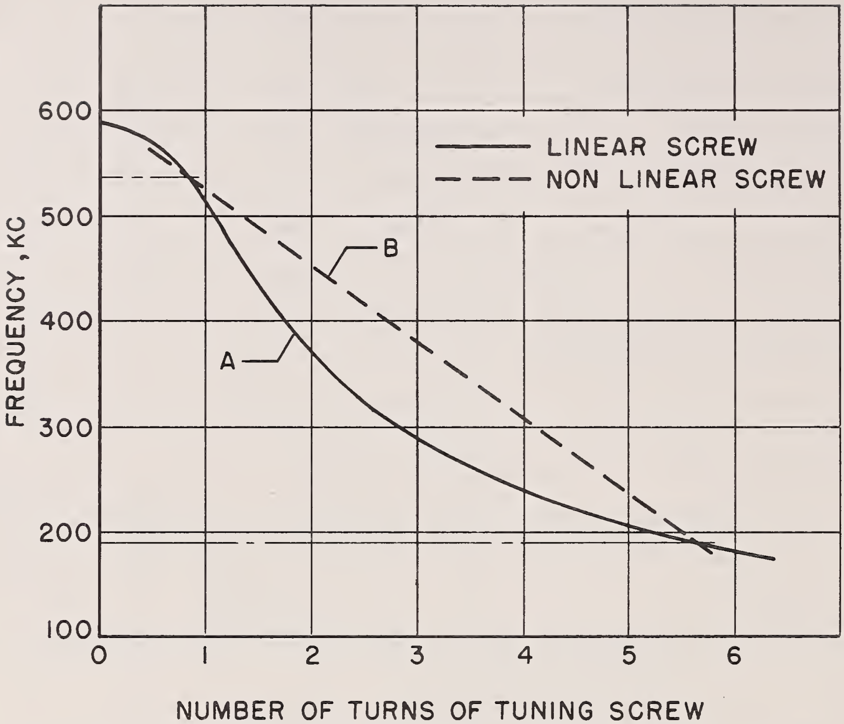


Figure 18. Frequency versus rotation of tuning screw.

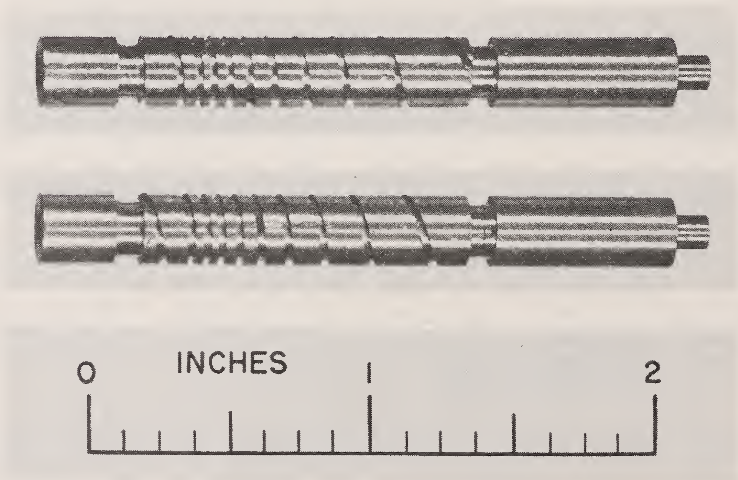


Figure 19. Nonlinear-pitch screws.

The r-f inductor assemblies differ only in the value of the resonating capacitors. The local oscillator-inductor assembly has two capacitors mounted on the end of the inductor. These capacitors are series-connected, with the common point grounded to provide a capacitive tap for the Colpitts-type local oscillator.

Each r-f inductor assembly is mounted in a sleeve of ferrite B material, which in turn is enclosed in a cadmium-plated copper shield. A 1/16-in.-thick metal strip, drilled and tapped for two 0-80 screws, provides means for mounting the inductors.

The resonating capacitors are made up of stacks of paralleled silvered-mica washers, housed in steatite cups and mounted at the ends of the inductors. The holes in their centers permit the tuning slugs to enter the inductors. The silvered pattern of the mica washers is not circular but C-shaped. This prevents them from behaving like shorted turns inductively coupled to the inductors, thereby lowering the inductor Q's. The silvered patterns are so arranged that no mica washer pattern will short the gap of the adjacent one. This shorted-turn effect can be very serious because of the tight coupling caused by the presence of the tuning slugs inside both the inductors and the capacitors.

The entire inductor assemblies are held compressed by silicone-rubber washers that rest against the capacitor cups.

12. LINEAR TUNING DIAL

The tuning dial of this equipment was required to be as linear as possible, so that operating personnel could read it with maximum ease. This was especially desirable in this receiver since its tuning dial was considerably smaller than that usually found on military equipment. In order to achieve a linear dial presentation for a multilayer permeability-tuned inductor, the inductors are usually wound with a variable build-up so that there are more layers of wire on one portion of the inductor form than on another. The procedure for arriving at the proper build-up form factor for the inductor is usually empirical. Such an inductor assembly, however, has waste space created by those sections containing few layers of wire, which from a miniaturization standpoint is undesirable. The fact that these inductors had to be wound with ceramic-Teflon-insulated litz wire provided another reason for ruling out this conventional linearizing method. The slippery texture of the ceramic-Teflon-insulated litz-wire surface makes it impossible to wind variable build-up inductors with any degree of uniformity and reproducibility, because of the tendency for the wires to slip and slide when wound in a sloping lay.

It has been suggested that this problem might be approached through the use of a tuning slug with variable cross-section areas down its length. Because the difficulties of reproducing and quality-controlling such slugs is apparently beyond the present technology of the inductor-slug fabricators, this approach was ruled out also.

The inductance required for these inductors was sufficiently large to preclude the winding of single-layer solenoids with a variable pitch, as is usually done in high-frequency applications.

It was argued that a suitable solution would consist of winding the r-f inductors uniformly and displacing the slug nonuniformly. In this manner, the familiar S-shaped tuning curve of a permeability-tuned inductor (fig. 18, curve A) could be compensated for (fig. 18, curve B). There are many ways for accomplishing this objective, but most of these are rather complex and space consuming. The simplest and least space-consuming mechanism for accomplishing a nonlinear displacement is a screw with a nonlinear pitch (fig. 19).

The idea of a nonlinear screw drive for permeability-tuned inductors is not particularly novel. The difficulties in achieving the required nonlinearity and the expense of fabricating small quantities of these screws have prohibited the adoption of this idea in the past. A device for producing these screws efficiently and economically was invented as part of this development (see appendix C).

13. RADIO-FREQUENCY AMPLIFIER CIRCUIT

The major problems encountered in the r-f circuit are as follows:

1. Because the grid-to-plate capacity of the subminiature r-f pentode used is greater than that of the equivalent octal or miniature-tube types lower stable gains per stage may be realized.

2. Small size, high-Q components are difficult to realize.

3. All components must be able to withstand high temperatures,

4. With the plates of the tubes operating at 26 v, the low output impedance of the tubes tends to deteriorate the tuned-circuit Q's.

Because of the low-output impedance of the r-f pentodes, it was intended that the interstage inductors would be tapped so that the tubes would not load the tuned circuits excessively. It was found, however, that the resonant impedance and Q of the unloaded r-f tuned circuits varied considerably with frequency. In general, the circuit Q's and resonant impedances were higher at the lower frequencies.

When untapped inductors were used as part of the interstage networks, the loading effect of the tubes tended to minimize variations of the tank resonant impedance and caused the Q to vary in such a manner as to equalize the r-f selectivity over the tuning range.

Because tuning is accomplished by varying the inductance of the r-f tuned circuits, the capacitive reactance, hence the resonant impedance, rises at the low-frequency end of the band for a constant Q. If the Q's of the inductors increase at the low-frequency end of the band, as occurred with the tapped inductors, the resonant impedance rises even more.

In the case of the untapped inductors, however, the constant plate impedance of the tubes maintains the resonant impedance of the tuned circuit relatively constant. This tends to equalize both gain and band width over the entire band. For this reason, and because in the case of the tapped inductor the loss in gain far overshadowed the simultaneous increase in selectivity, the untapped r-f inductor was used in the tuned circuit.

It was expected that the use of grid-leak bias, dictated by the 26-v operation of the tubes, would load the tuned circuits. However, the high value of grid-leak resistance (2 megohms) restricted this loading to negligible proportions.

As one r-f amplifier stage would have yielded marginal spurious-signal rejection, two stages were used to provide a conservative design. This was more desirable from a stability standpoint also, because it was then possible to operate each stage with lower gain.

To obtain satisfactory Q's between 190 and 550 kc, it was necessary to wind the r-f inductors with ceramic-Teflon-insulated litz wire described elsewhere in this report. The original intention was to use 9/44 wire; however, it was discovered that 3/42 ceramic-Teflon-insulated litz wire gave adequate performance when three tuned circuits (2 r-f stages) were employed. Inasmuch as 3/42 ceramic-Teflon-insulated litz wire was used in the i-f section, the use of 3/42 litz in the r-f section made for economy in production. The r-f inductors, in their final form, were wound with 3/42 ceramic-Teflon-insulated litz wire in three layer-wound pies. The overall structure, including the sleeve and shield, was 1/2 by 9/16 by 1 1/2 in.

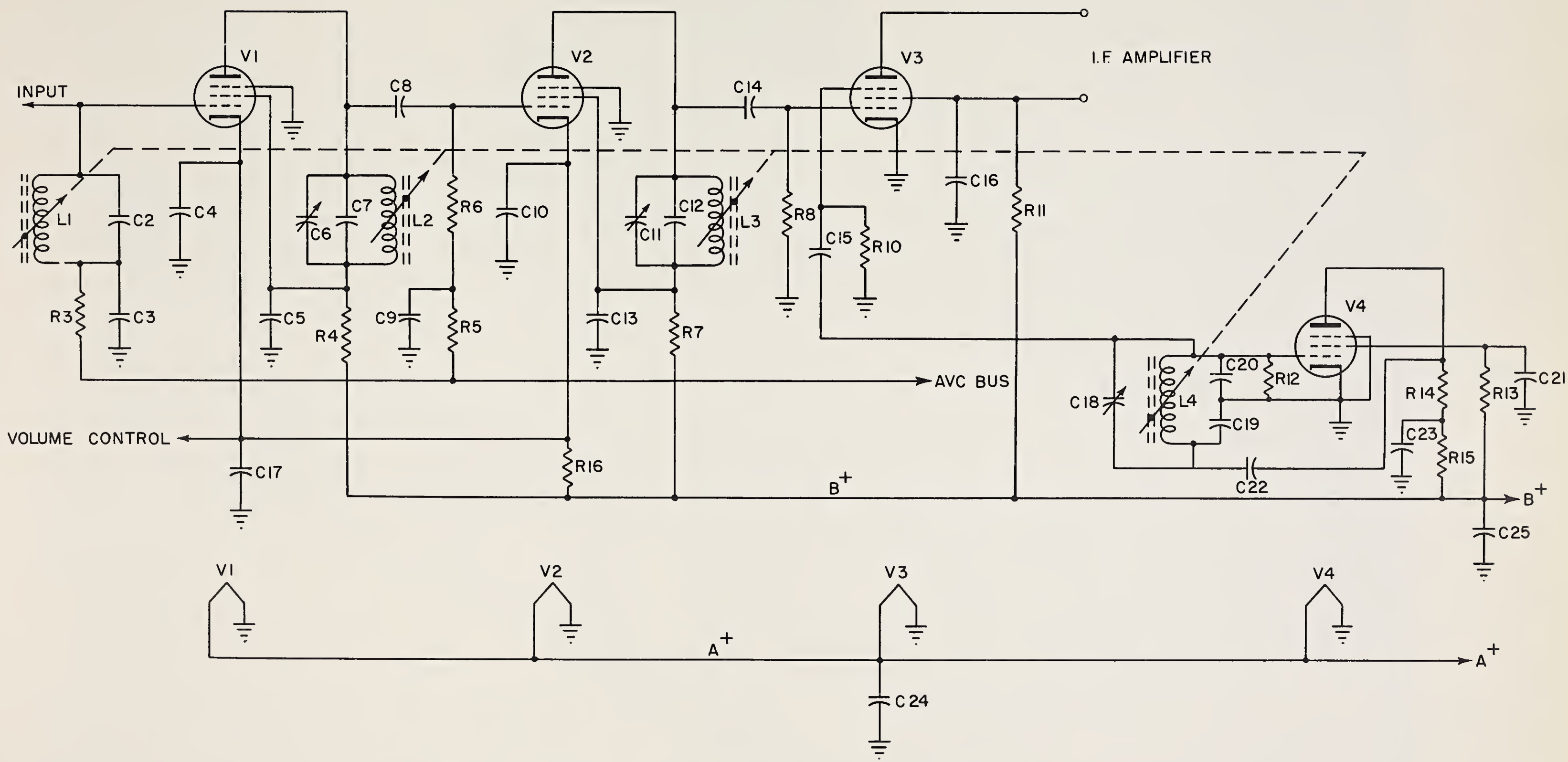


Figure 20. Radio frequency amplifier schematic diagram.

The oscillator-tuning slug could have been made identical with the r-f tuning slugs by using a smaller resonating capacity. This, however, would shorten the throw of the local oscillator slug and lead to mechanical difficulties. The intent was to use a slug made of ferrite A, the permeability of which is much lower than that of the B material used for the r-f tuning slugs. The manufacturer, however, was unable to deliver any of these slugs in time for use in the receiver. Hence, a substitute was developed. Thin slabs of ferrite material were cemented with vitreous enamel into slotted steatite rods, forming an assembly dimensionally identical with the r-f tuning slugs. By varying the cross-sectional area of these slabs, widely differing effective permeabilities were obtained. Although it was not done in this development, these ferrite slabs could conceivably be cut triangular so that an electrically tapered core could be obtained. This would increase the slug displacement required at the high end of the frequency spectrum when the tuning varies so rapidly with slug displacement that problems of backlash and other mechanical tolerances can be critical.

AVC voltage was applied to the grids of the two r-f amplifier tubes. The cathodes of both tubes were tied together and returned to ground through a rheostat that functioned as a gain control. A resistor was connected from B+ to the gain control so that cutoff bias could be developed for the r-f amplifier tubes. The local oscillator was capacitively coupled to the mixer oscillator injection grid. Figure 20 is a schematic diagram of the r-f amplifier of this receiver.

The r-f amplifier and oscillator stages used type 5797 hard-glass-envelop tubes. For application where the hard-glass envelop is not desirable, the type 5916 tube could be used instead. There was no suitable hard-glass envelop mixer type available; hence a soft-glass type, 5908, had to be used in the receiver.

14. RADIO-FREQUENCY TUNING ASSEMBLY

The tuning assembly of this receiver is a separate mechanical subassembly, the only electrical components being the r-f and oscillator inductors (fig. 21). This assembly mounts on the rear of the front panel (fig. 5) with the r-f wiring assembly, filter-inductor assembly, and filter-capacitor assemblies mounted on top (fig. 6).

Figure 22 illustrates the principle of the r-f tuning mechanism. Two nonlinear screws are used. One screw drives the three r-f tuning slugs and a second screw drives the oscillator tuning slug. The tuning knob is coupled directly to the oscillator tuning slug so that frequency control of the receiver is accomplished with a minimum of backlash. The r-f nonlinear screw is geared to the oscillator screw through a 1:1 gear train. The r-f follower housing contains 3 cam followers, 1 for each tuning slug. The oscillator follower housing has one cam follower. Each cam follower is pivoted so that it may displace a button to which is fastened the tuning slug. The opposite end of the cam follower rides against an adjustable contour cam made up of a row of setscrews with a metal strip bridging the gaps between the setscrews. In this manner, cams are set up with a controllable contour that may be varied by the cam adjustment screws. Coil springs placed behind the buttons spring load the cam followers against the cam surface. As the follower housings are driven by the nonlinear screws, the cam followers are raised or depressed by the contour of the cam surface, thereby advancing or retarding the displacement of the tuning slugs. Therefore, the tuning curve set up by the nonlinear screws may be modified slightly for each individual slug. This means that the quality-control limits for the tuning slugs, the r-f coils, and their resonating capacitors, may be quite wide. Good tracking on all points of the dial is obtainable if a multiplicity of alignment points is used.

A slight modification of this tuning mechanism would permit temperature compensation of the permeability-tuned inductors. There was not enough time during this development to incorporate this modification into the receiver. However, the basic ideas are presented here so that they may be applied by others in the future.

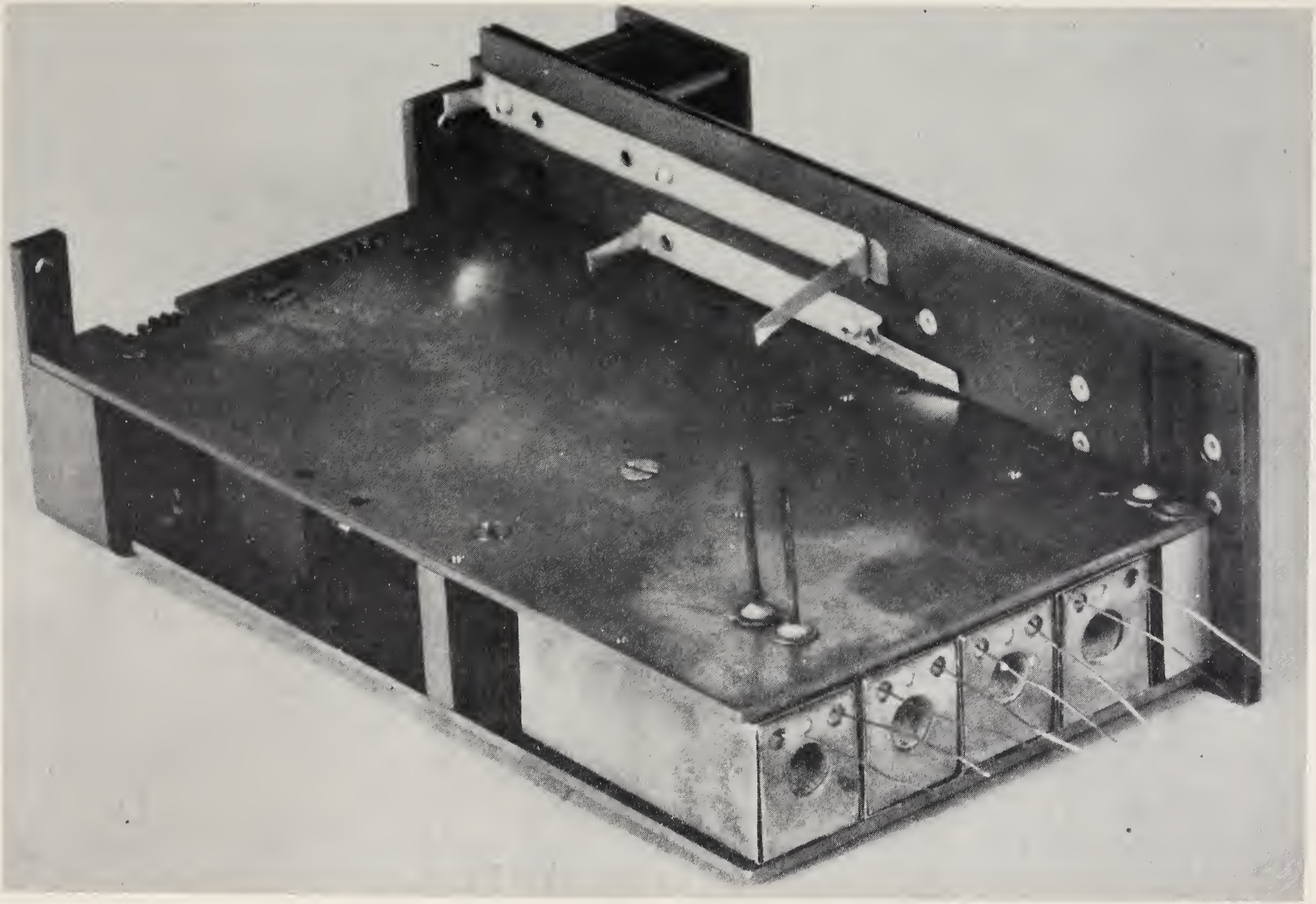


Figure 21. Tuning assembly.

284541 O - 54 - 5

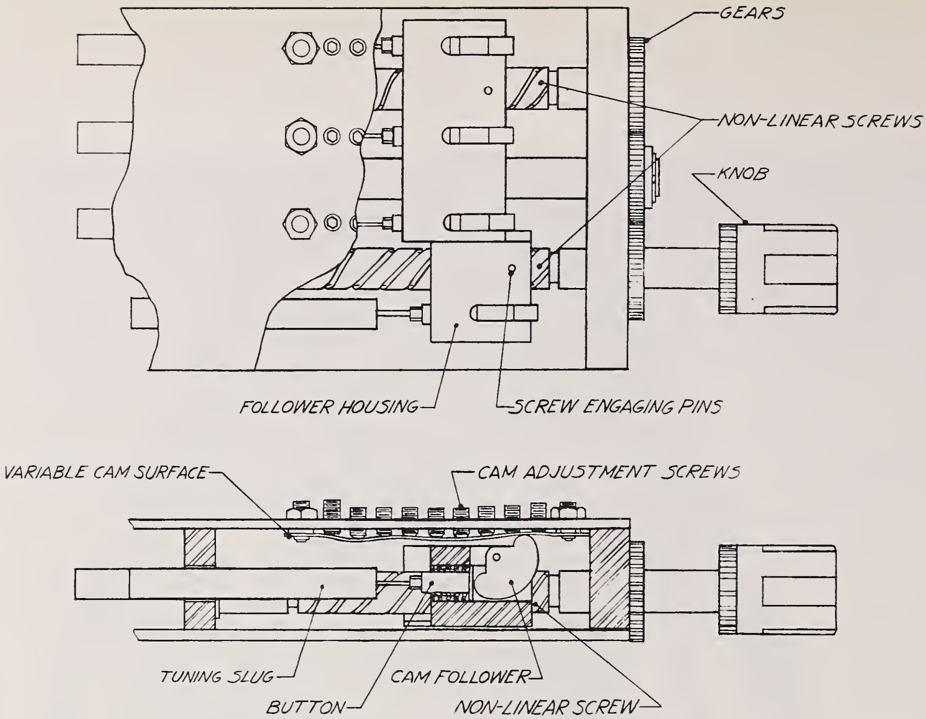


Figure 22. Tuning mechanism.

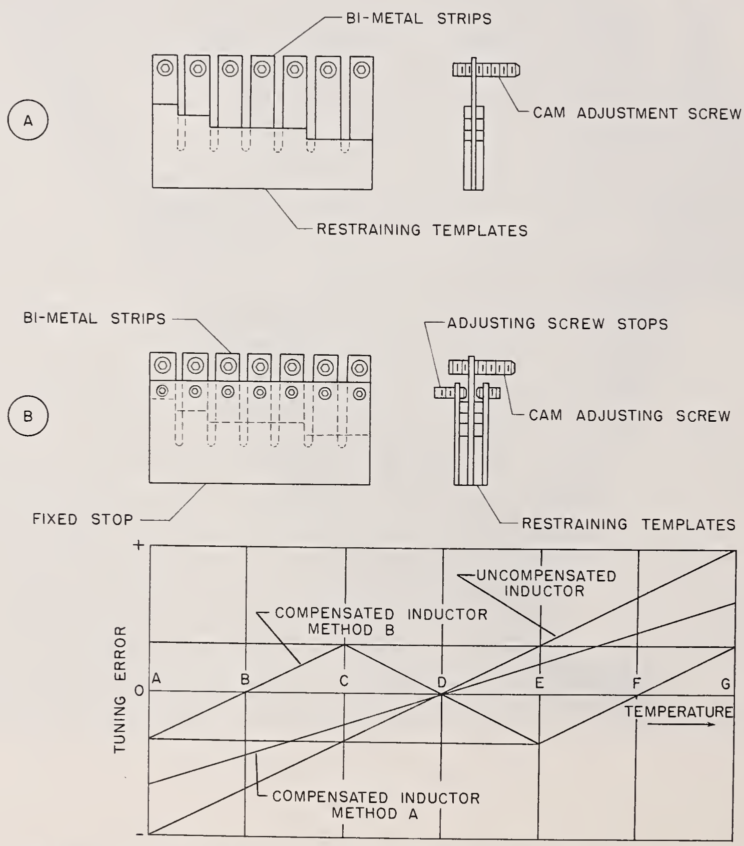


Figure 23. Temperature compensating elements.

It is usually very difficult to temperature compensate permeability-tuned inductors, especially if much of the temperature effect can be attributed to the magnetic material of which the tuning slug is made. Under these conditions, different lengths of tuning slug penetrate into the inductor. This causes widely varying temperature coefficients over the frequency spectrum. To temperature compensate a permeability-tuned inductor, it is necessary to provide different amounts of correction for different positions of the tuning slug. If each row of cam-adjustment screws is mounted on bimetallic fingers (fig. 23, A), this result may be achieved. The fingers are made by slotting a bimetallic plate. Contoured restraining templates are rigidly fastened to each side of the fingers, thus producing bimetallic fingers of different effective lengths with different degrees of freedom to warp. The cam-adjustment screws are mounted in the ends of the bimetallic fingers. The longer the nonrestrained length of a finger, the greater the distance an adjustment screw is deflected by a change of temperature. Assuming that the inductor temperature-coefficient curve is positive (which is the case for some ferrites), and given an initial setting of a tuning slug, the inductor will mistune as illustrated in figure 23. To simplify the example, a constant temperature-coefficient has been assumed. If the cam-adjustment screw is mounted in a bimetallic finger instead of a solid metal plate, the condition represented by the curve for method A in figure 23 could conceivably be assumed. This obviously represents only one of many possibilities. Therefore, a condition exists wherein the maximum mistuning error may be considerably less than in the original case. If stops for the bimetallic finger are provided (fig. 23, B), the correction caused by the fingers may be inactivated at predetermined temperatures, so that the nominal positive temperature curve of the inductor and tuning slug may take over. This can produce three zero-error mistuning crossover points, (method B, fig. 23). Here the maximum mistuning error is reduced still further.

Opportunities for the application of the principle are legion. For example, instead of fixed stops, a number of different stops could be employed to continuously modify the displacement of a cam-adjustment screw as the bimetallic finger warps.

A novel superheterodyne tracking scheme using only one nonlinear screw and identical inductors, resonating capacitors, and slugs for the oscillator and r-f amplifiers was advanced too late in the development to permit its use. It is based on the existence of a linear relationship between the angular displacement of the screw and the resonant frequency of the permeability-tuned inductor. The r-f inductor slugs are driven by one rider on the screw and the oscillator inductor slug is driven by a second rider on the screw angularly displaced from the first rider by a fixed amount. Under these conditions the oscillator inductor must always track a fixed frequency away from the r-f inductors. One limitation to the application of this scheme is that the permeability-tuned inductors must be able to tune from the lowest r-f frequency to the highest oscillator frequency. With the type of inductor structure and the ferrite slugs used in this receiver, such a frequency coverage could have been attained. A second limitation is introduced by the short displacement of the oscillator slug and the attendant mechanical problem of close tolerances it presents.

15. RADIO-FREQUENCY AMPLIFIER ASSEMBLY

The r-f section of the receiver is made up of two assemblies, one of which is essentially electrical; the other is the mechanical assembly previously described. The r-f electrical assembly (fig. 24) mounts on top of the mechanical assembly and is built around a brass chassis plate on which the tubes are mounted. Four channels, milled into the chassis plate just below the tubes, contain the bypass capacitors for the r-f assembly. The tube heaters derive their power from a sheet-metal bus-bar system fastened to the chassis plate. The circuitry is contained on two printed steatite plates mounted on the ends of the r-f chassis (fig. 25). To compensate for the different temperature-expansion coefficients of metal and steatite, mounting holes in the steatite

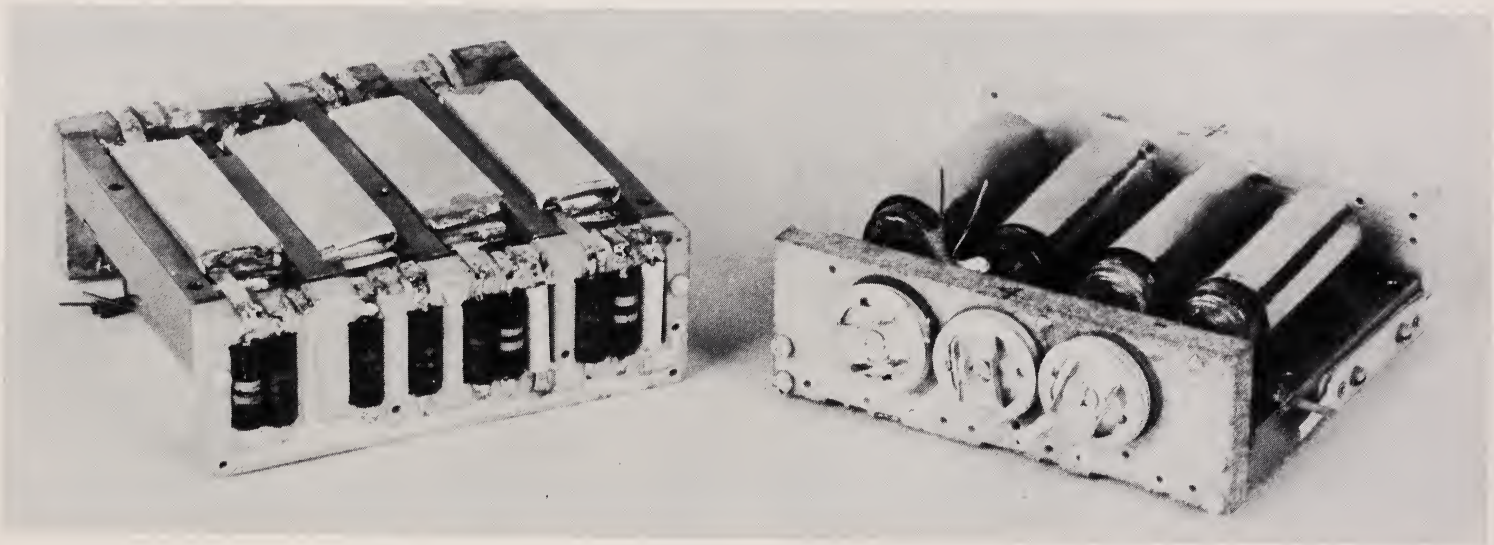
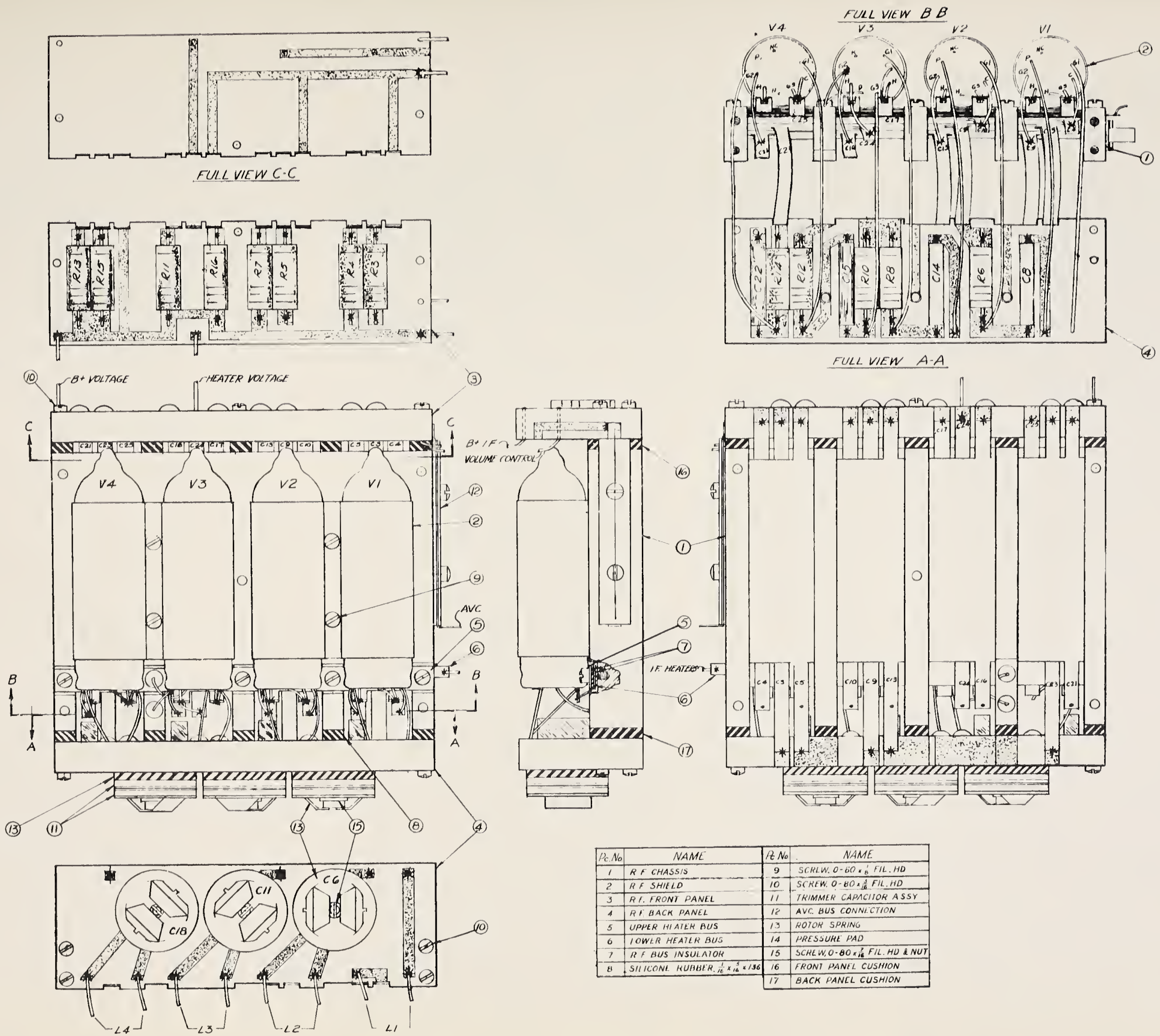


Figure 24. Radio frequency amplifier assembly.



Pc. No	NAME	Pc. No	NAME
1	R F CHASSIS	9	SCREW, 0-60 x 1/8 FIL. HD
2	R F SHIELD	10	SCREW, 0-80 x 3/16 FIL. HD
3	R.F. FRONT PANEL	11	TRIMMER CAPACITOR ASSY
4	R.F. BACK PANEL	12	AVC. BUS CONNECTION
5	UPPER HEATER BUS	13	ROTOR SPRING
6	LOWER HEATER BUS	14	PRESSURE PAD
7	R F BUS INSULATOR	15	SCREW, 0-80 x 7/16 FIL. HD & NUT
8	SILICONE RUBBER, 1/16 x 5/16 x 136	16	FRONT PANEL CUSHION
		17	BACK PANEL CUSHION

Figure 25. Radio frequency amplifier pictorial.

plates are oversized to permit the plates to shift their position slightly as the operating temperature changes. Silicone-rubber pads are used to cushion the steatite plates where they are secured to the r-f metal chassis.

It was intended that this design should not be rendered obsolete by the advent of new resistor types. On the assumption that new resistor types would not be larger than conventional 1/4-w resistors, space was provided to accommodate these conventional resistors. The resistors are mounted in depressions on the steatite plates; lines are silvered up to the edge of the depressions and the resistors are soldered into place. The printed circuits for the r-f unit are so laid out that they may use either conventional or printed resistors. The only modification necessary for the use of printed resistors is the elimination of the depressions in which the conventional resistors rest. Although the original design used steatite as the base material for these printed circuits, this does not imply that ceramic alone may be used. Since this project was concluded, new high-temperature base materials for printed circuits have become available, and these could be substituted for steatite. Reference is made to some of the recently available sheets of Teflon-and silicone-impregnated fiber glass bonded to copper foil. Etched circuits of these base materials may be layer-assembled to yield the same function that the steatite printed circuits provide.

The grid and plate decoupling resistors are mounted on the front printed-circuit plate. A B+ bus, an AVC bus, and a volume-control bus are silvered on this plate. All the circuits on this plate are at r-f ground potential, so that all the connections to this plate could be made by means of the bypass-capacitor high-potential terminals. The lower edge of this plate contains silvered depressions for soldering each capacitor lead into place, making it impossible to connect a capacitor to the wrong slot.

The rear printed circuit is somewhat different from the one just described. It contains the interstage coupling capacitors, grid resistors, trimmer capacitors, and the terminations for the r-f and oscillator inductors. The three trimmer capacitors are for the oscillator, mixer, and second r-f amplifier inductors. The trimmer for the first r-f amplifier inductor is mounted on the receiver case and is externally adjustable. The trimmer capacitors on the r-f assembly have been designed specifically for application to printed circuits and occupy a minimum area on both sides of the printed base plate. The high-K ceramic dielectric disks are mounted on silicone-rubber cushions. The capacitors are held under compression by metal spring washers which also furnish the means for tuning the capacitors with a screwdriver. By using springs of this type, the minimum possible space is occupied by the capacitors on the rear of the printed-circuit plate. This special screwdriver-slot, spring-washer member is part of a commercially discontinued capacitor. The company still has the dies, and has expressed a willingness to furnish this special part.

The procedure for assembling the r-f amplifier circuit is straightforward. If the assembly schedule recommended is adhered to, there will be no necessity for excessive finger dexterity on the part of the assembly personnel.

The heater buses are mounted on the milled chassis plate first, and the tube shields and tubes are mounted next. All the tube leads, except the grid and plate leads, are connected to their appropriate bypass capacitors, grounding points or heater buses. The printed circuits are mounted next. It should be noted that the printed circuits have notches along one edge for placement of the high-potential tabs of the bypass capacitors prior to soldering(fig. 25). These tabs are staggered so that it is impossible to wire them incorrectly into the steatite plates. No wires are used to connect the front steatite plate to the rest of the r-f assembly circuit, all of the connections being made throught the r-f bypass capacitor tabs. Some connections to the rear steatite plate are made through bypass capacitor tabs, the remaining connections being furnished by the grid and plate leads of the vacuum tubes. The tubes have been oriented so that the plate and grid leads appear at the top of the steatite plate where they are readily accessible. The connection points for the grids and the plates have been so placed that the tube leads are as short and straight as possible. Incorrect connection of these leads becomes difficult because any

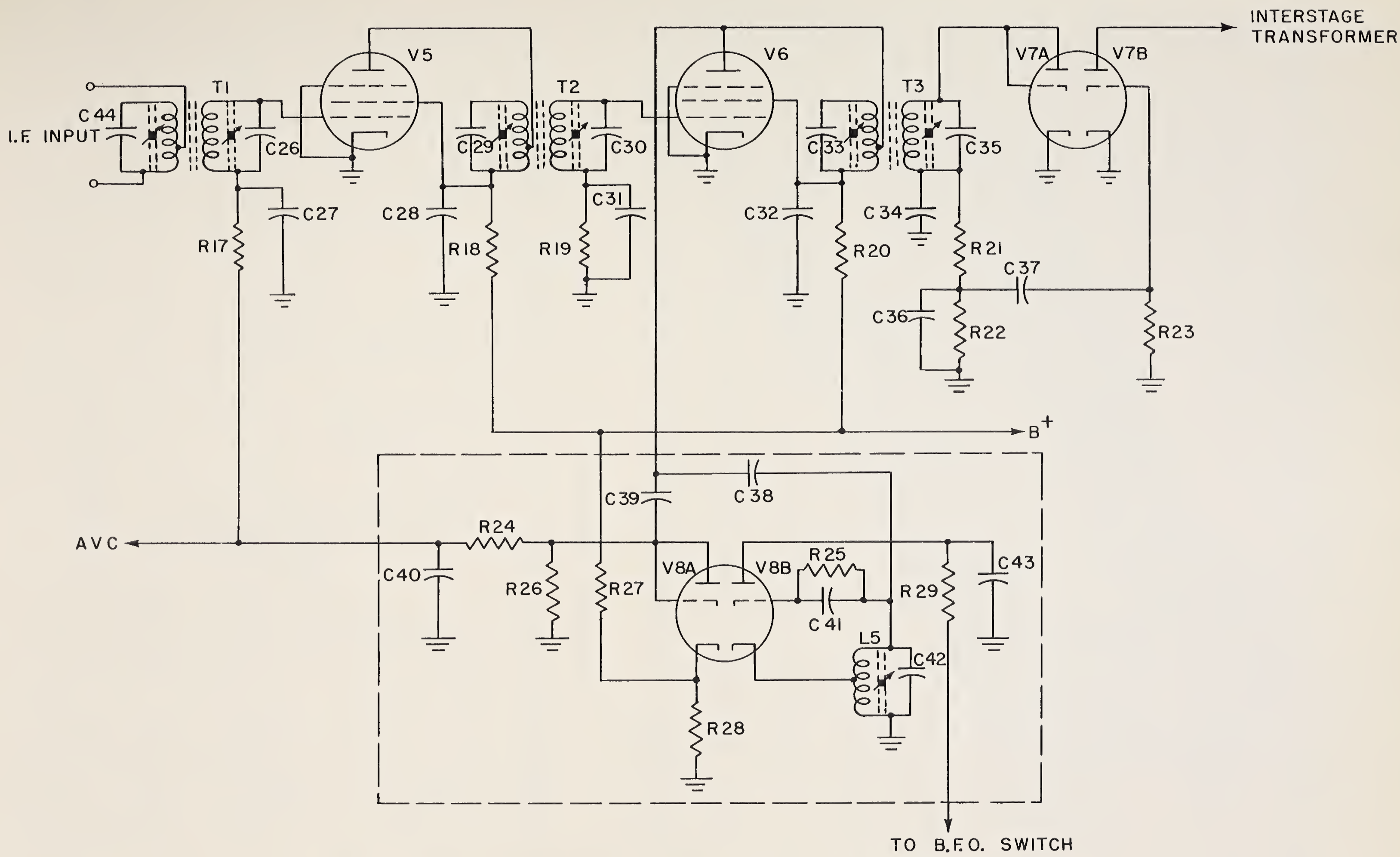


Figure 26. Intermediate frequency amplifier schematic.

wiring errors will show up as crossed leads. The three trimmer capacitors mounted on the rear steatite printed circuit could have been eliminated in the design and the trimming accomplished entirely with the tuning mechanism. However, it was recognized that it might be desirable to simplify the mechanical aspects of this equipment in production by eliminating the set screws. In this case trimmer capacitors would be required for aligning the receiver. The trimmer capacitors can therefore be regarded as an extra precaution against obsolescence if this design change appears warranted.

The entire electrical assembly can be pre-assembled and then bolted to the mechanical assembly as a unit.

16. INTERMEDIATE-FREQUENCY AMPLIFIER CIRCUIT

The i-f amplifier frequency was established at 135 kc. The assembly referred to as the i-f amplifier consists of two amplifier stages, a diode detector, a delayed AVC diode, a beat-frequency oscillator and an audio amplifier(fig. 26). Type 5797 hard-glass envelope pentodes were used as the i-f amplifiers. For applications where a soft-glass envelope is acceptable, the type 5916 tube may be used. When this development was started, no subminiature double diodes with 26-v heaters were available. The two diode functions required were obtained by diode-connecting one triode section in each of two subminiature double triodes, type 5798. These tubes have hard-glass envelopes. One of the 5798 tubes functions as a diode detector and audio amplifier; the other functions as a delayed AVC diode and beat-frequency oscillator. A suitable double-diode, type 5903, did not become available until it was too late for it to be incorporated into this equipment.

The i-f amplifier stages use grid-leak bias. Delayed AVC voltage is applied to the first i-f amplifier grid as well as to the r-f amplifiers.

The beat-frequency oscillator is a conventional triode oscillator. The beat-frequency signal is applied to the primary of the last i-f transformer.

It was found that the low plate impedance of the tubes deteriorated the Q's of the i-f transformer primaries excessively. To minimize this effect the primaries were tapped.

17. INTERMEDIATE-FREQUENCY AMPLIFIER-GENERAL LAYOUT

Figure 27 illustrates the i-f amplifier plug-in assembly. The chassis is fabricated from 1/32-in. sheet metal. The shielded enclosure to the right contains a separate subassembly, the beat-frequency oscillator and the delayed AVC circuits. This subassembly is connected to the rest of the i-f amplifier through openings in the bottom and side of the shield can. The component layout on top of this assembly is, from left to right, input i-f transformer, first i-f amplifier tube, second i-f transformer, second i-f amplifier tube, output i-f transformer, diode detector and audio amplifier (double triode with one section diode-connected). The basic layout for the i-f amplifier is illustrated in figure 28. The tubes are mounted in sheet-metal clips with the capacitor sections below the tubes. A printed-circuit assembly mounts underneath the chassis. This assembly uses conventional resistors and printed wiring. Because these circuits are printed on a steatite base plate, precautions were taken to prevent fracture of the steatite by placing a silicone-rubber cushion between it and the chassis to which it is fastened. Teflon or silicone-impregnated fiber glass laminated to copper foil could be etched into printed circuits to replace the steatite. The bypass capacitors and coupling capacitors are of the glass-dielectric variety previously described. They are located under the tube mounts of the individual stages. The printed circuit is slotted to accommodate the connecting tabs from these capacitors. These capacitor tabs thereby interconnect the components on top of the chassis to the printed circuit below the chassis (fig. 29). Perforations are provided in the chassis so that the capacitor tabs and vacuum-tube-heater leads may be connected to the printed circuit without shorting to the chassis.

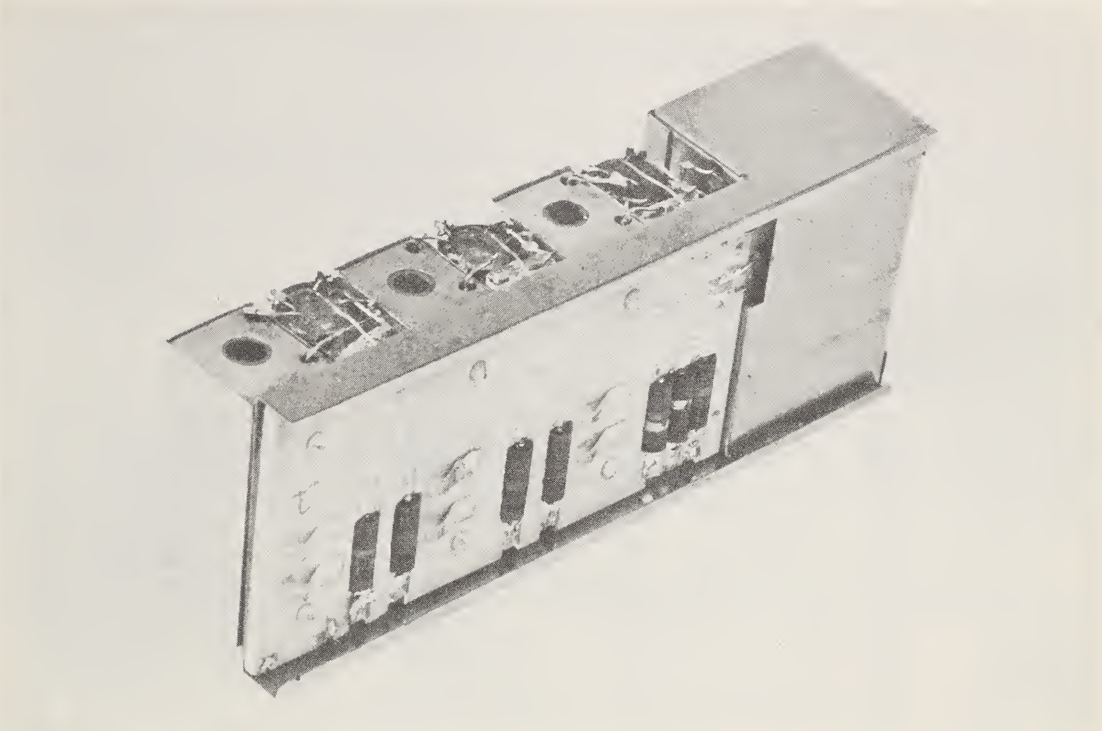


Figure 27. Intermediate frequency amplifier, bottom view.

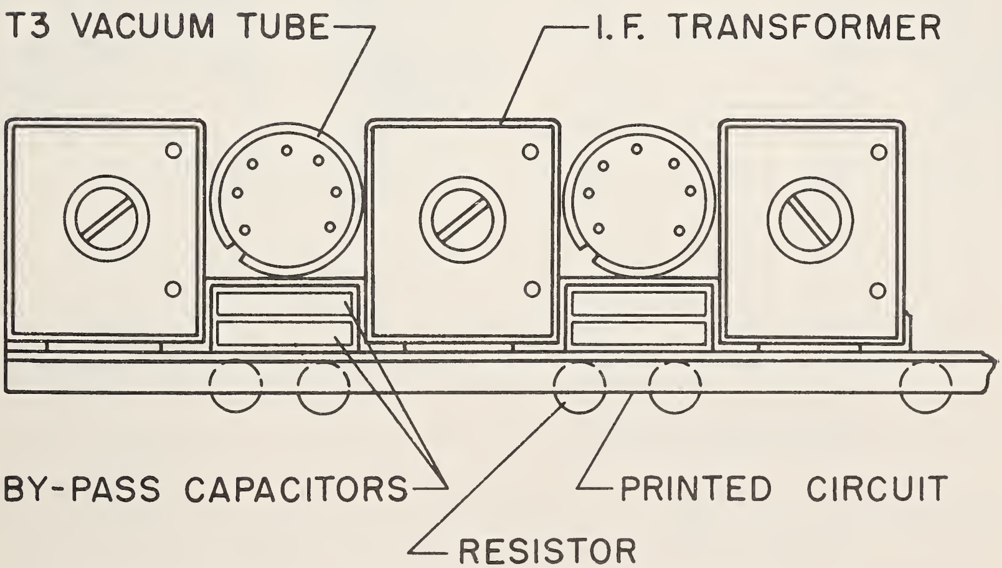
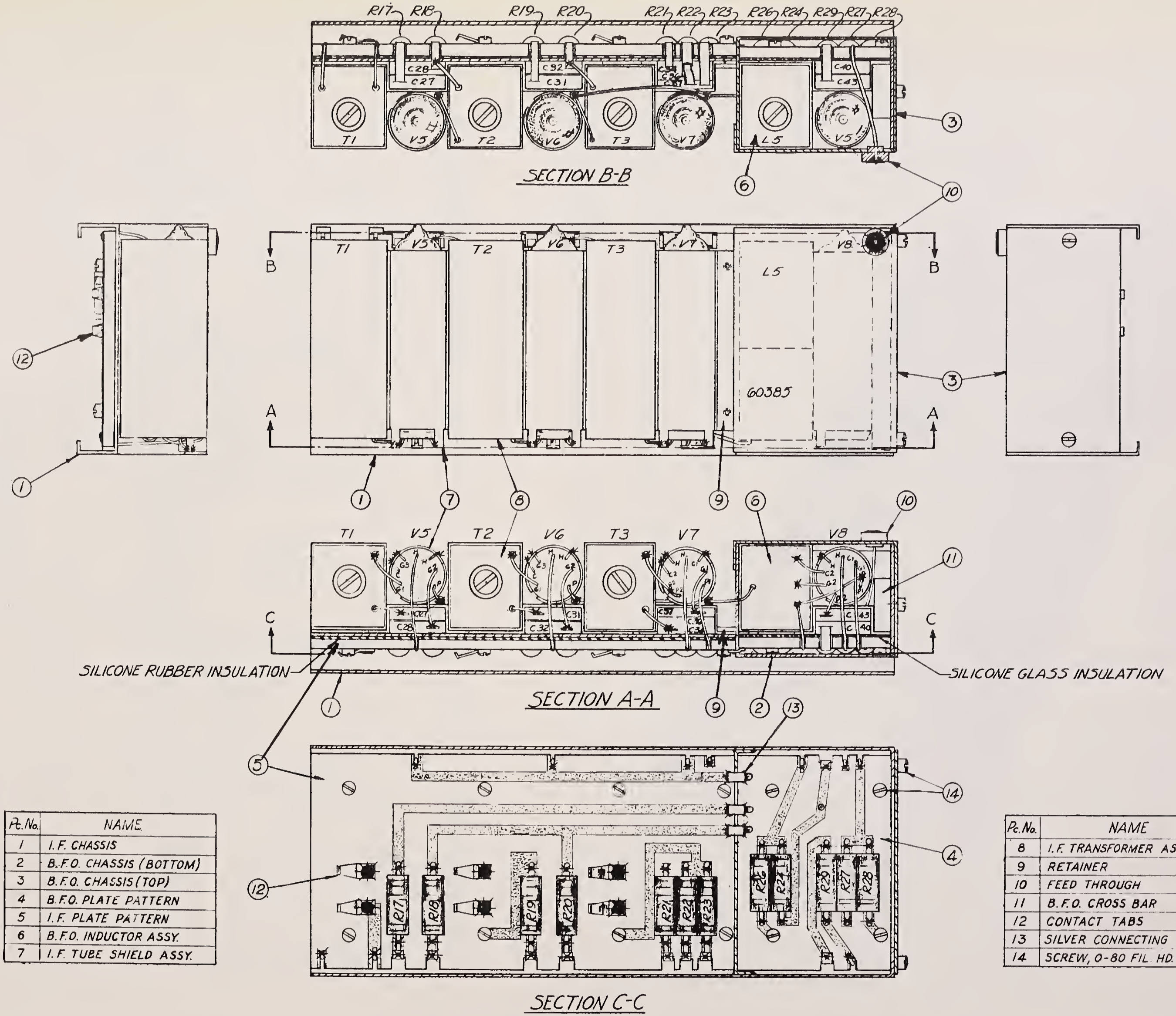


Figure 28. Intermediate frequency amplifier assembly configuration.



Pc.No.	NAME
1	I.F. CHASSIS
2	B.F.O. CHASSIS (BOTTOM)
3	B.F.O. CHASSIS (TOP)
4	B.F.O. PLATE PATTERN
5	I.F. PLATE PATTERN
6	B.F.O. INDUCTOR ASSY.
7	I.F. TUBE SHIELD ASSY.

Pc.No.	NAME
8	I.F. TRANSFORMER ASSY.
9	RETAINER
10	FEED THROUGH
11	B.F.O. CROSS BAR
12	CONTACT TABS
13	SILVER CONNECTING TABS
14	SCREW, 0-80 FIL. HD.

Figure 29. Intermediate frequency amplifier wiring assembly.

Six metal-spring contacts are fastened to the steatite printed circuit for the purpose of contacting the silvered steatite buttons recessed in the tuning assembly wall. Connections between the i-f amplifier and the rest of the receiver are made to the middle of these buttons. As this assembly is a completely independent unit, it may be removed from the receiver for repair or replacement. When the i-f amplifier is mounted in the receiver, the i-f transformer and the beat-frequency-oscillator tuning adjustments are readily accessible.

The beat-frequency oscillator tuned circuit resembles one-half of an i-f transformer. The resistors and capacitors for the beat-frequency oscillator are housed in a steatite block which is placed, together with the beat-frequency-oscillator tuned circuit, in a shield resembling an i-f transformer shield can. The entire subassembly is assembled externally and then slipped into place in the shielded enclosure. The B+ feed for the beat-frequency oscillator is applied through a spring on an adjacent bracket to a silvered steatite button at the top of the i-f assembly shielded compartment.

The sheet-metal lips on the bottom of the i-f-assembly chassis engage two slots in the tuning-assembly wall when the i-f assembly is plugged into the receiver.

It can be seen from an examination of the pictorial wiring diagram (fig. 29) that all interconnections and wire runs have been kept as short as possible, and great pains have been taken to minimize the possibility of wiring errors during the assembly of this device.

Because this assembly is a completely self-contained functional device, it can be manufactured as a separate item and plugged into this or other pieces of equipment.

18. INTERMEDIATE-FREQUENCY TRANSFORMERS

The optimum i-f frequency was established as 135 kc. To achieve a 2.8- to 1.9-kc bandwidth 6 db down and a maximum of 11.4 kc 60 db down, it was calculated that six tuned circuits (three double-tuned i-f transformers almost critically coupled) having inductor Q's of about 60 would be required. To ensure circuit stability and a reasonable transformer size, the resonating capacitors were set at 500 $\mu\mu$f. Because trimmers are space consuming, the inductors were designed for permeability tuning with 10-32 ferrite screws.

The i-f transformers for this receiver were designed with certain definite objectives in view. These objectives were:

1. A transformer with a very high space-utilization factor.
2. A transformer with no basic limitation that would prevent its use up to ambients of 200° C.
3. A transformer that made use of the newer magnetic materials having superior characteristics.
4. A transformer with high Q and high resonant-impedance windings.
5. A transformer of such size that it would provide a fitting mate for T-3 subminiature tubes.
6. A transformer that could be readily manufactured using mass production methods.
7. A transformer structure with such flexibility that it could serve as a prototype at various frequencies and bandwidths.

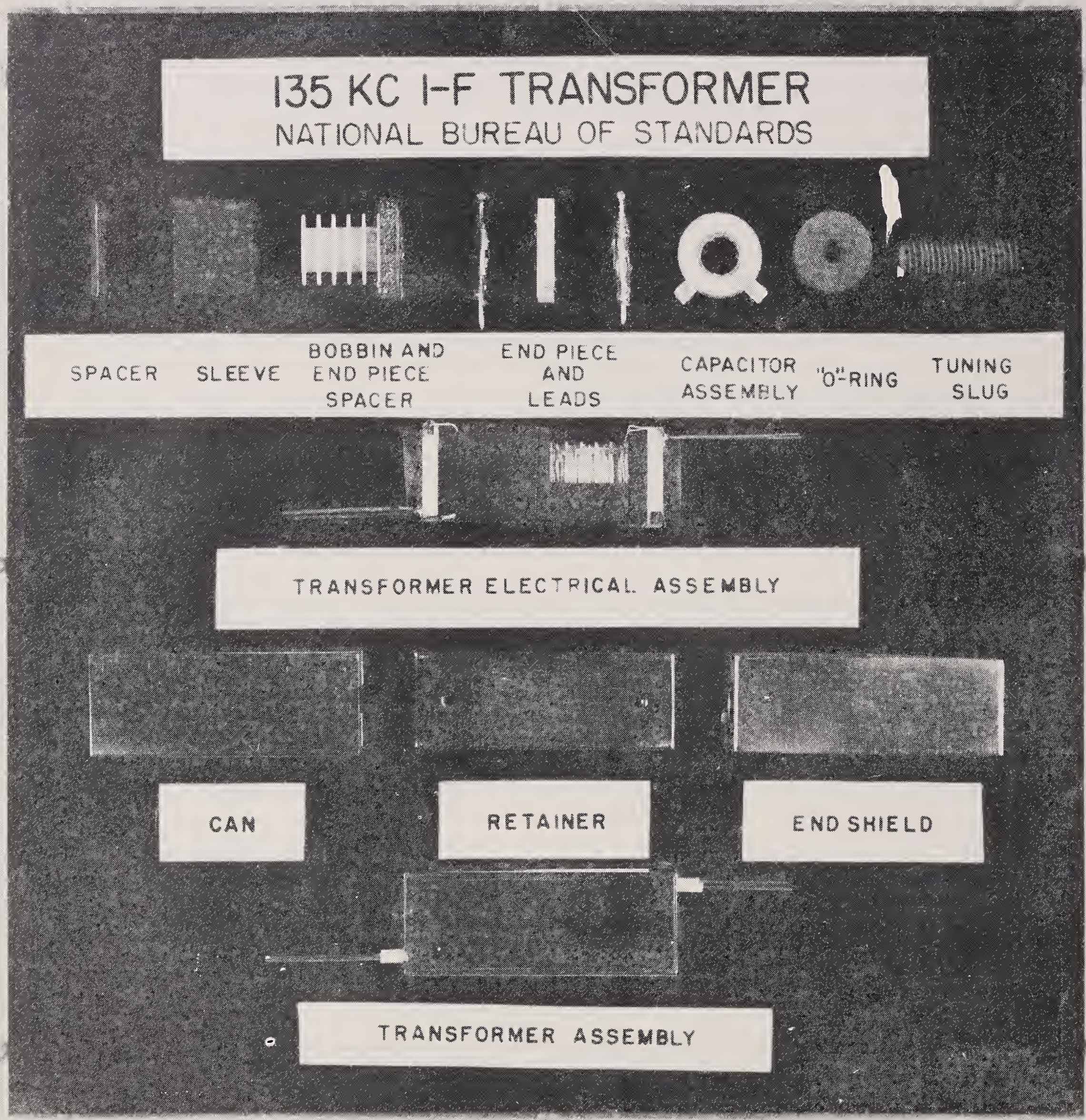


Figure 30. Intermediate frequency transformer parts.

It was recognized that a transformer with the cross-sectional dimensions of a T-3 bulb would fall short of objective 4, especially at the 135-kc i-f frequency. In order that a transformer cross section larger than a T-3 tube could be fitted into the layout with maximum space economy, the entire subminiaturized i-f amplifier assembly configuration was considered in arriving at the most desirable size and shape factor for the transformers. The i-f assembly configuration illustrated in figure 28 provides a satisfactory solution. All bypass and coupling capacitors are mounted under the tubes and the i-f transformers between the tubes. The space required to house the capacitors raises the tubes to a level that permits the i-f transformer height to be about 5/8 in. The high-permeability shields, established at 1/2 in. sq. left sufficient room for the transformer mounting means employed in the sample case design illustrated in figure 30. The case length was the maximum that could be conveniently employed without couplicating the manufacture of the i-f amplifier assembly. The outside case dimensions of the transformers were set at 0.520 by 0.582 by 1.375 in.

The considerations that led to the adoption of a highly permeable shield with a square outside shape rather than a round outside shape have been treated previously in this report. The considerations that led to the adoption of magnetic ferrite bodies rather than powdered iron have also been discussed.

It was decided that each inductor should be enclosed in two adjacent magnetic structures and that the coupling between the inductors should be controlled by the thickness of the magnetic material separating them. Obviously, for transformers requiring a low coefficient of coupling, this procedure yields a shorter structure than if air alone separates the inductors. The conventional cup-core was not used for three reasons:

1. From a production standpoint it was desirable to use a shield structure with a cross section similar to that of the r-f inductors.

2. Since the degree of quality control possible in the manufacture of ferrite is an unknown factor, a simple means is required by the inductor manufacturer for easily increasing or decreasing the coefficient of coupling in fine increments. This feature is also a great help when working toward the initial design in the laboratory.

3. The shape and size of the transformer structure should be capable of application as a standard for transformers with wide variations of coupling coefficients and center frequencies.

A rough calculation of inductor dimensions and required number of turns was made, taking into account the effective permeability of the core. The first few inductors, wound with ceramic wire, indicated that it was possible to obtain enough inductance to resonate it with 500 μμf at 135 kc if fairly small wire (No. 36) was used. These inductors, slightly over 1/2 in. long, were layer-wound; however, the Q of these inductors was too low to allow their use.

Attempts were made to lower the distributed capacity of the inductors as it seemed to be the cause of the low Q. It was found that the ceramic wire could not be universal-wound without cracking the insulation and that Teflon was too slippery. The next type of inductor tested was one built up in pies. This was made on an asbestos-paper inductor form with asbestos-paper washers separating the pies. These inductors had slightly less inductance, but they showed a large improvement in Q over the previous ones. The paper, however, was not strong enough to support the winding.

Various methods were tried to make supported and self-supporting inductors. In one method the pies were wound on a break-apart Teflon-coated jig, impregnated with silicone resin, and baked into self-supporting series-connected pies. Because the silicone would not stick to the Teflon, the jig, when disassembled, could be separated from the pies. The pies were then slipped over a piece of asbestos tubing and closely spaced. Although it was satisfactory for a laboratory technique, this method was not suitable for mass production and was

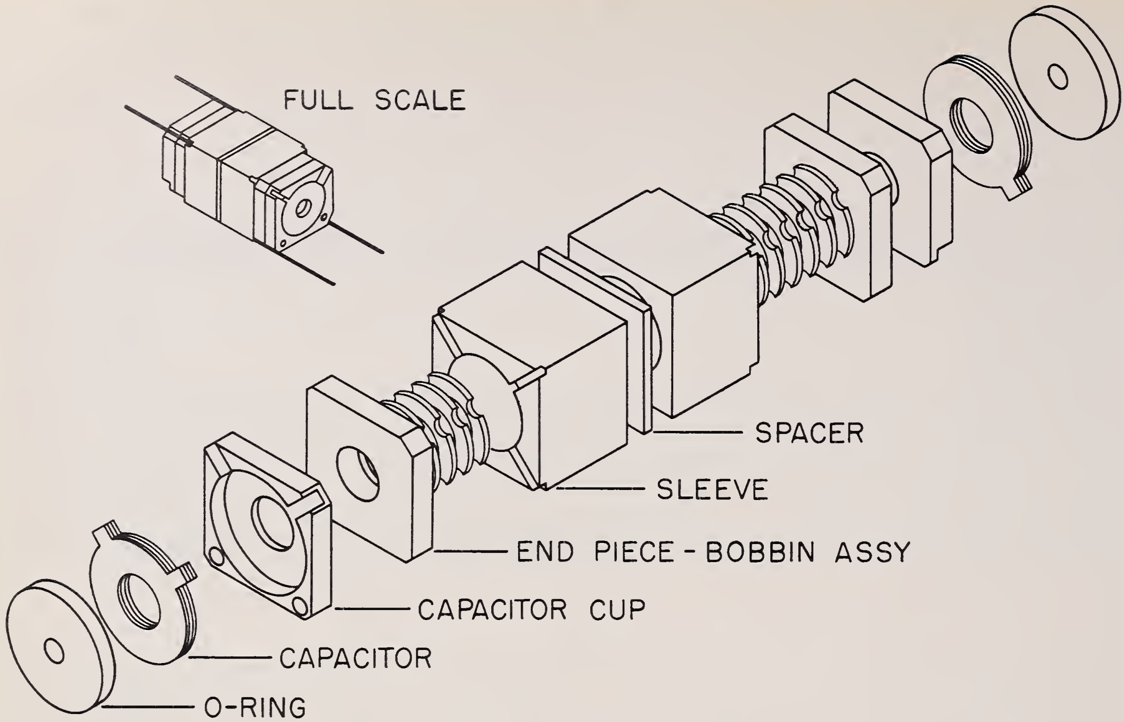


Figure 31. Intermediate frequency transformer assembly.

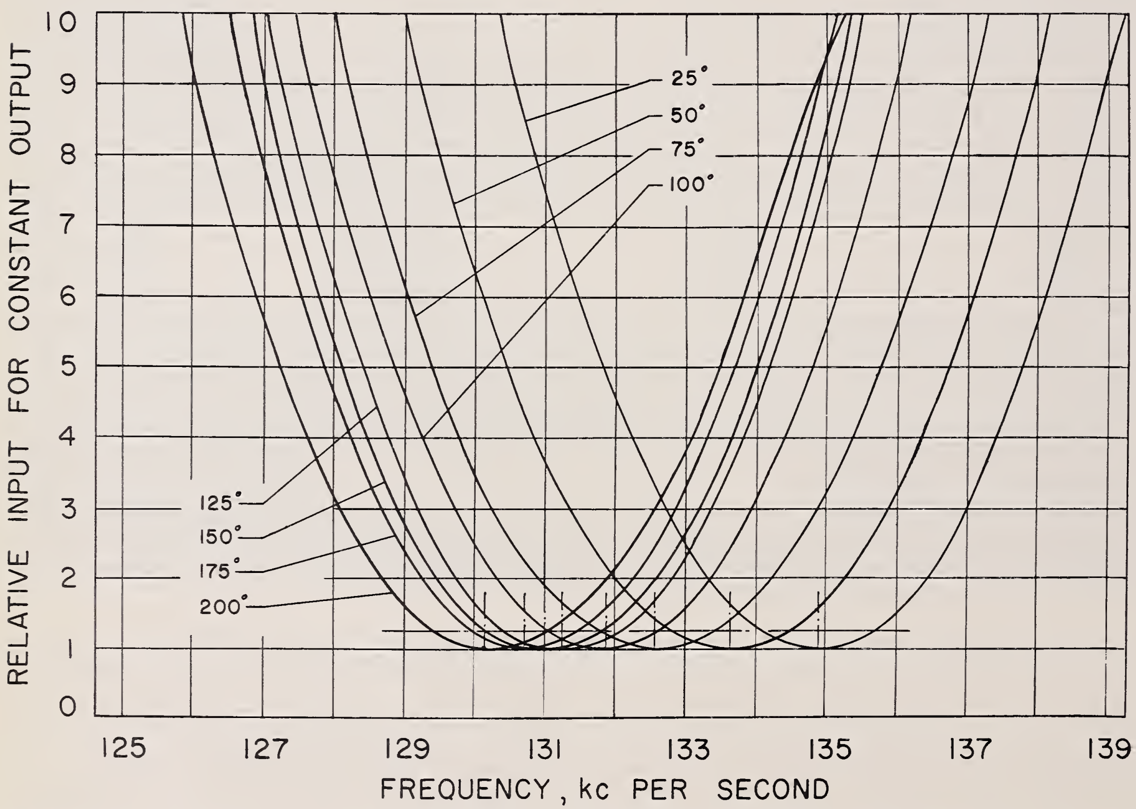


Figure 32. Intermediate frequency transformer bandpass characteristics.

therefore abandoned. A steatite bobbin was finally found to be satisfactory. This bobbin provided for a 10-32 slug and supported the five 1/16-in.-wide pies of the inductors. These bobbins were permanently attached to the ferrite end piece with vitreous enamel. The end piece was made to accommodate the leads coming from the inductors and capacitors. These washer-shaped mica capacitors were mounted on the end piece in such a manner as to make electrical connection to the inductor and still permit screwdriver adjustment of the tuning slug. It was found that a ceramic-Teflon-insulated litz-type wire would give a better Q than solid wire, so the same type of high-temperature Teflon-insulated wire used in the r-f section was selected for the i-f coils. It was found that three strands of No. 42 ceramic-Teflon-insulated litz wire gave the best results. The inductor consisted of 5 pies, each containing 60 turns, making a total of 300 turns per inductor. The wound coil was inserted in a magnetic sleeve and a spacer placed between the primary and secondary inductors. This spacer acted as a magnetic shunt to control the coupling between the two inductors. The i-f transformer design is such that the maximum possible space is provided for the windings, almost double that provided by the common powdered-iron cup cores.

Figure 31 illustrates the first version of the i-f transformer assembly.

The sleeve shields of the individual inductors were ferrite extrusions 1/2 in. square and 13/32 in. long with a 3/8-in. hole in the center. The r-f magnetic sleeves had an identical cross section. The ferrite spacer between inductors was 1/2 in. square and about 3/64 in. thick. The 1/2 in. square ferrite pieces that closed off the other ends of the inductors were recessed to house washer-shaped resonating capacitors. Holes in the centers of these end pieces permitted 10-32 ferrite tuning screws to be inserted into the inductors. A pattern of conducting silver paint was fired on these end pieces so that the external transformer leads could be solder-anchored and connected to their respective inductor and resonating capacitor. The function of the silicone-rubber O rings was to maintain the entire assembly under longitudinal compression, secure the washer capacitors in their recessed end pieces, and function as elastic stop nuts for the tuning screws.

In the course of the development, it was found that at 200° C the d-c resistance between the fired silvered lines on the recessed ferrite end pieces had dropped to 0.05 percent of the room-temperature value. The 200° C resistance of 100,000 ohms was sufficiently low to materially reduce the Q's of the inductors at that temperature. A design change was immediately made to eliminate the use of ferrite as a printed-circuit base material (fig. 30). The resonating capacitors were housed in thin silvered steatite cups (end pieces), to which the inductor terminations were connected. The transformer leads were also anchored to these end pieces.

The original intent was to fabricate the resonating capacitors from thin ceramic having the proper temperature coefficient to compensate the i-f transformers. To expedite the development, however, mica-dielectric capacitors were used. It was intended that these would be changed to ceramic later when the optimum temperature coefficient had been determined. However, the mica capacitors were not replaced by ceramic capacitors in the models fabricated by NBS because poor deliveries of the ceramic sheet would have seriously retarded the delivery of the receiver models to the Navy Department. Because fabrication of either mica or ceramic capacitors would proceed in a similar fashion, the methods used to construct the mica capacitors will be described.

Sheets of 2-mil mica were painted with silver paint, fired, and punched into the shape illustrated in figure 30. Silver was removed from one side of each tab so that it could function as a means for connecting the capacitor wafers in parallel. In the beginning, these tabs were wrapped with No. 28 tinned copper wire and then soldered into the slots provided in the steatite capacitor cups. Later, it was found that better electrical connection between tabs could be achieved by inserting 2-mil silver strips between capacitor tabs, soldering each strip into the slots as the capacitor was assembled. This procedure, however, does not lend itself to production methods as it is too laborious. Conceivably, another procedure would be to load the capacitor disks on a mandrel alternately with semicircular sheet-silver interconnectors. Then

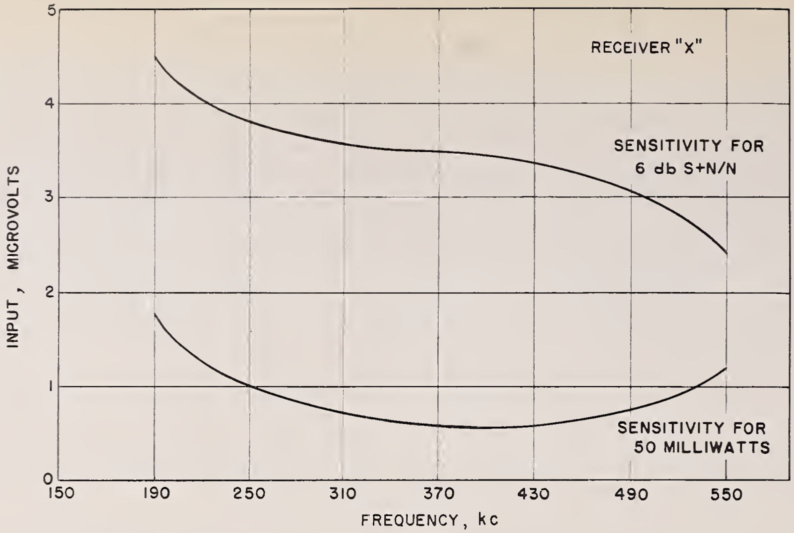


Figure 33. Sensitivity versus frequency.

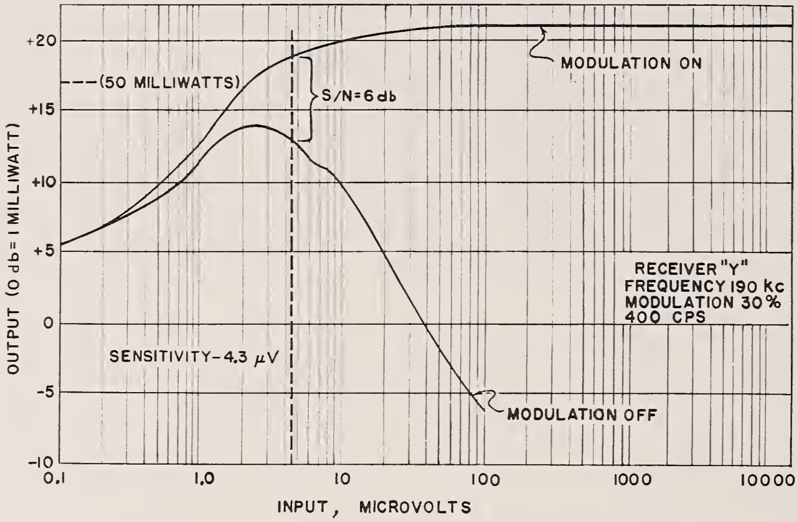


Figure 34. Receiver performance at 190 kc.

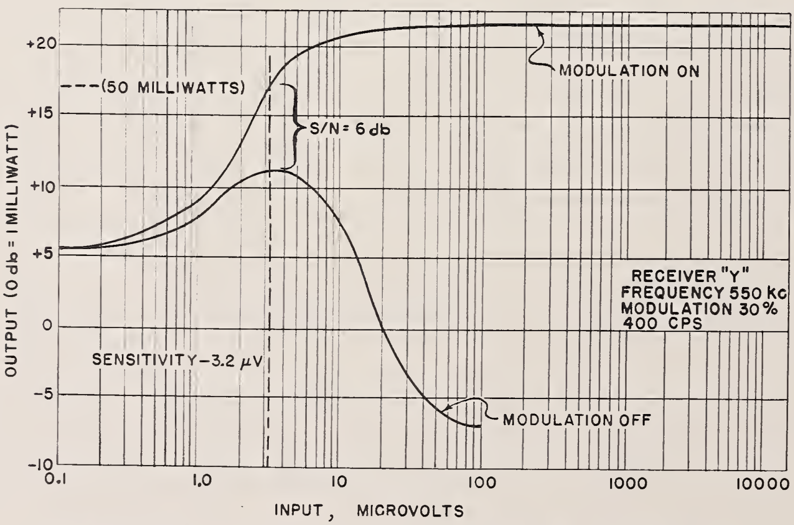


Figure 35. Receiver performance at 550 kc.

the entire assembly would be soldered into place. This procedure would be better from the standpoint of production. To prevent the capacitor from functioning as a shorted transformer turn, thereby reducing the inductor Q, gaps were scraped with a jig on each circular pattern to make them discontinuous. Much can be done to reduce further the production cost of these capacitors. For example, the capacitor wafers could be punched in the form of C rings without connecting tabs. Connections to the wafer could be made by placing between them thin metal C-ring punchings, each having one tab. This would eliminate any selective silvering operations. A stop, molded into the steatite end pieces, can serve to orient the C rings.

Figure 32 illustrates the i-f transformer band-pass characteristics from 25° C to 200° C. The ferrite material has a positive temperature coefficient; therefore, it was expected that the transformers would have the negative frequency drift indicated by the curves. The transformers should obviously be temperature compensated by negative temperature coefficient (about 300 ppm/° C) ceramic dielectric capacitors. It is interesting to note that the band-pass characteristics remain nearly constant.

The constantly recurring question as to the production cost of special subminiature electronic components has prompted the investigation of the anticipated cost for these subminiature i-f transformers. Based on figures obtained from commercial companies, the cost of the ceramic and ferrite parts of the i-f transformers would be $3.29 per transformer in lots of 500 transformers and $1.32 per transformer in lots of 5,000 transformers. A rough estimate based on laboratory experience indicates that the cost for the remainder of the transformer is roughly equal to the cost of the steatite and ferrite parts alone. These transformers should therefore cost $6.58 each in lost of 500 transformers and $2.64 each in lots of 5,000 transformers.

These approximate figures seem to indicate that the cost of special subminiature electronic components of this general type is not excessive for the function they perform.

19. RECEIVER PERFORMANCE

Upon completion of the development, electrical tests were conducted on the models to determine their performance.

The selectivity had to be such that signals 5.7 kc off resonance would be subjected to 60 db of rejection. This was exceeded by a large margin. A typical value was 80 db rejection for signals 5.08 kc off resonance.

A rejection of 60 db was required for spurious signals, the i-f frequency, and the image frequency. The rejection attained in each case was better than 80 db.

An output of 50 mw was required for a 6-db signal-plus-noise to noise ratio with 5 μv of input. All the receivers met this requirement with typical input values varying from 1.8 to 4.0 μv. Figure 33 illustrates typical variations of input signal required over the band to realize 50 mw output, and typical variations of input signal required to realize a 6-db signal-plus-noise to noise ratio.

The noise quieting action of the carrier and the input-output characteristics of the receiver at 190 kc are illustrated in figure 34. Figure 35 presents the same information for 550 kc.

With the AVC inactive, the volume control supplies over 100 db of attenuation. The gain of the receiver is so high that the noise reduces the dynamic range of the volume control to 80 to 85 db with the AVC on.

As anticipated, it was impossible to achieve more than 100 mw audio output with the available tubes. Aural tests indicated that this power output was too great for headphone comfort. A miniature tube designed for audio power output

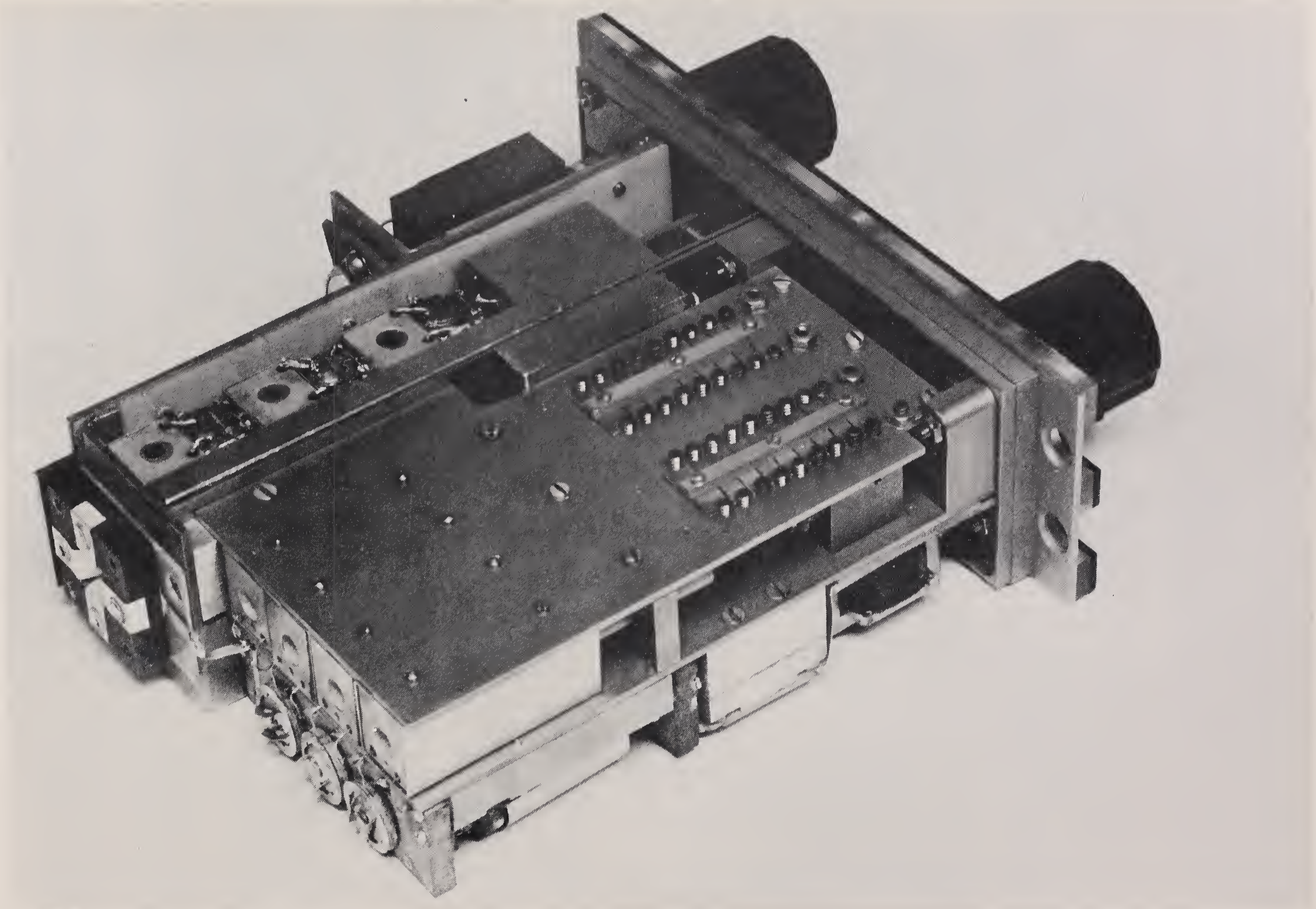


Figure 36. Bottom view of assembled receiver.

operation from a 26-v supply should be available soon. This receiver has been so designed that this tube may replace the four output tubes now used without any major design changes.

20. PRODUCTION CONSIDERATIONS

This equipment has been designed so that it may be fabricated in separate assemblies which are combined into the complete receiver.

The following procedure describes the order in which the r-f assembly (fig. 24) is constructed for maximum ease of assembly:

1. Mount r-f shields on r-f chassis.
2. Mount heater buses.
3. Insert proper tubes and connect filaments.
4. Mount preassembled r-f front panel with silicone-rubber pads in place.
5. Connect all capacitors to r-f front panel.
6. Connect tube leads to the capacitors.
7. Mount preassembled r-f back panel with silicone-rubber pads in place.
8. Connect tube leads to r-f back panel.
9. Mount AVC bus.

The i-f assembly (fig. 27) should be constructed in the following order:

1. Mount i-f transformer and preassembled i-f plate to the i-f chassis. Make sure silicone pad is in place. Do not tighten screws.
2. Slide tube shields under transformers and tighten screws.
3. Insert the bypass capacitors into place from the tube base end, and connect to i-f plate.
4. Insert proper tubes in shields and connect leads.
5. Connect transformer leads.
6. Mount beat-frequency oscillator inductor assembly on pre-assembled beat-frequency oscillator plate, separated by a silicone-glass insulator.
7. Slide tube shield under inductor assembly and fasten in place with a cross bar.

After the r-f and i-f electrical assemblies are constructed, the complete receiver (fig. 36) can be put together.

1. The bulkhead assembly (fig. 4) functions as the receiver chassis.
2. The tuner assembly (fig. 21) is mounted to the bulkhead. (fig. 5).
3. The r-f assembly (fig. 24) and the required power filter sections (fig. 13) are mounted on the tuner assembly (fig. 6).
4. The transformer bracket assembly (fig. 7), volume-control element (fig. 11), switch assembly (fig. 8), and output transformer, are mounted on the bulkhead assembly (fig. 9).

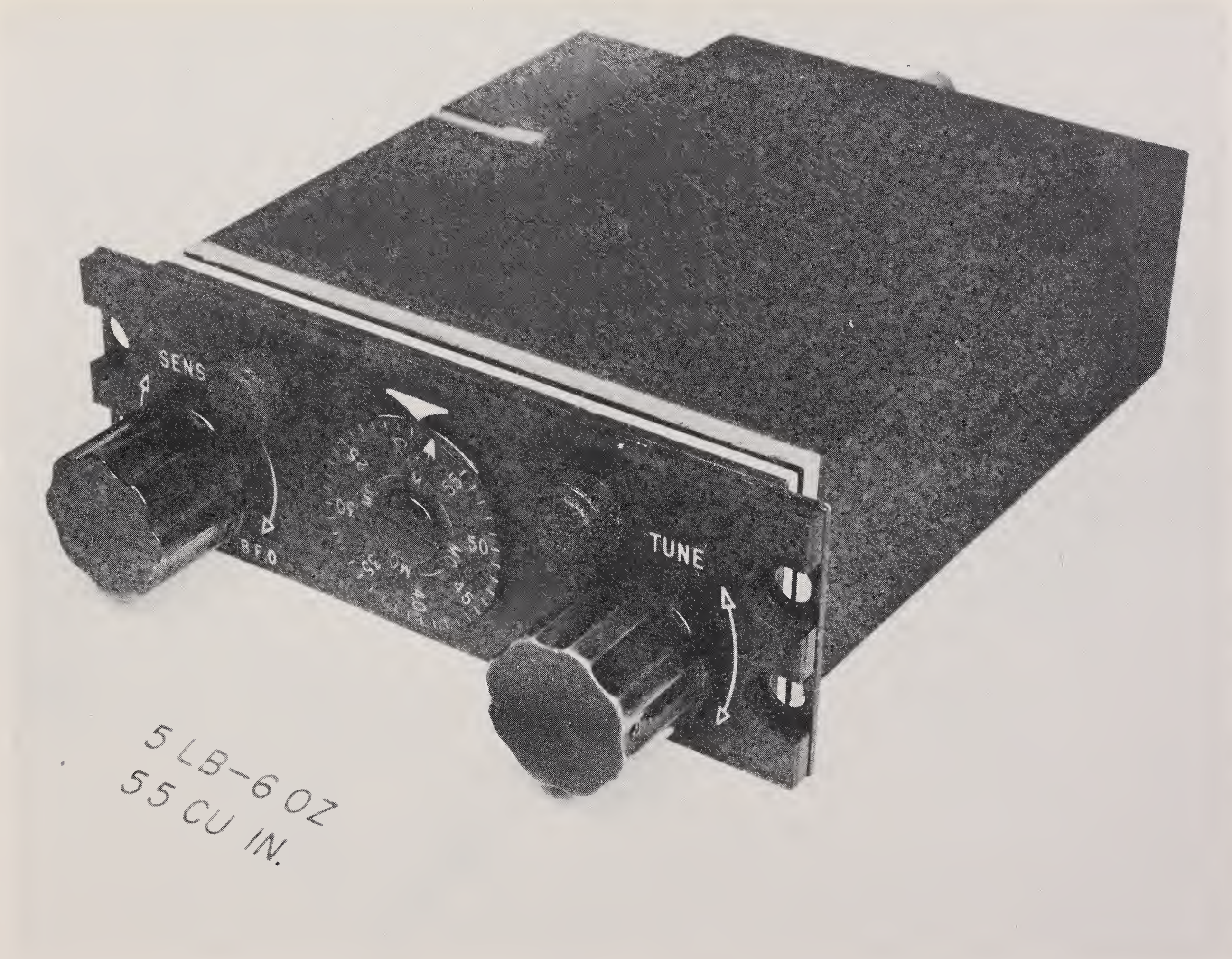


Figure 37. Receiver in case.

5. The i-f amplifier assembly (fig. 27) is slipped into place (fig. 10).

6. The rear bracket assembly is mounted next (fig. 10). The bottom view of the receiver assembly is illustrated in figure 37.

7. The receiver assembly is put into the case (fig. 37), sealed and filled with nitrogen.

21. PRODUCTION SUGGESTIONS

The housing for the tantalum capacitors used as line filters may be eliminated. A commercial company has recently reduced the size of their tantalum capacitor cases so that the housing used in the receivers may be eliminated and three commercially packaged capacitors used instead.

The receiver-case design is such that it should be possible to deep-draw it in production, instead of fabricating it as was done during this development. The case should also be provided with an exhaust nozzle so that it may be filled with nitrogen after it has been sealed.

Toward the end of the development, silicone and Teflon-impregnated glass laminated to copper foil became available for etched circuit applications. All the steatite printed circuits used in the receiver can easily be replaced by these more shock-resistant circuits, and the silicone-rubber shock pads can be eliminated.

The wobbling-bellows rotary seals, while the best commercially available, are still far from ideal. Their backlash is such as to prejudice the radio equipment operator against the receiver. There is a definite need for armed services support for continued development of rotary seals.

Out of the experience gained from the fabrication of a number of receiver models, it can be said that lighter springs should be used in a production version of the tuner mechanism. This will reduce the torque required for tuning. Tuning slugs of slightly smaller diameter will reduce the longitudinal backlash introduced by the weaker springs.

The four output tubes should be discarded as soon as a replacement becomes available.

The transparent lucite behind the engraved front panel may be replaced for heat reasons by tempered glass. The engraved front panel should protect it from direct blows.

Ceramic dielectric capacitors with the proper temperature coefficient should be used to resonate the i-f transformers.

An r-f tuner temperature-compensating scheme, similar to that suggested previously, should be incorporated.

22. CONCLUSION

A prime consideration in the receiver's development was its adaptability to large-scale production. Printed-circuit assemblies in combination with miniature piece-components and novel electromechanical assemblies were liberally used to minimize the cost of mass production. Practicality and reproducibility were kept in mind at all times in this program.

The problems encountered during the subminiaturization of this receiver were numerous because they lay in a virtually unexplored field of applied electronic engineering. In the limited time allotted for this investigation only the most pressing and basic problems could be examined. While the solutions evolved are entirely practical and workable, it must be emphasized that additional development can bring about considerable improvement.

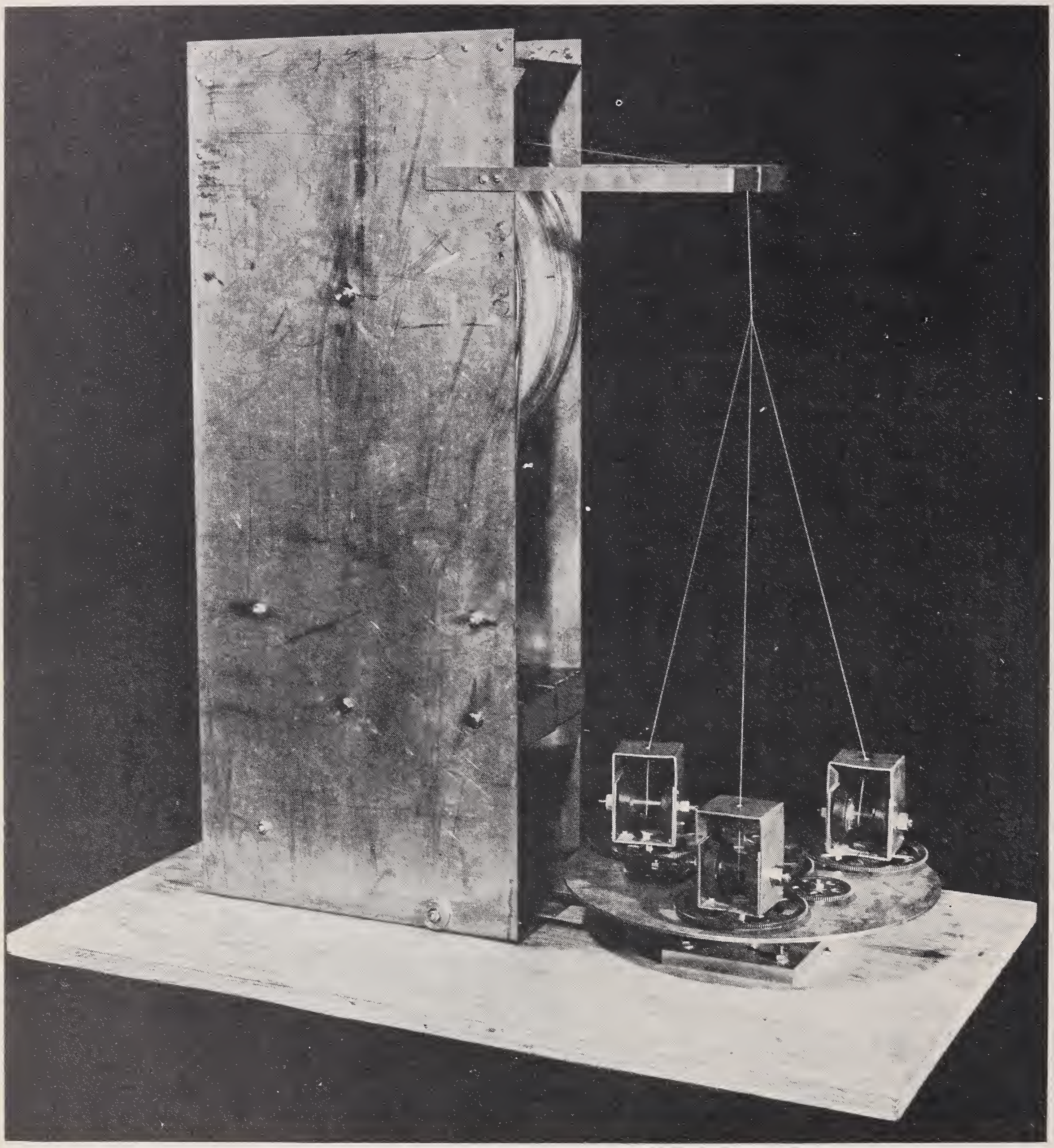


Figure 38. Litz wire fabrication.

Radio-range receivers for aircraft, with their function of keeping the pilot on course, are of obvious importance in themselves. The significance of this development, however, lies largely in its implications for communications equipment of all types, where small size is important.

It has been difficult or impossible to set up intelligent specifications for very compact electronic equipment. In the absence of proof of what was feasible, the tendency in the past has been to make concessions in the direction of conservatism in size specifications. Now that it has been demonstrated how small practical reproducible equipment of this type can be made, and now that many of the special problems involved have been solved, procurement officers and manufacturers alike will be able to plan diminutive equipment more realistically and intelligently.

Size reduction of electronic equipment in planes, tanks, and other military vehicles is important for two reasons. In the first place, with the use of constantly increasing quantities of electronic equipment in vehicles, size restriction becomes important lest armament be crowded out. Secondly, and fully as important, the asymptotic goal of 100-percent functional reliability of electronic equipment can be more nearly approached through the use of functional assemblies that can be quickly replaced by unskilled personnel. The total elimination of equipment failure, must as it is to be desired, is not realistically foreseeable. But the greater the degree of miniaturization, the more feasible it becomes to keep complete replacement equipment or assemblies on hand. The spare assembly is quickly substituted for the defective one, and the latter is returned to a higher echelon for repair and reissue. Not only may a higher level of functional reliability be thus realized, but scarce skilled repair personnel may be more efficiently and economically utilized when concentrated in higher echelon repair centers. In the case of this receiver, the entire equipment has been made so small that the entire unit may be regarded as a replaceable plug-in assembly.

23. DETAILED CONSTRUCTIONAL INFORMATION

Very complete sets of drawings for this receiver, litz-wire machine, and nonlinear screw-cutting attachment have been prepared. The large number of drawings involved make it impossible to include them in this report; however, a limited number of drawing sets will be available to qualified organizations upon request through the proper channels.

24. APPENDIX A. CERAMIC-TEFLON-INSULATED LITZ WIRE MACHINE

This machine (fig. 38) can accommodate up to four spools. The strands of wire are twisted as the group is twisted together, thereby relieving the torsion of the individual strands. The reason for doing this was two-fold. (1) In using ceramic insulated wire, it was believed that should torsion be set up in the individual strands, the ceramic might strip from the copper wire. (2) The strands could not unravel of their own accord but would require an external force.

Another possibility of this machine, one that was not utilized because of circuit considerations peculiar to this receiver, was that of making bifilar litz wire. If, in the final twist, a wire spool is located on the stationary center gear where it may feed a solid or stranded wire to serve as a core around which the wire is twisted, the resulting composite cable can be used for winding unity-coupled transformers with the wire core forming one winding and the rest of the cable the other. Such a wire could eliminate the grid or the plate resistor and a coupling capacitor in single-tuned r-f stages.

If a higher wire-production rate is desired, a triple turn-table device could be designed on the same principle so that continuous wire production would be possible.

It has been estimated that a simple machine of this type could be built for approximately $400. Its rate of production is such that should a manufacturer be awarded a contract for 100 receivers to be produced in 1 year, he could in 6 months, by operating this machine for 8 hours a day, produce all the special wire required for the project. Because this machine is very simple to operate, it would not require special know-how on the part of the equipment manufacturer.

In this development both 9/44 and 3/42 ceramic-Teflon-insulated litz wire were used. In the interest of uniformity, those inductors that were wound with 9/44 wire were subsequently wound with 3/42 wire also. Despite the reduction of circuit Q that resulted, the final performance of these circuits, while not the optimum, was still very satisfactory.

25. APPENDIX B. THIN CERAMIC DIELECTRIC CAPACITORS

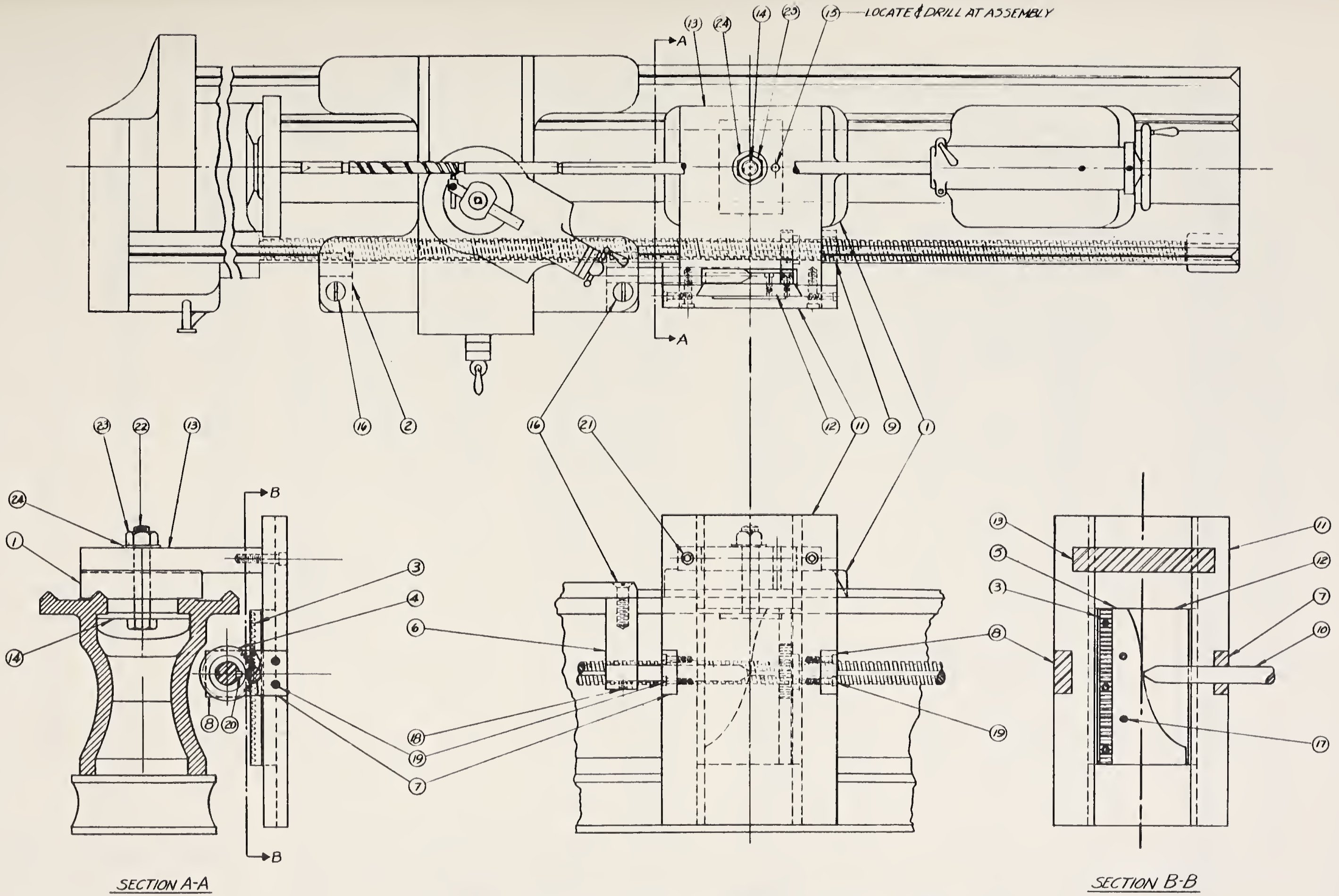
The first problem was that of overcoming the tendency for thin ceramic wafers to curl during the firing cycle. A reasonably satisfactory solution was realized by the ceramic section of the National Bureau of Standards when they evolved the technique of firing stacks of dry pressed wafers with a parting layer of zirconium dust between layers. This method proved to be quite capable of yielding flat wafers as thin as 0.004 in.

The next phase of this problem was devoted to silvering these wafers. First, a masking method was employed, but this was not too successful because of excessive handling to which the fragile wafers were subjected.

It was next reasoned that if an overall silver coating was first fired on the ceramic wafers to lend them strength and then the wafers were cut to size, a satisfactory method might result. The extreme thickness and flatness of the wafers made a punching process seem practical. Punches were made with a properly designed pressure system to support the ceramic all along the edges. The pressure plates were slightly recessed in the areas away from the cutting edges so that even slightly warped wafers could be handled. As it was believed that such punches would wear rapidly, the long-wearing qualities of some of the earlier soft punches was surprising. Upon examination of the cut ceramic edges, it was found that the punching process resulted in a controlled fracture edge, instead of a sheared edge. Under magnification the edge resembled tiny irregular saw teeth. Apparently, a combination of the pressure-plate system and the restraining force of the fired-on silver coating tends to restrict the cracking to the desired area. It was expected that difficulties caused by short-circuiting over the edges would be encountered. Except on rare occasions, however, this problem did not materialize. Disks, washers, and a wide variety of other shapes have been punched out, indicating that shape factor does not seem to impose too much of a restriction on this process.

The third phase of the investigation was concerned with paralleling a stack of capacitor plates, bringing out terminals, and packaging the capacitor assembly. An attempt was made to fire the wafers with a thin shim of metal between them using conductive silver paint as a bonding agent. The high volumetric shrinkage of the paint made this impractical. Various methods were then employed to achieve a conductive bond with solder. The sheet metal and ceramic wafer parts and the thin stamped solder washers were loaded into a positioning jig with individual weights on each capacitor assembly. The entire jig was placed in an oven at a temperature sufficiently high to liquify the solder washers. The results were so erratic that this method also was abandoned.

Pretinned ceramic wafers sweated together very well; hence a setup for dip-tinning the wafers was arranged. Temperature control of the solder bath was very important because too hot a bath stripped the fired-on silver coating and shattered the ceramic while too cool a bath left masses of solder on the ceramic wafer. Some progress was being made along these lines when the results of life tests on the ceramic bodies became available. It was found that the d-c leakage for thin sections of conventional high-K bodies increased with age



Pt. No.	NAME	Pt. No.	NAME	Pt. No.	NAME
1	TAIL STOCK BASE PLATE	9	BEARING BUSHING	17	CAP SCREW, 8-32 x 5/8 HEX. SOCK.
2	CARRIAGE GUIDE	10	FOLLOWER ARM	18	SET-SCREW, 1/4-20 x 1/4
3	RACK	11	CAM GUIDE PLATE	19	CAP SCREW, 10-32 x 3/8 HEX. SOCK.
4	GEAR	12	SLIDING CAM PLATE	20	KEY, 3/16 SQ. x 1
5	CAM	13	GUIDE PLATE SUPPORT	21	CAP SCREW, 1/4-20 x 1 1/4 HEX. SOCK.
6	FOLLOWER SUPPORT	14	ANCHOR BOLT-PLATE	22	BOLT, 1/2-13 x 3 HEX. HD.
7	FOLLOWER GUIDE	15	DOWEL PIN	23	NUT, 1/2-13 HEX.
8	LEAD SCREW BEARING	16	CAP SCREW, 3/8-16 x 1 1/4 FLT. HD.	24	WASHER FOR #22

Figure 39. Screw-cutting attachment assembly.

at high temperatures. This deterioration was greatly exaggerated by the d-c polarizing voltage. The higher the polarizing potential, the greater the increase in leakage. This effect was so bad that the use of the thin sections of ceramic was abandoned. Because thick ceramic wafers would have yielded capacitors that were too bulky, it was decided that glass dielectric capacitors would be used instead.

26. APPENDIX C. NONLINEAR SCREW-CUTTING ATTACHMENT

The nonlinear screw-cutting attachment is a simple lathe attachment that can be used on a standard lathe. The device (fig. 39) was mounted on a standard 9-in. South Bend lathe. This lathe is not altered in any way except for removing the apron.

The attachment is locked rigidly to the lathe bed. The cam guide plate (11) permits the sliding cam plate (12) to move in a vertical direction only. The sliding cam plate is driven up and down by the engagement of the rack (3) and the pinion gear (4). The pinion gear is keyed to the lead-screw of the lathe, and its rotational speed relative to the lathe head-stock spindle is controlled by the gear ratio of the lead-screw drive. The cam, moving upward at a linear rate, longitudinally displaces the lathe carriage. The nonlinear motion of the lathe carriage is determined by the cam contour and its vertical speed. The contour of the cam (5) is determined from the curve of tuned-circuit resonant frequency versus tuning-slug displacement.

The procedure for establishing the cam contour is straightforward. The inductor and its tuning slug are placed in a jig containing a conventional linear screw drive for the slug. The inductor is resonated by the required capacity in a Q-meter. Readings are taken of the resonant frequency for different increments of slug penetration into the inductor. The ensuing curve (fig. 18, curve A) is the basis for the establishment of the variable cam contour (fig. 40).

The maximum vertical dimension (L_1) of the cam is limited by the vertical travel of the cam attachment. The dimension L, which encompasses the useful portion of the cam, should be approximately 90 percent of L_1. The arbitrarily shaped cam sections, M and N, on each side of L are to allow time for the lathe operator to back out his cutting tool and reverse the lathe. As the threads cut on the nonlinear screw by M and N are never engaged in the tuner, their contours are arbitrarily established.

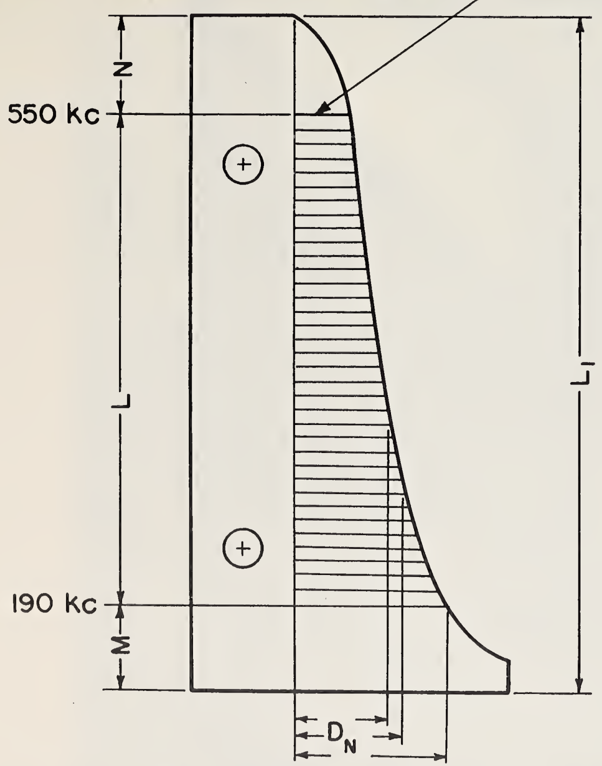
The number of revolutions the nonlinear screw must make to displace the slug over the desired tuning range is chosen by the designer. The gear ratio between the headstock spindle and the lead screw must then be set to a value that will cause the sliding cam plate to be displaced approximately 90 percent of its maximum possible vertical travel for the desired number of revolutions of the nonlinear screw blank that is mounted in the headstock spindle. In this manner, the actual physical length of L is established for the cam. The distance L is divided into as many equal increments as there are frequency increments for which the slug displacements will be plotted. The following example is given:

1. The maximum possible vertical displacement of the cam plate for a particular attachment on a particular lathe is measured (e.g. 4 in.).

2. The number of lead-screw revolutions required to displace the cam plate 90 percent of 4 in., or 3.6 in., is determined (e.g 0.81 revolutions).

3. The number of nonlinear screw threads desired is set (e.g. 9 turns).

4. We find then that 9 turns of the lathe headstock spindle must cause the lead screw to rotate 0.81 turn or that a gearing ratio of 90 to 8.1 is required.



ACTUAL CAM OUTLINE USED TO CUT NON-LINEAR SCREW TO TUNE A LINEARLY WOUND COIL FROM 190 kc TO 550 kc. NOTE THE EXTENSION OF CAM ABOVE 550 kc AND BELOW 190 kc TO ALLOW TIME FOR THE LATHE OPERATOR TO ENGAGE AND DISENGAGE THE CUTTING TOOL.

Figure 40. Screw-cutting attachment cam.

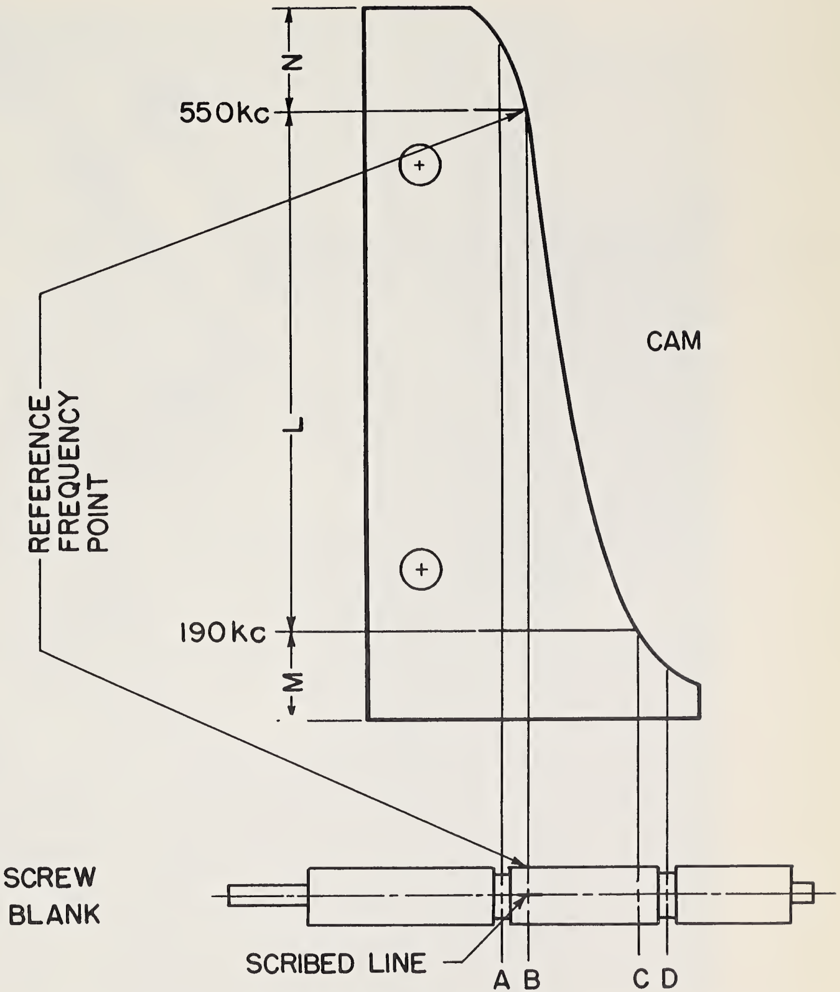


Figure 41. Relation of cam and screw blank.

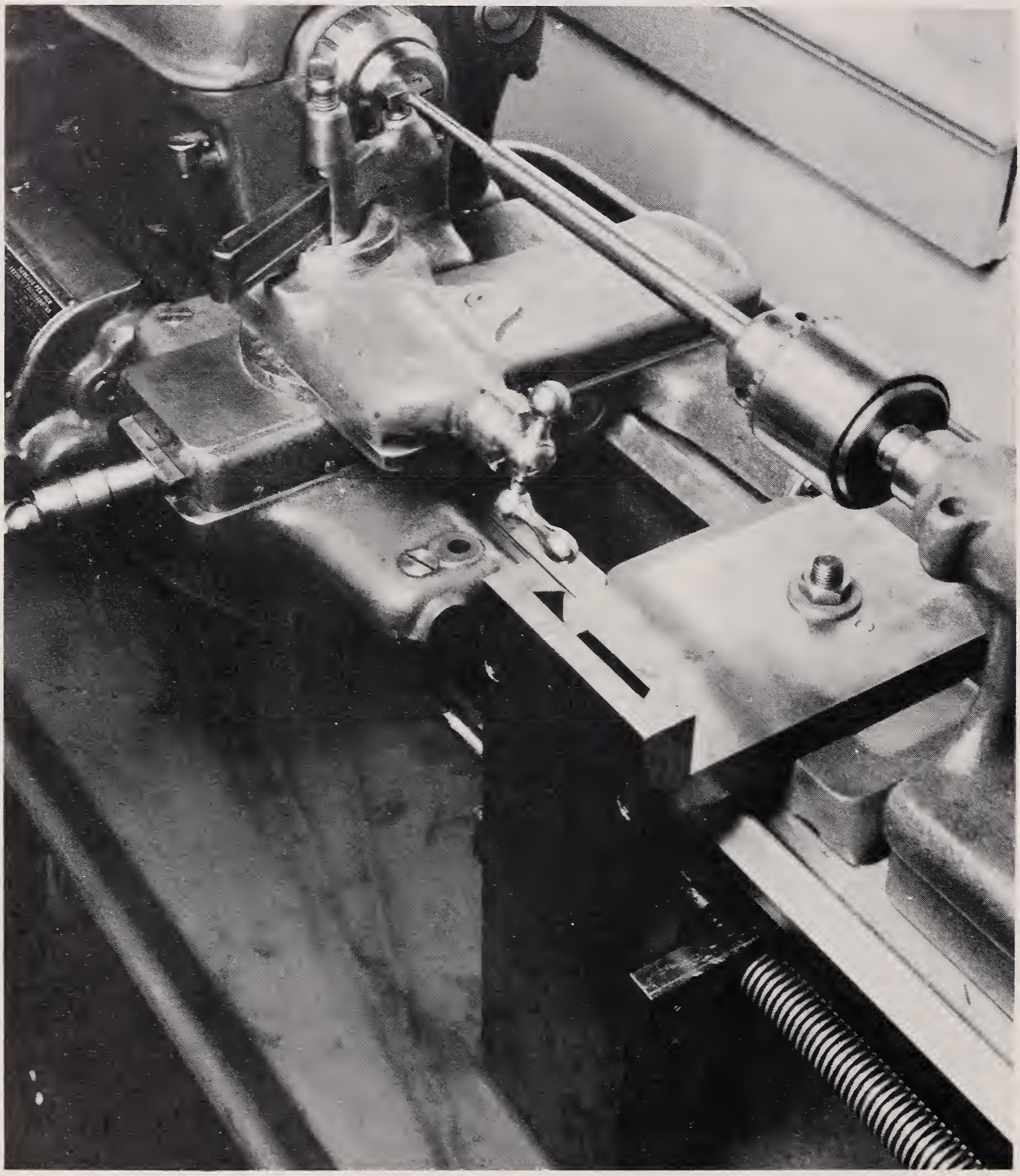


Figure 42. Screw-cutting attachment, side view.

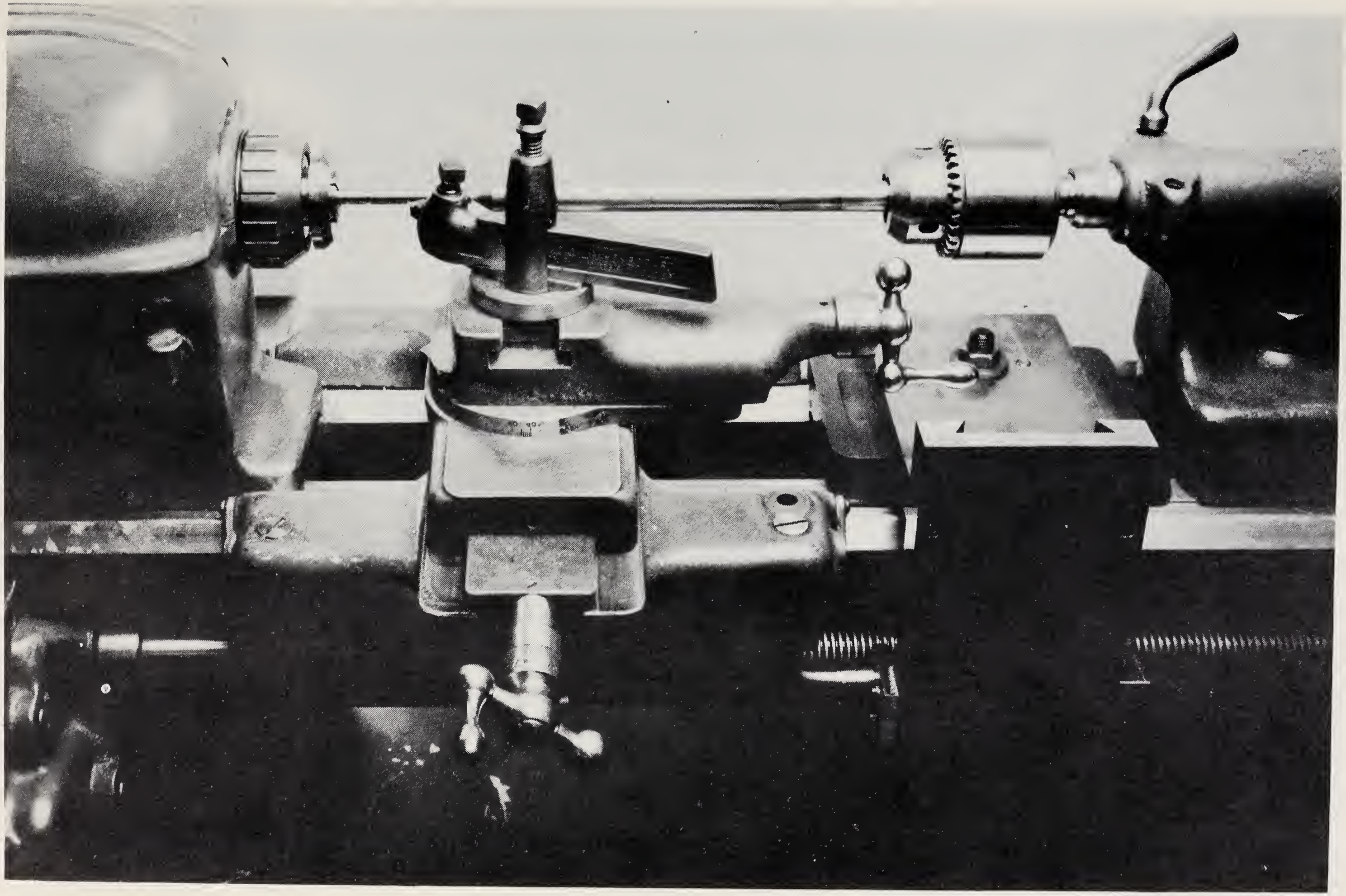


Figure 43. Screw-cutting attachment, front view.

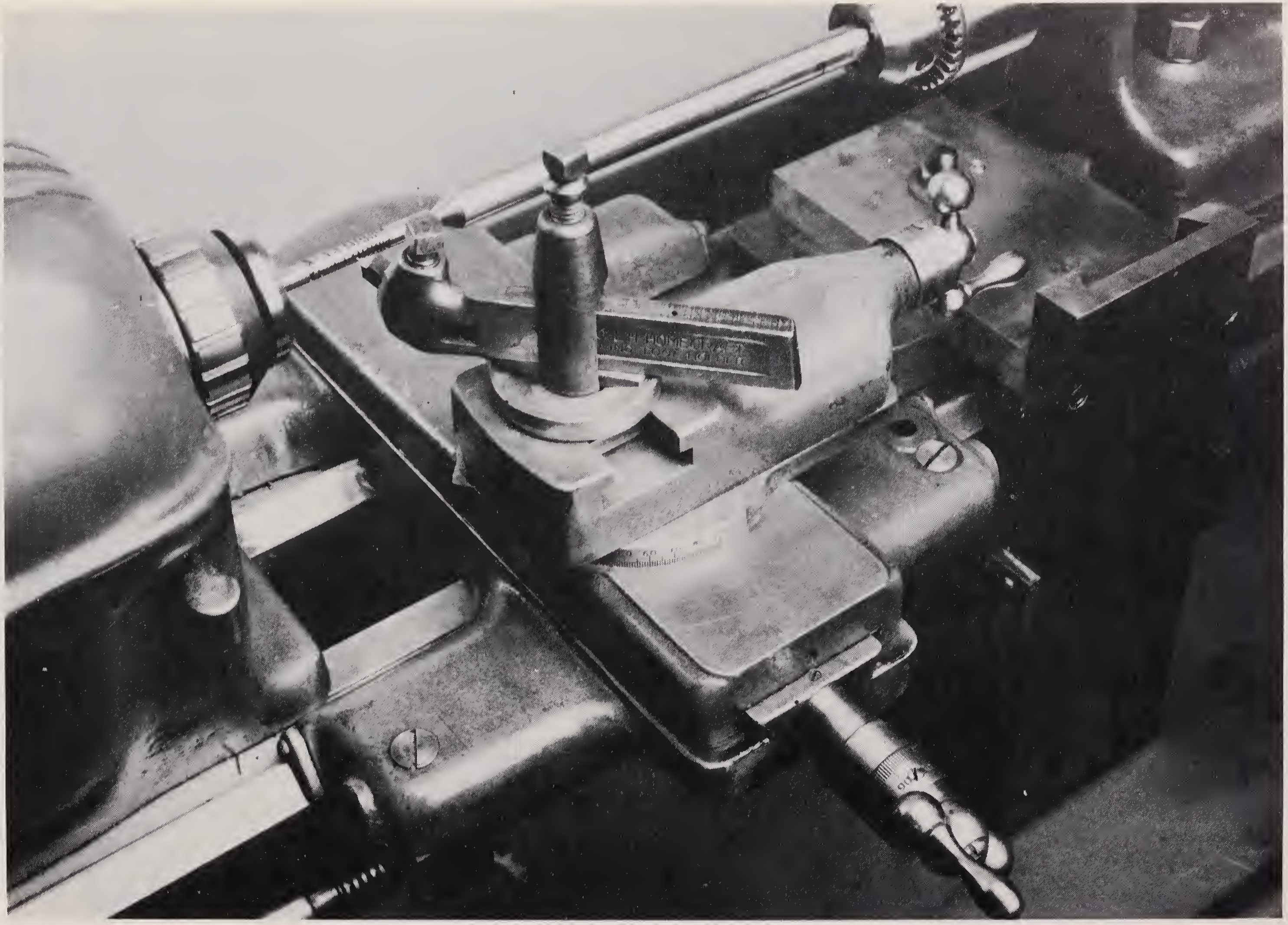


Figure 44. Screw-cutting attachment, top view.

5. If this precise gearing ratio cannot be set up on a particular lathe, then the closest ratio to the desired one is set up.

6. With this new gear ratio set (e.g. 90 to 8) and the headstock spindle rotation fixed at 9 turns, the corrected displacement (L) of the cam is computed to be 3.56 in.

7. It is desirable to plot the slug displacements for every 10 kc, and since there are 36 such increments from 190 to 550 kc, the distance L on the cam is divided into 36 equal spaces, and the actual required slug displacements are laid off as illustrated in figure 40.

8. These plotted points are connected and the curve continued in an arbitrary manner in regions M and N.

The coordinates of the curve may be plotted on a thin brass or steel plate if a template is desired, or they may be plotted directly on the cam material. The exact dimensions and points, O_n, can be located with a height vernier and can be plotted very accurately. The outline of the curve is then machined.

The distance BC (fig. 41) is equal to the actual tuning slug displacement required to tune over the frequency spectrum. The location of BC on the screw blank is determined by the tuning mechanism in which the screw is to be used. Distances AB and CD are approximately one-twentieth of BC. Undercut A is located when the follower is in approximately the central region of N. Undercut B is located when the follower is in approximately the central region of M. The undercuts so located are required only to facilitate the machining operation. Points B and C may be located in the lathe, using the 550 and 190 kc cam markings, respectively, as indicators. Because point B must later function as a reference for orienting the screws in the tuner, a line is scribed through it.

With the blank undercut and scribed, the thread is ready to be cut on the lathe. The spindle of the lathe is rotated until the follower is opposite the 550 kc marking on the cam and the cutting edge of the tool bit is opposite the reference point B on the screw blank. The final step is a conventional thread-cutting operation with the lathe carriage being displaced by the moving cam.

Figures 42, 43 and 44 illustrate a setup in a South Bend lathe for chasing a nonlinear thread.

If a pivoted bar is used in place of the cam, the attachment becomes a useful laboratory tool. By adjusting the slope of this bar, it becomes a cam surface that permits the cutting of any nonstandard linear thread.

27. REFERENCES

M. J. Ainsworth, Bendix Aviation Pacific Division, Subminiature packaged electronic sub-assemblies, Contract NObsr-43430.

American Television & Radio Co., Miniaturized power supplies, Interim Engineering Report, Contract No. AF 33(038)-11220 (August 17, 1950).

Design and development of miniature hermetically sealed power transformers, Armour Research Foundation of Illinois Institute of Technology, Contract W-36-039-SC-38221.

Automatic Manufacturing Corporation, Miniature I.F. transformer suitable for automatic assembly to printed circuits, Fourth Quarterly Report, Contract No. W36-039-SC-44498 (April, 1950)

I. L. Auerbach, Plug-in electronic construction solves maintenance and space problems, Elec. Mfg. [3] 46, 105-107 (1950).

Balamuth and Cohen, A study of the development of thin ceramic films, Balco Research Lab., Signal Corps Contract No. W-36-039-SC-38248.

A study of printed resistors for printed circuits, Balco Research Lab., Signal Corps Contract No. W-36-039-SC-38136.

Electrical insulation films for high temperature insulation, Balco Research Lab., Final Report, Signal Corps Contract No. W-36-039-SC-32088.

A study of high dielectric constant films for high temperature operation, Balco Research Lab., Signal Corps Contract No. W-36-039-SC-32361.

A study of automatic printed circuit techniques, Balco Research Lab., Signal Corps Contract No. W-36-039-SC-38146.

Fixed composition resistors, Batelle Memorial Institute, Air Force Contract AF-33(038)-468.

S. R. Beitler and R. H. Lynch, Status of test apparatus and literature survey on convective heat transfer, Ohio State University Research Foundation, Reports No. R-27, R-29, R-33, R-34 and R-35.

S. R. Beitler and R. H. Lynch, Status of test apparatus and literature survey on surface temperature measurement, Ohio State University Research Foundation, Report No. 17.

High operating temperature transformers, Bell Telephone Laboratories, Final Report, A.M.C. Contract W-33-038-AC-13939 (June 1948).

Bendix Aviation Corporation Red Bank Division, Miniaturized rotating power supplies, Final Engineering Report, Contract No. AF. 33(038)-11219 (October 31, 1950).

C. I. Bradford, B. L. Weller, and S. A. McNeight, Printed vitreous enamel components, Electronics [12] 20, 106-108 (1947).

A. I. Brouer and S. M. Marco, Introduction to heat transfer (McGraw-Hill Book Co., Inc., New York, N. Y., 1942).

C. Brunetti and A. S. Khouri, Printed electronics circuits, Electronics [4] 19, 104-108 (1946).

C. Brunetti and R. W. Curtis, Printed circuit techniques, Cir. NBS 468 (1948).

C. Brunetti, T. H. Morrin, and J. W. Dawson, Unitized electronic design and construction techniques, Elec. Mfg., [2] 47, 78-83 (1951).

E. N. Bunting, G. R. Shelton, and A. S. Creamer, Properties of barium strontium titanate dielectrics, J. Research NBS 38, 337 (1947) RP1776.

Alfred H. Canada, Simplified calculations of black-body radiation, Gen. Elec. Rev. [12] 51, 50-54 (1948).

Capehart-Farnsworth Corporation, Heat dissipation capabilities of aluminum containers for electronic components, Report No. FAR-I-L, Contract No. NOrd-9099.

Chance, Thurston, and Richman, Some designs and applications for packaged amplifiers, using subminiature tubes, Rev. Sci. Instr., p. 610-616 (Sept. 1947).

Chatham Electronics Corporation, Development of rugged electron tubes, Signal Corps Contract W36-039-SC-33677.

V. W. Cohen and A. Bloom, Microphonism in a subminiature triode, Proc. Inst. Radio Engrs., p. 1039-1048 (Aug. 1948).

J. T. Collier, Metallized circuits reduce wiring costs, Elec. Mfg. [3] 40, 116 (1947).

J. T. Collier, Metallized circuits, Product Eng., p. 141-143 (April 1948).

W. R. Conway, Resistors for deposited circuit techniques, Electronic Eng., p. 403-408 (Nov. 1949).

Corning Glass Works, Development leading towards improved or new designs of glass dielectric capacitors, Signal Corps Contract No. W36-0390SC-38.

W. R. Cuming, Plastic embedded circuits, Electronics [6] 23, 66-69 (1950).

G. B. Devey, Reliability in electronic equipment, Elec. Mfg. [3] 46, 107 (1950).

G. B. Devey, Reliable electronic equipment, Elec. Mfg. [1] 47, 107-109 (1951).

J. F. Dexter, Silicone rubber emerges as a dielectrical material, Elec. Mfg. [6] 45, 100-103 (1950).

Development of small size high temperature radio hookup wire, Federal Communication Lab., Inc., Signal Corps Contract No. W36-039-SC-44583.

Low loss heat resisting molding compounds, Federal Telecommunication Lab., Inc., Signal Corps Contract No. W36-039-SC-38191.

General Electric Co., Capacitor development, Signal Corps Contract No. W36-039-SC-32252.

E. H. Hall, A dual theory of conduction in metals, The Murray Printing Company, Cambridge, Mass., (1938).

J. H. Hall and F. H. Berghorn, Miniaturizating the tantalum capacitor, Elec. Mfg. [6] 46, 82-85 (1950).

W. H. Hannahs and E. S. Bennett, Miniaturization-crux of contemporary product design, Elec. Mfg. [6] 45, 89-91 (1950).

G. A. Hawkins and J. T. Agnew, The solution of transient heat conduction problems by finite differences, Research Series 98, The Engineering Experiment Station, Purdue University (1947).

Herlec Corporation, A study of automatic unitized printed circuit techniques, Signal Corps Contract No. W36-039-SC-38153.

L. R. Ingersoll, O. T. Zobel, and A. C. Ingersoll, Heat conduction with engineering and geological applications, (McGraw-Hill Book Co., Inc., New York, N. Y., 1948).

M. Jakob and A. H. Hawkins, Elements of heat transfer and insulation (John Wiley & Sons, Inc., New York, N. Y., 1942).

M. Jakob, Heat transfer (John Wiley and Sons, Inc., New York, N. Y., 1947).

A. E. Javitz, Report on dielectric research, Elec. Mfg. [2] 47, 101-106 (1951).

A. E. Javitz, Fluorocarbon resins appraised, part I, Elec. Mfg. [2] 46, 76 (1950).

A. E. Javitz, Research developments in dielectrics, Elec. Mfg. [1] 45, 80-85 (1950).

A. E. Javitz, Fluorocarbon resins appraised, part II, Elec. Mfg. [3] 46, 80 (1950).

Kenyon Instrument Co., Development of printed electronic circuits, Signal Corps Contract No. W36-039-SC-33659.

D. D. Knowles, Extending Life of electron tubes, Elec. Mfg. [2] 47, 114 (1951).

Lear, Inc., Miniaturization techniques for low-frequency multiband receiving equipment, Interim Engineering Report, Report No. 2015-4 (August 1950).

J. C. Lebens, Three metallizing techniques for component design, Elec. Mfg. [2] 43, 120-125 (1949).

B. H. Marks, Ceramic dielectric materials, Electronics [8] 21, 116-120 (1948).

J. Marsten and A. L. Phugh, Jr., Operating characteristics of film resistors, Tele-Tech. [3] 7, 46 (1948).

W. H. McAdams, Heat transmission, National Research Council, McGraw-Hill Book Co., New York, N. Y.).

C. E. Meinheir and W. Snyder, Electronic counter and divider circuits, Sylvania Technologist [3] 1 (1949).

M. L. Miller, The design of electronic equipment using subminiature components, Proc. Inst. Radio Engrs., p. 130-135 (Feb. 1950).

A. F. Murray, Evolution of printed circuits for miniature tubes, Tele-Tech [6] 6, 58 (1947).

Development of the National Bureau of Standards casting resin, Cir. NBS 493 (May 22, 1950).

National Bureau of Standards, Electronic miniaturization, Final Report, PB 100949 , Office of Technical Services, Department of Commerce, (Sept. 1949).

NBS Printed circuits, Final Report, PB 100950 , Office of Technical Services, U. S. Department of Commerce (Jan. 1950).

NBS, Model V miniature I-F amplifier, Terminal Report, NBS Project No. 01-36-403 (May 1950).

Cooling methods for electronic equipment in general, Ohio State University Research Foundation, A.M.C. Contract W-33-0382C-14987.

F. J. Oliver, Ceramics as insulators and dielectrics, Elec. Mfg. [5] 45, 100-105 (May 1950).

D. M. Powers, Melpar, Inc., Subminiature packaged electronic I-F amplifier sub-assemblies, Bur Ships Contract NObsr-43417.

Raytheon Manufacturing Co., Subminiature versions of 6L6, 6AG7, and 1/2 of 6AS6, Contract No. AF 33(038)-5734.

W. Robinson, R. H. Zimmerman and J. A. Stevenson, Design and control of blowers for uniform cooling of electronic equipment from sea level to 70,000 feet altitude, Ohio State University Research Foundation.

E. Rolle, NEL casting resins, Navy Electronics Lab.

K. Rose, Materials and techniques for printed electrical circuits, Materials and Methods 25, 63 (Jan.-June, 1947).

F. B. Rowley and A. B. Algren, Thermal conduction of building materials, University of Minnesota (1937).

J. A. Sargrove, New methods for radio production, Electronic Eng. [230] 19, 124 (April 2, 1947).

G. Shapiro, R. L. Henry, and R. K-F Scal, New techniques for electronic miniaturization, Proc. Inst. Radio Engrs. [10] 38 (1950).

C. L. Snyder, E. Alberts-Shoenberg, and H. A. Goldsmith, Magnetic ferrite core materials for high frequencies, Elec. Mfg. [12] 44 (1948).

N. H. Snyder and J. H. Koenig, Design limitations for ceramic parts, Elec. Mfg. [6] 46, 90-94 (1950).

I. Sovey, Trends in development of parts and components, Tele-Tech. Electronic Industries [7] 6, 57(1947).

Sprague Electric Company, Development of miniaturized hermetically sealed variable capacitors, Signal Corps Contract W36-039-SC-3824.

Sprague Electric Co., High temperature dielectric film, Signal Corps Contract No. W36-039-SC-38110.

Sprague Electric Company, High temperature magnet wire, Signal Corps Contract No. W36-039-SC-38142.

Sprague Electric Company, Research investigations of metallized paper capacitors, Signal Corps Contract No. W36-039-SC-36860.

The auto-sembly system of circuit fabrication, Squire Signal Laboratory, Fort Monmouth, New Jersey, Information Bulletin #120.

Electronic equipment construction, Stanford Research Institute, Task Order 10.3, Contract N7onr-32103.

E.B. Steinberg, Hermetically sealed components for industrial control, Elec. Mfg. [1] 46, 110 (1950).

E. B. Steinberg, Improved cooling of electrical devices, Elec. Mfg. [1] 45, 70-75 (Jan. 1950).

H. J. Stoever, Applied heat transmission (McGraw-Hill Book Co., New York, N. Y., 1941).

Stupakoff Ceramic and Mfg. Co., Ceramic dielectric fixed capacitors, U.S. Signal Corps Contract No. W28-003-SC-1411.

P. G. Sultzer, Circuit techniques for miniaturization, Electronics [8] 22, 98-99 (1949).

Sylvania Electric Products, Inc., Development of automatic assembly techniques for transformer coupled circuits, Interim Engineering Report No. 3, Air Materiel Command Contract AF 33 (038) 9350 (Sept. 1950).

Sylvania Electric Products, Inc., Research and development of double diodes, low mu triodes, high mu triodes, and r-f pentodes for operation within hermetically sealed expendable assemblies, Interim Engineering Report AD-TD-1 (Jan. 1947), Interim Engineering Report AD-TD-6 (AT137820), (July 1 - August 30, 1947), Contract No. W-33-038-AC-15441.

Sylvania Electric Products, Inc., Sylvania subminiature tubes, premium performance types.

Gustave Shapiro, Subminiaturization techniques, Advances in Electronics, Vol. III, p. 195-218(Academic Press, New York, N. Y., 1951).

Titanium Alloy Mfg. Co., High dielectric constant titania and titanate ceramics.

W. G. Tuller, Potted sub-assemblies for subminiature equipment, Electronics [9] 22, 104-105 (1949).

H. M. Zeidler and J. D. Noe, Pentriode amplifier, Proc. Inst. Radio Engrs., p. 1332-1338 (Nov. 1948).

M. Abramson and S. Danko, The auto-sembly system of circuit fabrication, Signal Corps Engineering Laboratories, Components and Systems Branch Information No. 102 (Aug. 1949).

W. W. Anspacher, Miniaturizing pentode amplifiers by positive feedback, Proc. Nat. Electronic Conf., Vol. VI, p. 103-111 (Apr. 1951).

Automatic Manufacturing Corp., Design of subminiature I-F transformer suitable for automatic assembly to printed circuits, Final Report Contract No. W36-039-SC-4498.

Art of electronic subminiaturization, Bendix Aviation Corporation Pacific Division Development Laboratories, Burbank, California, Contract NOBsr 43430.

Yale Jacobs, Fundamentals of electronic equipment miniaturization, AF Technical Report No. 6105, USAF Air Materiel Command, Dayton, Ohio (Jan. 1951).

U. S. GOVERNMENT PRINTING OFFICE : O—1954

Related Publication of the National Bureau of Standards

Printed Circuit Techniques:
An Adhesive Tape-Resistor System Circular 530, 40 cents

. . . For several years the Navy Bureau of Aeronautics has sponsored a program of printed-circuit evaluation and development at the National Bureau of Standards for the purpose of improving techniques for printing electronic circuits and subassemblies for airborne use. The production of individual resistors to close tolerance is difficult, and the reduced probability of producing a number of resistors on the same base to reasonable tolerances greatly affects the yield of acceptable assemblies. This Circular presents a complete description of NBS developmental work on an adhesive tape-resistor permitting close control of resistance values.

The tape-resistor, a carbon-film resistor in the form of an adhesive tape, covers a range of 10 ohms to 10 megohms. The use of asbestos paper tape and silicone resin binder results in a resistor capable of operation up to 200° C. Because the curing temperature is high, 300° C for several hours, the tape is applicable at present only to glass or ceramic base materials.

. . . The Circular gives detailed information on production of the resistors and on equipment and materials needed. It describes the ovens, switching equipment, and recorder for making load-life tests. Appendixes include data on each of the carbons studied and a source of supply list for all uncommon materials and equipment used. The book contains 5 chapters, 32 figures and 1 table that amply illustrate the text.

DEPARTMENT OF COMMERCE
UNITED STATES OF AMERICA