NBS CIRCULAR 548

Miniature Intermediate-Frequency Amplifiers

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Miniature Intermediate-Frequency Amplifiers

Robert K-F Scal

National Bureau of Standards Circular 548

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Price 40 cents

Foreword

Size and weight reduction of electronic equipment is becoming increasingly important for many applications, particularly in military equipment. A continuing program for the development of miniaturization techniques and their application to airborne electronic equipment has been carried out at the National Bureau of Standards under the sponsorship of the Bureau of Aeronautics and the Bureau of Ordnance, Department of the Navy. One phase of this program, the miniaturization of radar components, has resulted in a number of innovations in electronic miniaturization technology. The purpose of this Circular is to make the result of some of this work more readily available to the electronics industry.

The projects reported herein were performed under direction of J. G. Reid, Jr., former chief of the Electronics Division, National Bureau of Standards, and constitute part of a broad miniaturization program. The work on these projects was conducted under the general supervision of P. J. Selgin, Chief of the Engineering Electronics Section, and the direct supervision of Robert K–F Scal, Chief of the Radar Miniaturization Unit. This work was carried out as part of several broader projects during the period from 1948 through 1953 by R. K–F Scal, C. O. Lindseth, and L. Landsman. Mr. Scal and Mr. Lindseth cooperated in designing and detailing the model V and VI amplifiers, including preparation of section 3.1 of this Circular. Mr. Landsman was responsible for most of the work on the model VII amplifier. Mr. G. Shapiro assisted in planning the model V amplifier and contributed the idea of the individual stage chassis.

The nature of this work and the need for specific information on the part of the Navy and industry have led to the mention of specific proprietary products and manufacturers either by name or by identifying type number. Such mention of proprietary products does not mean that NBS conducted an exhaustive survey of these products; the objective was to achieve miniaturization techniques as quickly as possible. The fact that NBS has mentioned either products or manufacturers shall not constitute a basis for the use of the name of NBS, this Circular, or any portion thereof, in advertising, sales promotion, or public-relations activity. Here the policy of the National Bureau of Standards is explicit: Neither its name nor materials, including publications, shall be used in any way to suggest, directly or indirectly, the Bureau's endorsement of any proprietary product, process, or material.

A. V. Astin, *Director.*

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MINIATURE INTERMEDIATE-FREQUENCY AMPLIFIERS

by Robert K-F Scal

Three miniature high-gain, high-frequency, intermediate-frequency amplifiers (20 to 100 Mc) were developed with particular emphasis on the use of circuit elements suitable for maximum design simplicity, circuit flexibility, and ease of manufacture. The units are about one-eighth the size and one-half the weight of the equipments they supersede. The circuitry was designed with emphasis on the use of subminiature tubes and their application in low-noise input circuits. Some units are hermetically sealed for protection against contamination and moisture, and to provide for operation under the extreme temperature range (-65° to +200° C) required for such equipment.

1. INTRODUCTION

In military applications of miniature electronic systems, ease of production is almost as important as reduction in size. This requirement has motivated considerable research in new techniques and materials for use in the manufacture of electronic equipment. In the National Bureau of Standards program for adapting these techniques to more complicated electronic devices, the intermediate-frequency amplifier was chosen as an initial device for miniaturization because it embodies critical circuit layout and presents many typical problems.

Seven different models of intermediate-frequency amplifiers were designed for two bureaus in the Department of the Navy during the period from 1947 through 1953; models I, II, and IV are miniaturized versions of existing amplifiers and were developed for the Bureau of Aeronautics; models III and V were direct extensions of that work developed for the Bureau of Ordnance. Models I and IV were experimental designs, and only preliminary units were built. A report on model II, which was a considerably larger unit, is covered in the Final Report on Electronic Miniaturization (NAer 00685) issued September 1949[1]. Model III, also reported in the Final Report on Electronic Miniaturization, was another experimental unit used primarily for thermal tests, which are described in section 2 of this Circular.

The model V miniature intermediate-frequency amplifier (section 3.1 of this Circular) was designed in connection with a program of development of radar components at the National Bureau of Standards. The basic requirements of miniaturization without deterioration of electrical performance, and of producing a manufacturable end product have in general been fulfilled. Progress has been made toward fulfilling the secondary requirement of operation over the ambient temperature range of -65° C to +100° C. Provisions for hermetic sealing minimize the effects of moisture condensation at low temperatures and satisfy conditions for operation at high altitudes. Use of materials especially selected for high-temperature operation has given good indication that life expectancy of the miniaturized unit should be equivalent to that of conventional equipment, despite high internal temperatures.

The model VI miniature intermediate-frequency amplifier (section 3.2) is an improvement mechanically, and a simplification of fabrication of the model V. As an indication of the simplification of fabrication attained in the Model VI, only 40 drawings were required as compared to about 80 for the model V. As many types of circuitry may be used with this design, the circuitry incorporated in this particular amplifier is not of great significance and, therefore, is

[1] National Bureau of Standards, Electronic Miniaturization (Final Report), Office of Technical Services, Department of Commerce, PB-100949(1949).

not discussed in detail. However, it should be noted that this model is the first miniature amplifier built to a specific requirement, where no larger prototype previously existed. Certain other design details of the model VI amplifier are similar to those used in previous amplifier models. These details, such as ceramic metallizing techniques and potting methods, are discussed in the Final Report on Electronic Miniaturization (NAer 00685) September 1949.

It is believed that the general design of this amplifier is sufficiently flexible so that it can be used over a center frequency range of perhaps 20 to 100 Mc.

The model VII miniature intermediate-frequency amplifier (section 3.3) is another amplifier built to a specific requirement. This amplifier is very similar to the earlier models, but advantage was taken of slightly larger available installation space to design a more rugged and more easily manufactured unit. This amplifier also features a processed plate main chassis.

2. COMPONENT THERMAL REQUIREMENTS FOR COMPACT MULTITUBE MINIATURE ELECTRONIC ASSEMBLIES

2.1. Operation in Elevated Ambient Temperatures

Heat tests were performed to determine the operating characteristics with regard to heating in the model III intermediate-frequency assembly. The information obtained outlines the required heat characteristics of materials (such as wire insulations, coil forms, etc.) and components (such as resistors and capacitors) that are partially or completely enclosed within the intermediate frequency assembly. It should be noted that this unit is representative of many extremely compact multitube miniature electronic assemblies, and therefore the information gathered in these tests is applicable to such equipment whenever the heat dissipation and radiation efficiency are of the same order of magnitude.

Four series of tests were made. In each case the assembly was operated with its 11 tubes in place. Their heaters were energized with rated voltage and current, while their plates and screens, tied together, were supplied with a voltage such that the total power dissipation equalled that which prevails during actual operation. The total values for the 11 tubes were:

Heater power	14 watts.
Plate and screen power	12 watts.
Total dissipation	26 watts.

For all the tests, the internal temperatures were obtained by means of thermocouple elements placed within the assembly. Five thermocouples were used, located as follows (see fig. 1):

1. In the central tube cavity, between the tube and the cavity wall.

2. In a central resistor cavity, adjacent to the above tube cavity.

3. In a rear resistor cavity adjacent to position 2, above.

4. In a center resistor cavity adjacent to an end tube cavity.

5. In a center resistor cavity at the center of the lower (transformer) block.

Each of the resistor cavities holding a thermocouple was sealed at each end to prevent air circulation through it, thereby more nearly simulating operating conditions in which one or more resistors or capacitors occupy the cavity.

The first test was performed with the assembly placed on a Masonite surface and exposed to air circulating within the laboratory. Power was applied to the assembly, and the temperature at each test point was recorded every quarter hour until it had stabilized.

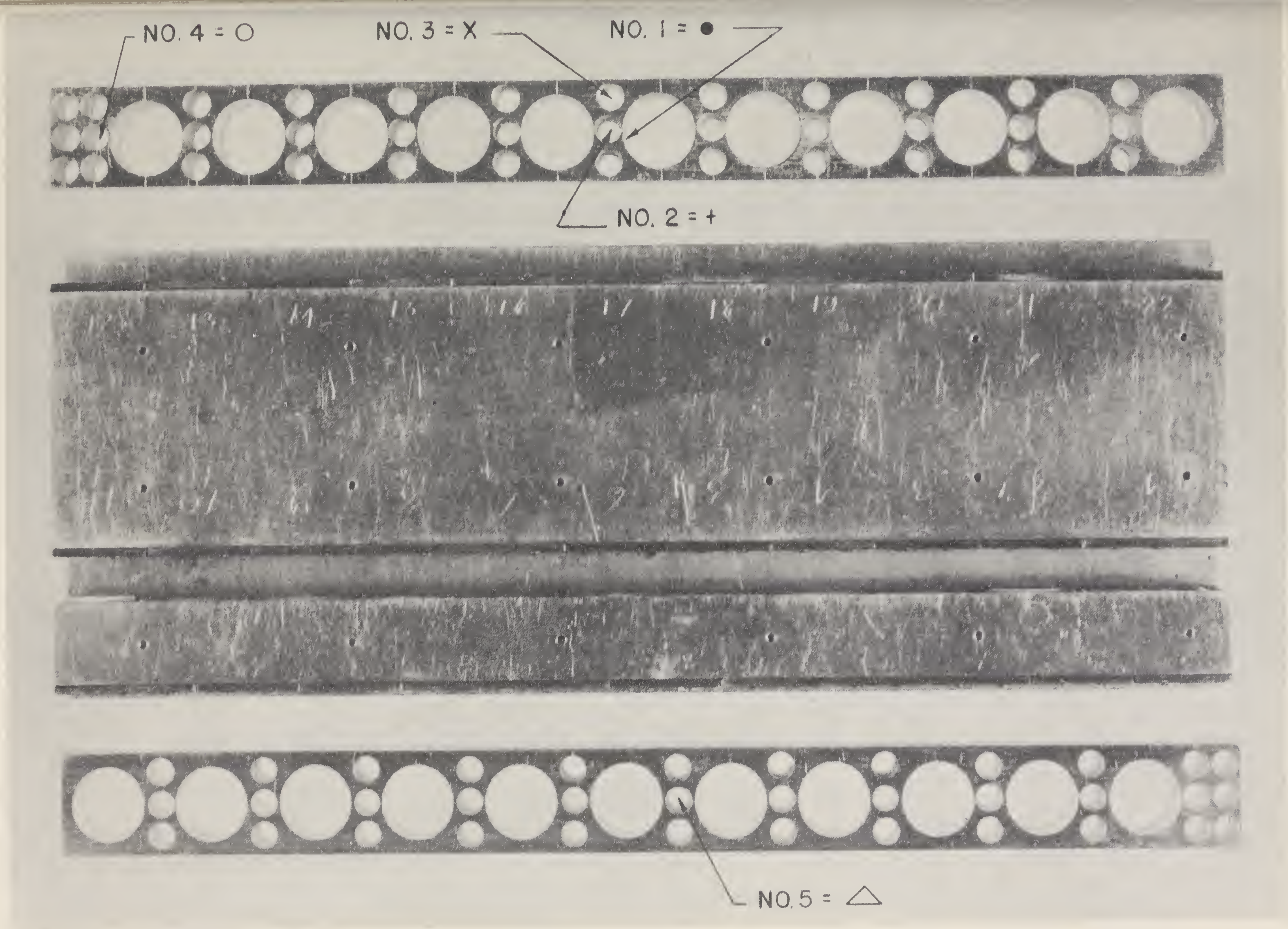

Figure 1. Thermocouple placement for heat tests of intermediate-frequency assembly.

The second test was a repetition of the first, with the exception that the i-f assembly was placed upon a 2-sq-ft sheet of 1/32-in.- thick aluminum. This simulated contact with a typical chassis radiating surface.

The third test was made with the i-f assembly supported on ceramic blocks in a temperature-controlled oven. The temperatures at the various test points were recorded as a function of oven temperature.

The lowest ambient temperature obtained was that which prevailed when the oven heater element was turned off, and stable temperature equilibrium was brought about by the heat radiated from the strip under test. From inspection of the linear curves obtained in this test, it appears that they may be extended to room temperature without introducing a serious error.

For each oven temperature, the i-f assembly temperatures were read about one-half hour after the oven temperature had attained equilibrium. This was sufficient time for the internal temperatures at the various test points to have reached equilibrium.

In the fourth test, the metal plate from the second test was placed directly under the i-f assembly, and, after thermal equilibrium had again been attained at an oven temperature of 85° C, the temperature at each of the five test points was recorded.

Figure 2, with temperature as a function of time for each of the five test points of the assembly placed on a Masonite surface, shows the following characteristics:

1. Temperature rise is quite rapid, reaching 90 percent of its equilibrium value during the first quarter hour.

2. The temperatures at the five test points have essentially the same relationships to one another throughout the test.

3. The temperature variation between the various test points does not cover a sufficiently large range to be a significant factor governing placement of parts.

Figure 3 (similar to fig. 2, but showing results of test two), with the i-f assembly on the metal plate, shows the following effects of the additional cooling area:

1. The internal temperatures were lowered by about 20 to 25 deg C for an ambient temperature only 5 deg lower. (The room temperature had dropped when test two was made.)

2. The temperature differential between the test points increased, but not sufficiently to be of any significance.

Figure 4, with temperature of the test points as a function of oven temperature, shows that the former varies directly with the latter.

Figure 4 also shows points obtained from test four (labeled strip on 2-sq-ft metal plate). These tests show that placing the assembly on a metal plate at the high ambient of 85 deg C reduces the temperature of the internal test points by about 20 deg.

2.2. Operation in Subzero Ambient Temperatures

This test was performed in order to determine the lowest operating temperature required for components within an i-f assembly operating in subzero ambient temperatures as low as -55° C.

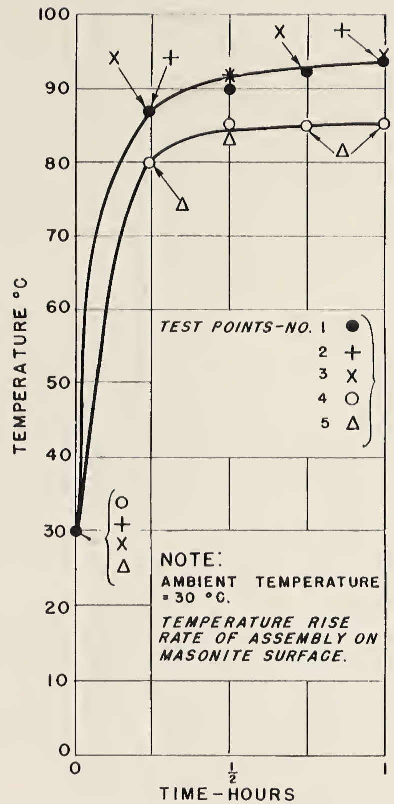

Figure 2. Heat test on Masonite surface.

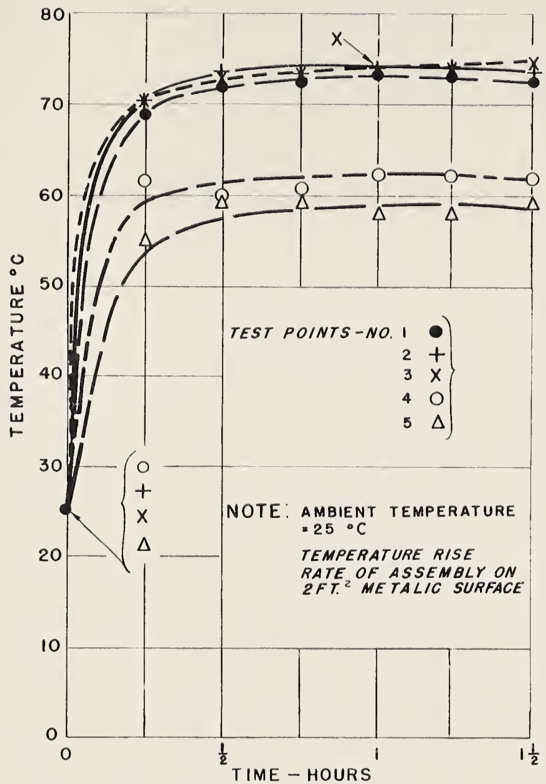

Figure 3. Heat test on metallic surface.

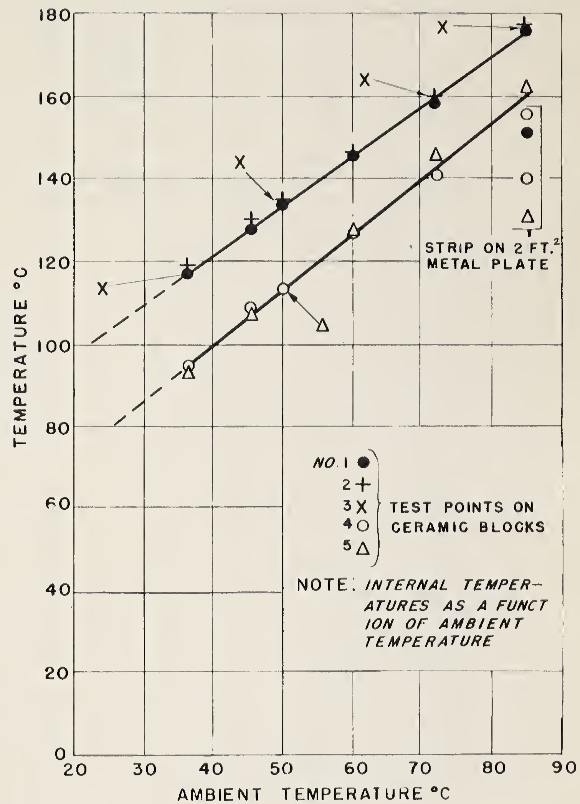

Figure 4. Heat test for various ambient temperatures (on metallic surfaces).

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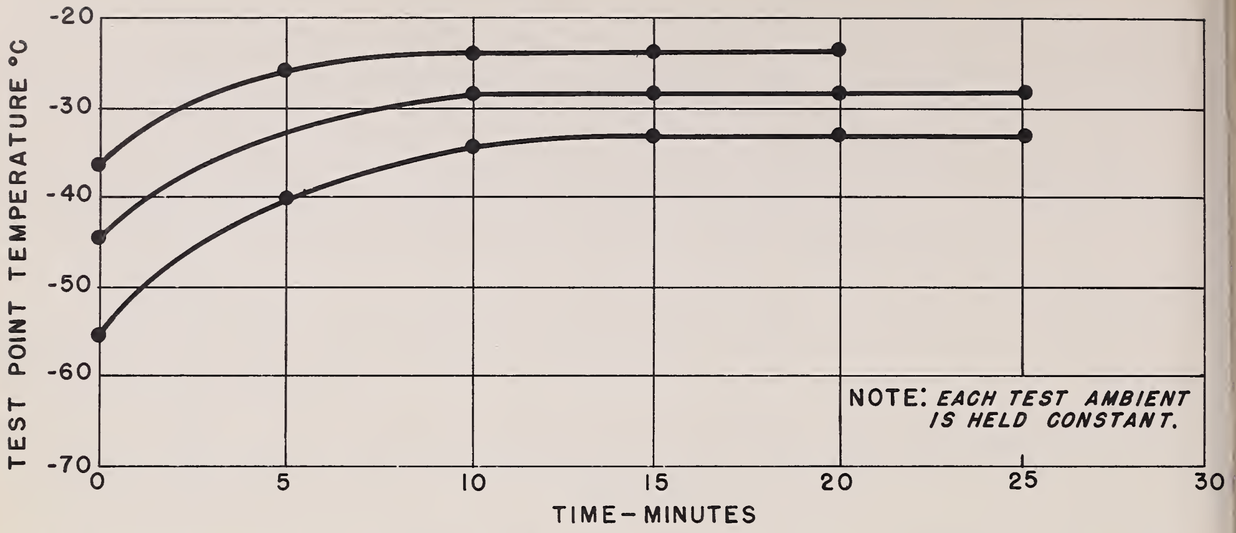


Figure 5. Heating in intermediate-frequency assembly at extremely low ambient temperature.

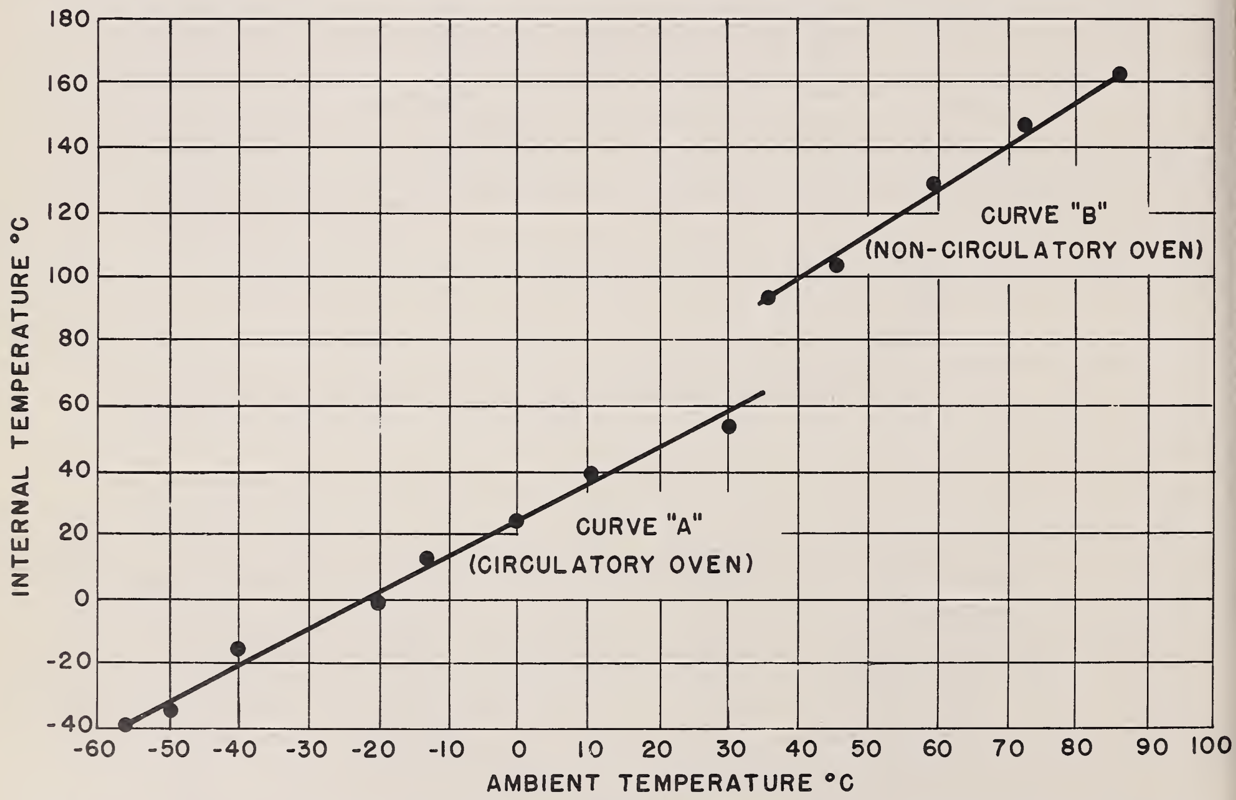


Figure 6. Internal temperature vs ambient temperature of intermediate-frequency assembly.

The assembly was placed within a cold chamber, the temperature of which was then stabilized at a subzero starting temperature. Power was applied to the heater, plate, and screen circuits, thereby simulating operating conditions.

Figure 5 shows three plots, the results of three similar tests but with slightly different starting temperatures; each showing the temperature of the test point (no. 5, fig. 1) as a function of time, starting when power was applied.

Maximum temperature at the test point was reached within 10 to 15 minutes after power was applied. This temperature varied from 12 to 22 deg C above the external ambient temperature in the three tests. It should be noted that the three curves differ in amount of rise largely due to experimental error. It is very difficult to control this type of determination. For example, holding the oven at a constant ambient temperature while the assembly is heating is complicated by the rise caused by the assembly. Even the measurement of this ambient is difficult due to the gradient within the heat test chamber. For these reasons the three curves of figure 5 must be considered as similar tests, varying experimentally, and no comparison should be made amongst these curves.

It is concluded that heat dissipated within the assembly cannot be relied upon to keep the internal components operating at a temperature appreciably above the ambient temperature when the latter is in the region of -55° C to -35° C. It is true that the chosen test point shows the extreme condition (in that it is the coldest), but it is the extreme condition that governs choice of components because one anticipates uniform temperature requirements for all components of a similar nature within the same assembly.

An additional test was made to ascertain variation of temperature at test point No. 5 with changes in ambient temperature in the region below room temperature. The test chamber was stabilized at each ambient temperature, and then the corresponding test-point temperature was measured. The resultant curve is shown in figure 6 (curve A). The slope of this curve is approximately 1.1, which indicates that there is a nearly constant difference between the ambient temperature and component operating temperature. Curve B, figure 6, is a similar plot for the region above room temperature (it is a replot for test point 5, fig. 4). It has a slightly greater slope than curve A, and at 30° C lies about 15 deg above curve A, which is attributed to the fact that the equipment necessary for obtaining curve A included a circulatory oven, whereas curve B was made in a noncirculatory oven, and therefore the temperature gradients around the assembly were different for the two cases.

2.3. Design Considerations

It should be noted that simply specifying an ambient temperature is not a sufficient description of operating conditions with respect to heat considerations. The nature and amount of air circulation must also be considered. Test three was made in a noncirculating oven, which simulates placing the i-f assembly in an electronic equipment having no ventilation. On the other hand, the room-temperature tests conducted in the open are more representative of equipment having free air circulation. In this connection, it is observed that the points from these tests lie below the curves obtained from the tests made in the oven.

The effect of circulating air at a given ambient temperature, together with the lower internal temperatures obtained with the i-f assembly placed on a metal plate, indicates that there is some value to increasing the surface area (by grooving, use of fins, etc.). Whether or not this is done should depend on the individual circumstances surrounding each application. In general, a 10 to 20 deg C lower internal temperature might be obtained in this way without even resorting to forced air circulation, which would, of course, further improve the cooling efficiency. On the other hand, unless this moderate lowering of internal temperature is clearly indicated as necessary for a particular application, it is doubtful as to whether this comparatively small gain is justified in view of the extra expenditures, both in design and construction of the equipment, and in the extra space required for fins, air passages, blowers, etc.

In view of the above, it might also be pointed out that even doubling the volume of a given assembly will not appreciably improve its internal temperature operating conditions as this does not double the radiating area. In fact, even if space is available for a larger assembly, it may still be desirable to design the assembly as small as possible and use the additional volume for cooling fins. It should also be noted that since the smaller (transformer) block of the i-f assembly, which is almost entirely separate from the upper (tube) block, operates at only a slightly lower temperature, there would be little value from the viewpoint of temperature considerations in isolating all resistors, capacitors, and inductors from the tube block. Of course, this might be quite disadvantageous with regard to certain other considerations. The absence of hot spots is a particular design advantage.

The metal on which the i-f assembly was placed assumed the temperature of the assembly in the region near the assembly, but the edges of the plate rose only slightly above room temperature. It is evident that a larger plate would have had little effect in reducing the temperature of the assembly still further.

When assemblies of this type are operated at room temperature, their components, such as resistors and capacitors, should be capable of operation at ambient temperatures of at least 100° C (i.e., the temperature within the component cavities, when no power is being dissipated by components within these cavities). Where the external ambient is in the region of 85° C, the components must be able to withstand a temperature in the region of 200° C.

It is obvious that insulating materials used within the block must also be of high-temperature type. Use of inorganic material is indicated. As parts of the assembly may exceed the melting temperature of ordinary solder, care must be taken to use special high-softening-point solder where required.

In installing this type of equipment, the mounting should be such as to provide a good thermal bond between the assembly and the mounting surface. Whether or not use is made of fins or grooving, free-air or forced-air circulation, and other aspects of cooling will depend on each individual installation. As these cooling problems must be considered in conjunction with the entire equipment, they can more readily be handled by the system engineer. In any case, any type of cooling should be held to the minimum commensurate with reliable operation, in order to conserve space.

Another possibility of reducing temperature is by improvement of radiation by means of blackening (black anodizing or similar processes). But here again the value of such treatment depends on each particular installation.

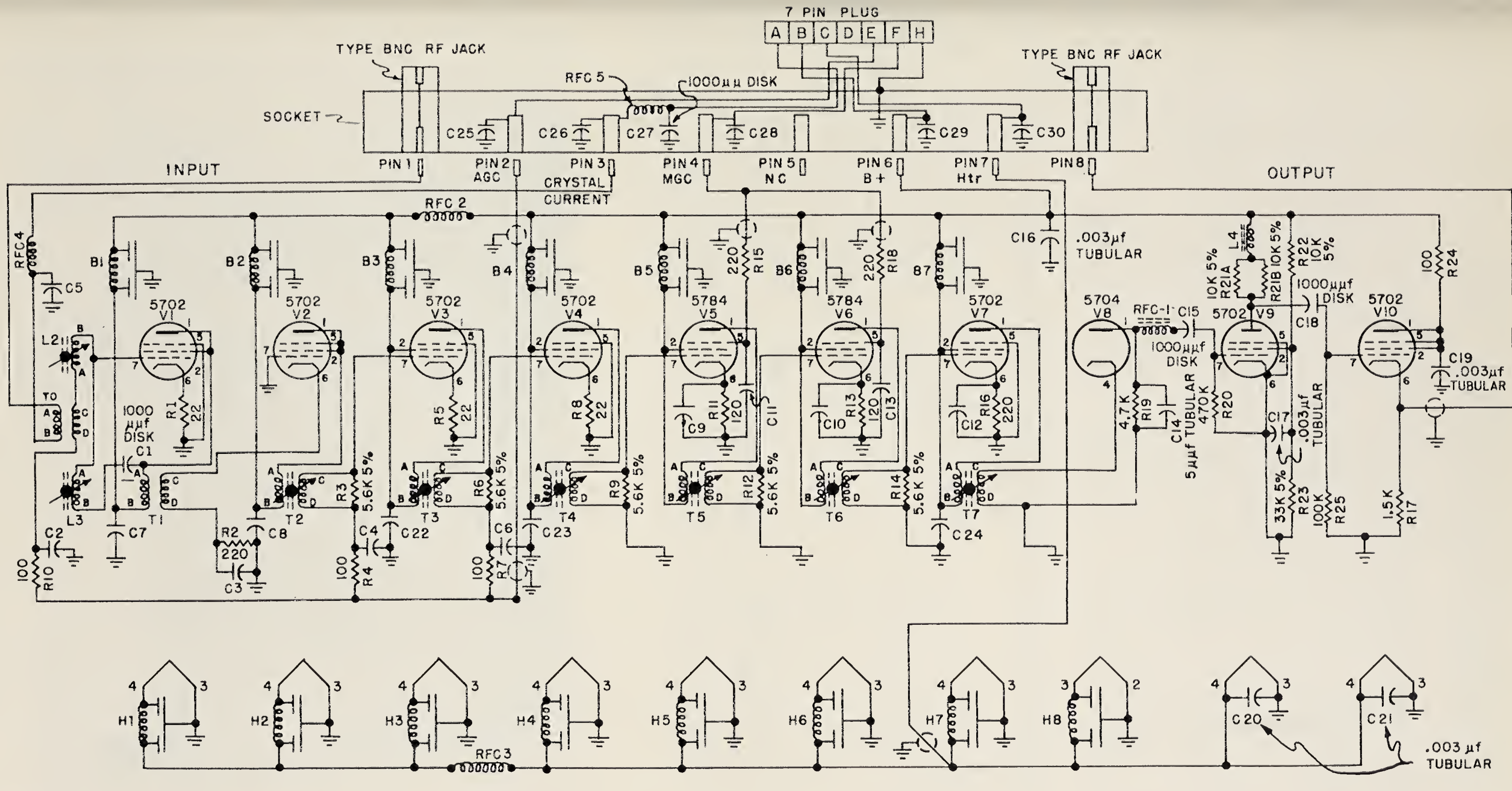
It is recommended that emphasis be placed on obtaining satisfactory results at high operating temperatures.

3. INTERMEDIATE-FREQUENCY AMPLIFIERS

3.1. Model V Miniature Intermediate-Frequency Amplifier

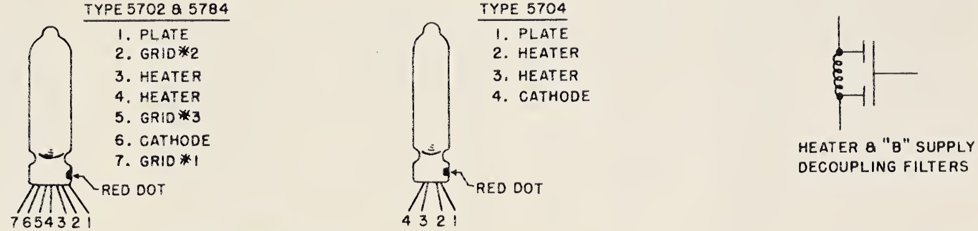
(a) General Description

A conventional i-f amplifier, designed earlier, which fulfilled the electrical requirements, was used as a model, and the general scheme of the earlier unit was followed. The major problem was expected to be the development of low-noise circuitry for the front end. This problem was treated as a separate study and is described in section 3.1(a) of this Circular. The final circuit, shown in figure 7, consists of an "L" input network coupling into a cascaded grounded-cathode triode and grounded-grid triode to form a low-noise input circuit. The input triodes and the first pentode stage form the first staggered pair, which is followed by two more staggered pairs. About 120-db gain over a 4-Mc bandwidth as shown in figure 8 is provided by these seven i-f stages. Automatic gain control is supplied to the first, third, and fourth i-f stages, and manual gain control to the fifth and sixth stages. Control voltages are supplied through the power cable. Compensation is included to minimize



NOTES:

1. ALL CAPACITORS ARE SILVERED CERAMIC TYPE. CAPACITORS NOT OTHERWISE IDENTIFIED, ARE TUBULAR CAPACITORS OF 1000μμf MINIMUM CAPACITY AT ROOM TEMPERATURE.
2. MINIMUM NEGATIVE AGC VOLTAGE = 0.5
   MAXIMUM POSITIVE MGC VOLTAGE = 6.0
   HEATER VOLTAGE: 6.3 AC; B+ VOLTAGE; +100
3. ALL RESISTORS 1/4 WATT 10% TOLERANCE UNLESS OTHERWISE NOTED. (WILKOR CP 1/4 OR EQUIVALENT.)
4. ALL TRANSFORMERS ARE BIFILAR WOUND.
5. TUNE LOW FREQUENCY STAGES (T2,T4,T6) TO 58 Mc
6. TUNE HIGH FREQUENCY STAGES (T3,T5,T7) TO 62 Mc



TYPE 5702 & 5784
1. PLATE
2. GRID #2
3. HEATER
4. HEATER
5. GRID #3
6. CATHODE
7. GRID #1

TYPE 5704
1. PLATE
2. HEATER
3. HEATER
4. CATHODE

TUBE CONNECTIONS

Figure 7. Circuit diagram of model V amplifier.

MANUAL AND AUTOMATIC GAIN CONTROL VOLTAGES				
	AGC (V)	MGC (V)	* CENTER FREQ.	* BAND WIDTH
	—3	— 3	60.2 Mc	4.7 Mc
			*··FOR 3 DB POINT	

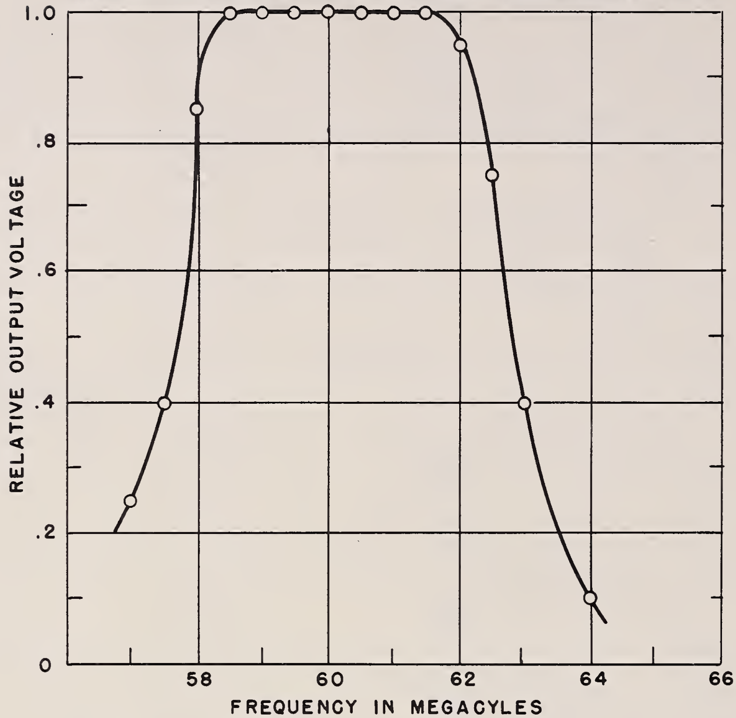


Figure 8. Bandpass characteristics of model V amplifier.

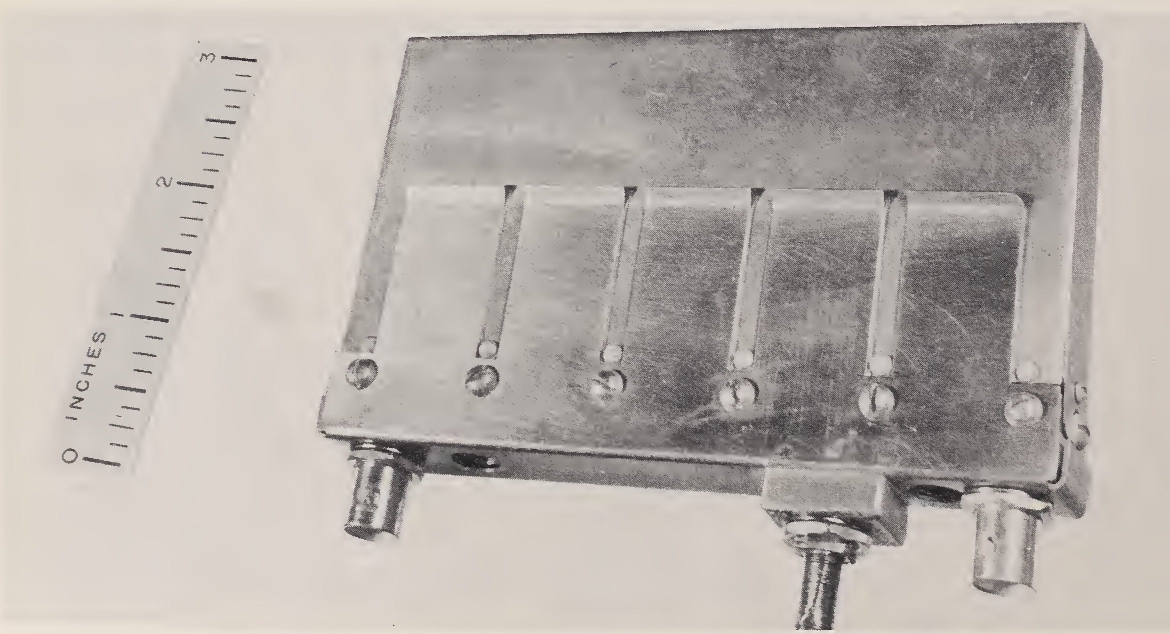


Figure 9. Model V amplifier seated in socket.

change of bandpass characteristics with variation of control biases. This i-f section is followed by a diode detector, a video amplifier, and a cathode follower output stage.

The basic i-f amplifier shown in figure 9, was designed with the intent of obtaining a design useful at any center frequency between 25 and 125 Mc. The model V unit operates at the commonly used center frequency of 60 Mc. However, sufficient bypass capacity has been provided for operation at the lower frequencies. For operation at either higher or lower frequencies, only slight modifications in the tuned circuits should be necessary.

The general amplifier construction follows a modular pattern designed for simple fabrication and straightforward assembly. The electrical characteristics and the physical embodiment have been designed to fulfill specific requirements. The completed assembly is very rugged mechanically.

In order to allow for possible large-scale production, each part of the amplifier has been critically reviewed with regard to producibility, and it is believed that all parts can be produced by ordinary manufacturing methods.

Several of these amplifiers have already been manufactured in the National Bureau of Standards shops with comparatively little difficulty.

The model V i-f amplifier is enclosed in a 4-3/4 by 2-5/16 by 5/8-in. case, which has been designed to lend itself to hermetic sealing. It is a plug-in-type unit. The socket adds an additional 9/16-in.-to the 2-5/16-in.-dimension. A multiple cable provides all connections to the socket except the coaxial input and output, which are provided by type BNC r-f jacks. The amplifier weighs about 8 oz, with slightly over half of this weight being contributed by the housing. The socket weighs about 4 oz.

The hermetic sealing provisions make it possible to operate the unit over the entire ambient range of -65° C to +100° C. It is anticipated that dry nitrogen would be used as an inert internal atmosphere. Another gas having better heat-transfer qualities might be chosen, however, in order to even further reduce the small temperature gradient within the strip. Finally, it is possible that a liquid might be used for filling the unit.

(b) Internal Structure: Component Parts

The internal structure consists of a linear array of individual subassembled stages shown in figure 10. The types and number of stages are selected to attain the desired amplifier characteristics. Assembly of the prefabricated stages, one of which is detailed in figure 11, is the final step in the amplifier construction.

Most of the component parts (which are illustrated in fig. 12) have been selected for this amplifier with the following criteria in mind: (1) to give equal or better performance than their larger counterparts, (2) to be adaptable to straightforward and large-scale production, (3) to be rugged mechanically, (4) to be trouble-free electrically, and (5) to withstand high-temperature operation (200° C being the goal).

The high-temperature requirement is brought about by the fact that, since the miniature amplifier is designed to be equal in performance to the conventional unit it replaces, it must be expected to dissipate approximately the same amount of power. Actually, as some of the subminiature tubes require more heater power than the equivalent performance miniatures, more power is dissipated in the i-f amplifier using subminiature tubes. About 20 watts are dissipated. The miniature amplifier occupies about one-eighth the volume of the unit it replaces. At room-temperature ambient, the internal temperature is in the region of 100° to 150° C, depending on automatic gain set (which influence power dissipation to a surprisingly large extent). At 100° C ambient, internal temperature may exceed 200° C.

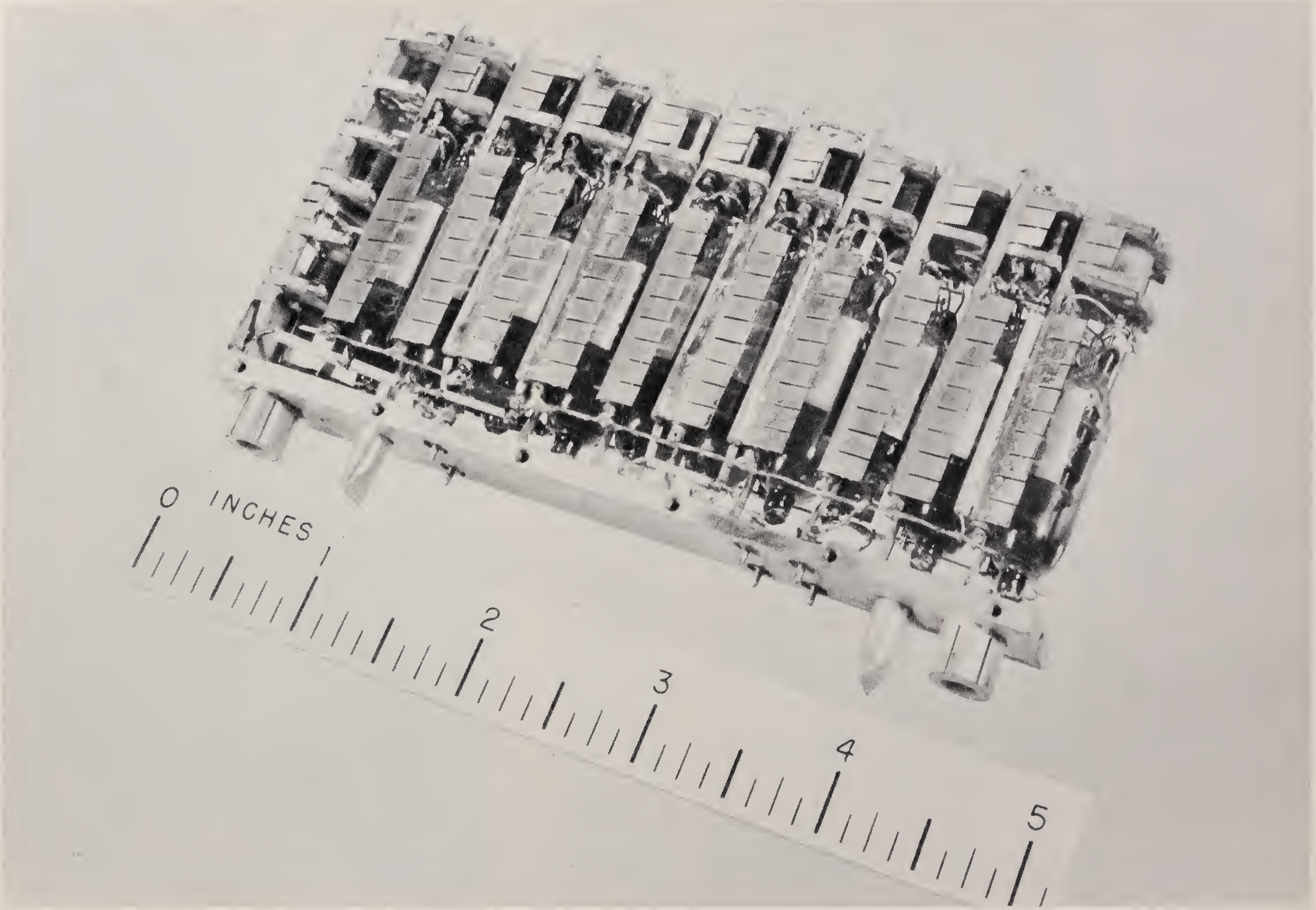


Figure 10. Model V amplifier mounted on plug type base plate.

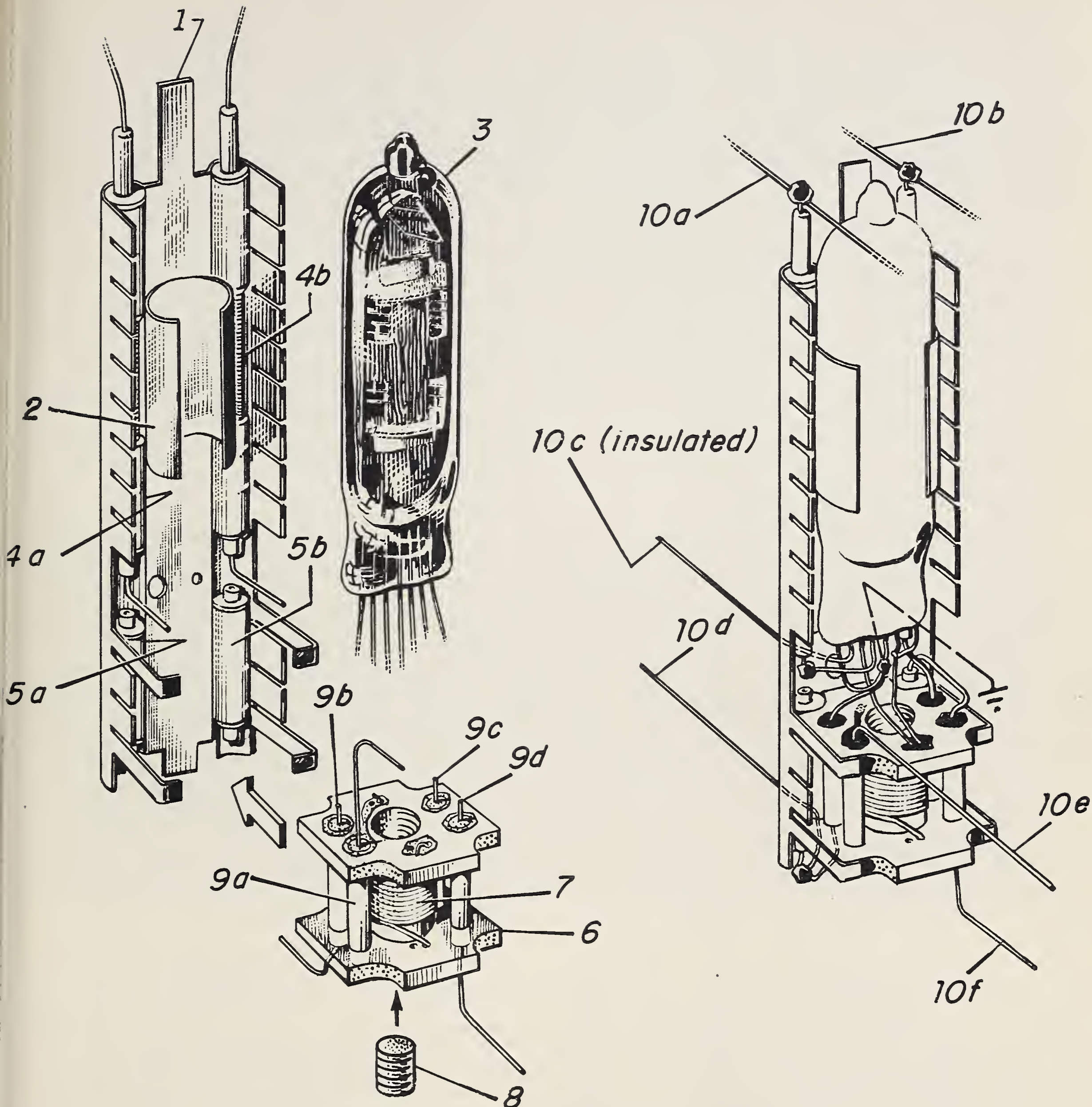


Figure 11. Model V amplifier stage construction.

1-Chassis plate	6-Inductor form
2-Tube clip	7-Bifilar inductor
3-Tube	8-Tuning core
4-Decoupling filters	9-Resistors
5-Bypass capacitors	10-Interstage connections

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Three standard subminiature tube types are employed. Type 5784 WA (T-3 subminiature type with characteristics similar to 6AK5) is used for all i-f stages except those to which MGC (manual gain control) is applied, and also for the video amplifier and cathode follower. The 5702 WA is a high-G_m, low-capacity pentode, but is used in a triode connection in the low-noise front end. The two stages to which MGC is applied use dual-control-grid pentodes, type 5784 (T-3 subminiature type with characteristics similar to 6AS6), and the diode detector is a type 5704 (T-2 subminiature type, single diode). The type 5702 WA is a ruggedized tube which is rated for 500-hour life at 250° C bulb temperature. Since the 5784 WA and 5704 construction is similar to that of the 5702 WA, it appears that in general the subminiature tube complement is quite satisfactory.

The resistors used for this amplifier are 3/8 in. long and 1/16 in. in diameter, and have axial leads. Cracked carbon on a ceramic rod (processed under Bell Laboratories patents) forms the resistor proper. Resistors in the range 22 to 6,800 ohms have the steatite rod completely coated with cracked carbon and are essentially nonconductive. The higher-value resistors have the resistive element spiralled on the ceramic rod. All of these resistors are rated at 1/4 watt, and, where no appreciable power is dissipated, they are useful at very high temperatures. There are only a few resistors in which appreciable power is dissipated; in one case two resistors are used in parallel, and in another case, the resistor is potted in a silvered ceramic jacket, which in turn is soldered to the metal chassis plate in order to increase the heat-dissipation rate.

Capacitors are of the uninsulated silvered ceramic type and are used in two configurations. One is the flat disk, 0.02 in. thick, silvered on both faces, and is used only in the 1,000-μμf (1/4-in.-diameter) size. The other configuration is tubular and is silvered inside and out. This type has an 0.020-in. wall thickness, and an over-all diameter of 0.125 in. It is used in lengths varying from 1/4 to 1-1/8 in., to give capacities varying from 5 to 3,000 μμf, depending upon the tube length and the dielectric constant of the ceramic used. The tubular type is used for bypass applications only, in which case the outer circumference forms the ground electrode. In most instances a metal insert is soldered into the tubular capacitor and extends beyond the ceramic in order to provide a convenient connection to the inner (ungrounded) capacitor electrode. The inner silvering is extended over one end of the capacitor to provide connection to the inner electrode of the socket bypass capacitors. Except for the 5-μμf capacitor, which is of steatite, all the disk and tubular capacitors are of ceramic having a dielectric constant of about 3,500. The silver is applied by painting or dipping in a special silver formulation, which is air-dried to remove the solvent, and is then fired at 700° C. Where necessary, excess silver is removed by grinding after firing.

The inductive elements fall into three classes: (1) bifilar transformers, (2) inductors, and (3) chokes. The bifilar transformers and inductors are wound on special steatite inductor forms in which holes are provided for supporting the resistors, and which have a threaded core for use of a screw-type powdered-iron tuning core where required. The chokes are wound on small-diameter steatite tubes, which have silvered ends so that both the axial leads and the windings may be securely soldered to the choke form at each end. All inductive elements are wound with Ceroc-ST ceramic-insulated wire. The inductors, bifilar transformers and chokes are vacuum-impregnated with silicone compound. and are cured for several hours at 200° C. Vacuum impregnation of the bifilar transformers is used to provide additional insurance against breakdown between primary and secondary as the plate supply voltage is impressed between these windings in all cases except the input transformer. In addition, during impregnation the threads in the steatite form become filled with silicone. A tap is then run through the form. By thus clearing the threads, a very smooth fit is obtained for the powdered iron core. After final adjustment, the cores are sealed with silicone.

Practically all wiring is accomplished by means of the component leads. In addition, printed leads are used on the ends of the inductor forms for interconnecting the windings with the various resistors mounted in the forms and

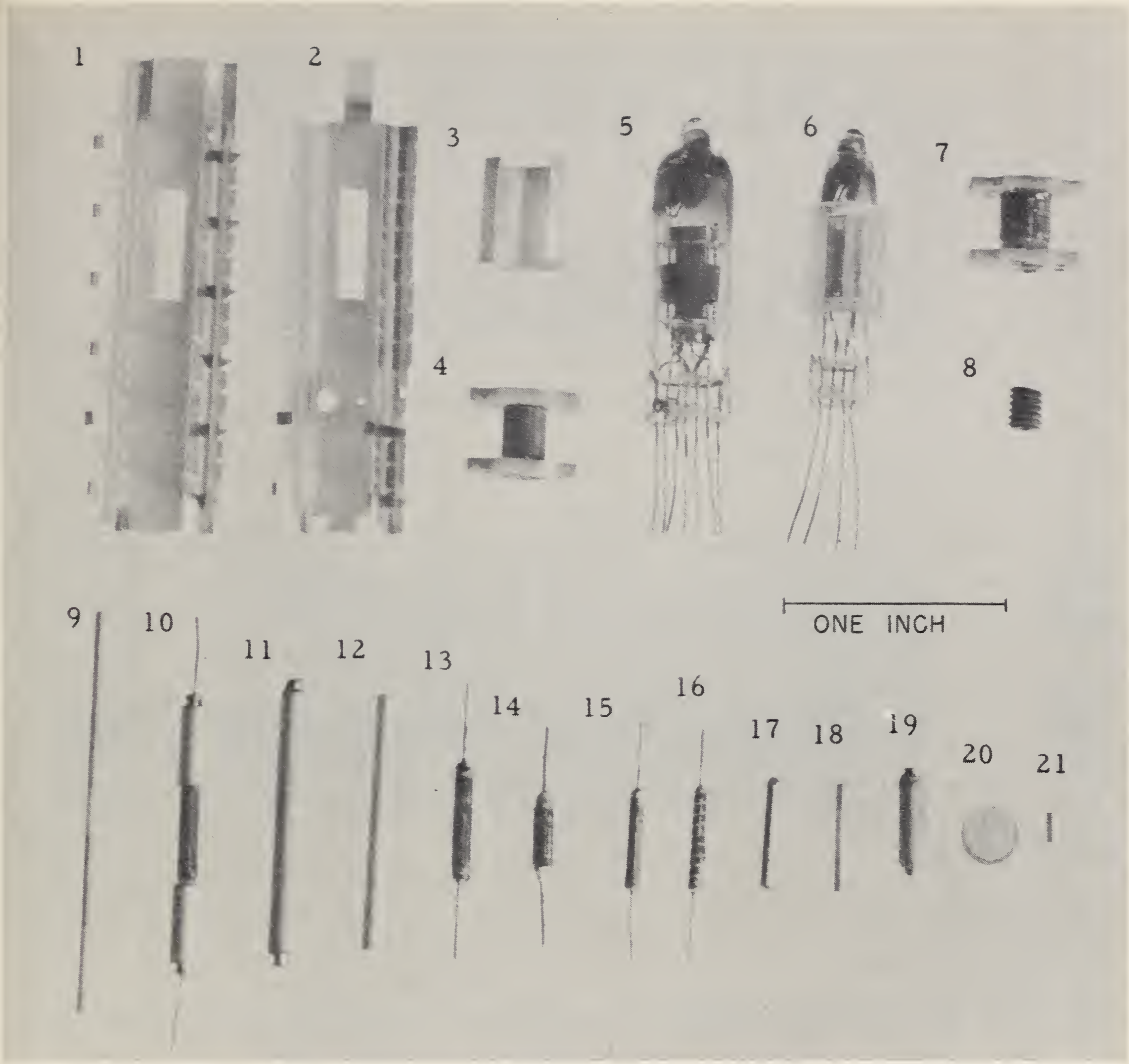


Figure 12. Model V amplifier components.

1.	Input chassis plate	11.	Bypass capacitor (3000 μμf)
2.	Chassis plate	12.	Steatite insulator
3.	Tube clip	13, 14.	Decoupling chokes
4.	Iron core inductor form (fixed-tuned)	15, 16.	Resistors
5.	Vacuum tube (T-3 envelope)	17.	Plate supply connector
6.	Vacuum tube (T-2 envelope) in glass mounting bushing	18.	Steatite connector (tie points)
7.	Inductor (variable tuned)	19.	Bypass capacitor (1000 μμf)
8.	Powdered iron tuning slug	20.	Coupling and blocking capacitor (1000 μμf)
9.	Printed circuit input connector	21.	Steatite grid lead insulator
10.	"Pi" decoupling filter		

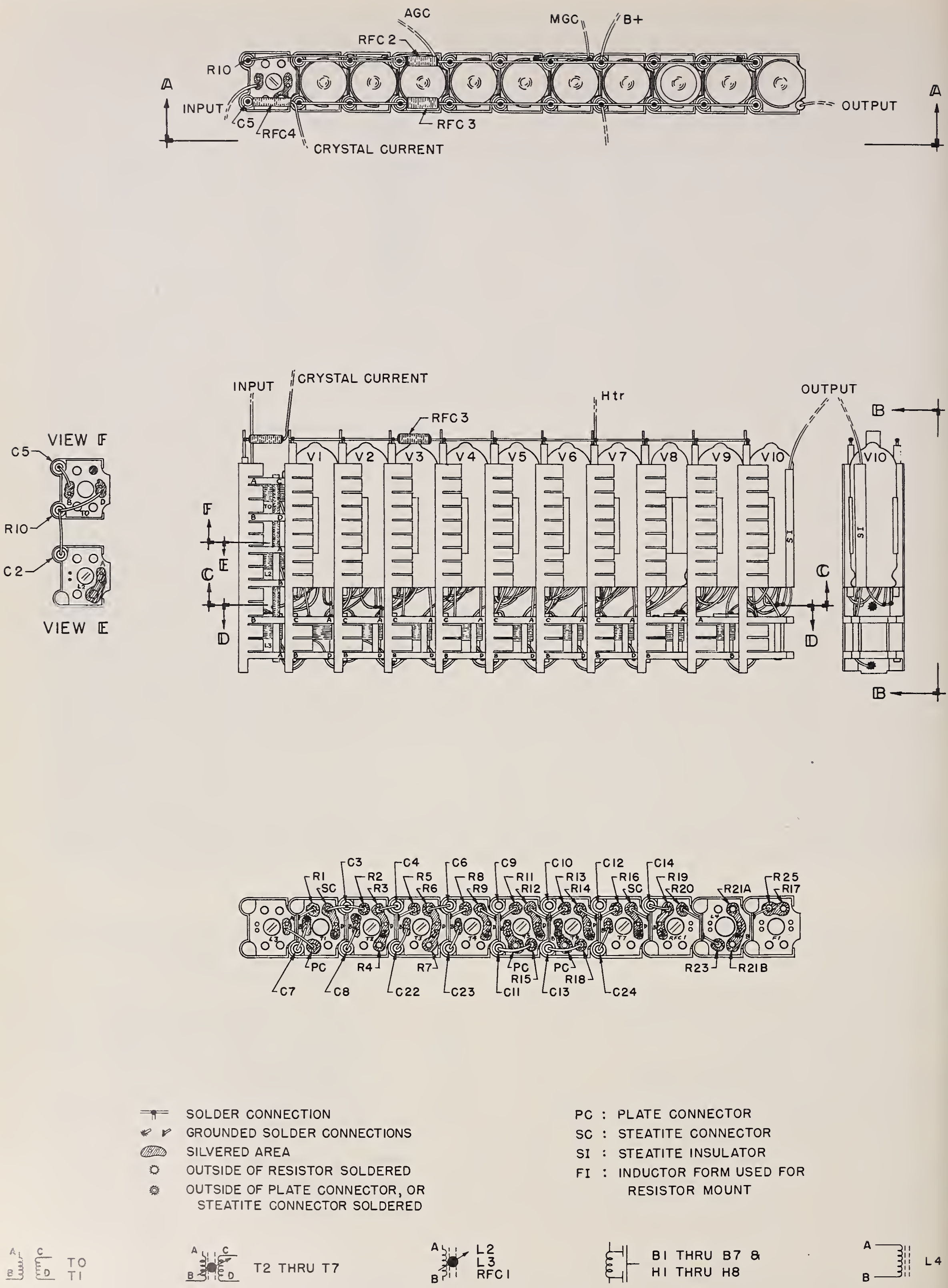
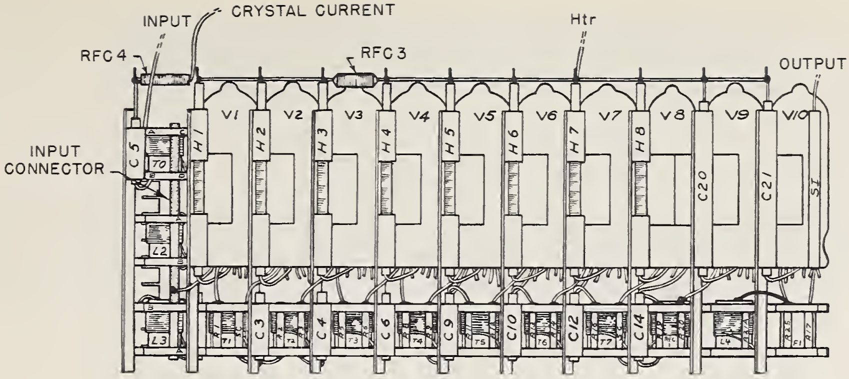
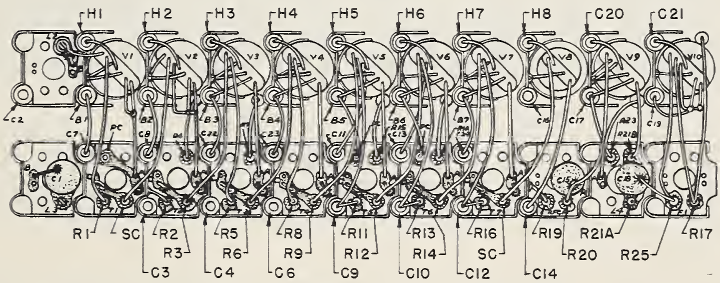


Figure 13. Model V assembly and wiring layout.

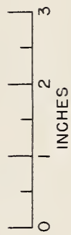


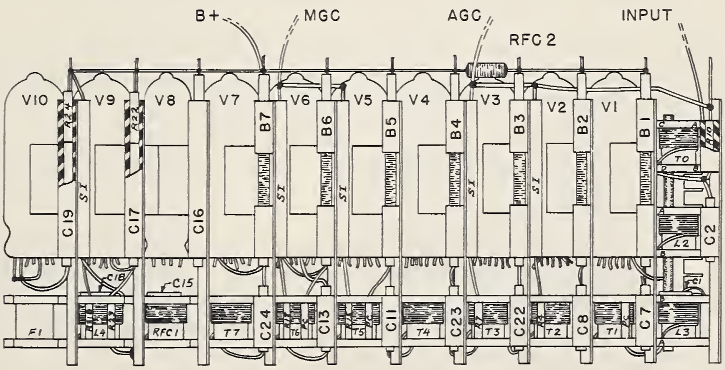
VIEW A-A WITH TABS REMOVED

C-C FULL VIEW

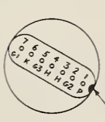


D-D FULL VIEW



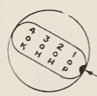


VIEW B-B WITH TABS REMOVED



ALL TUBES EXCEPT V8
V1 THRU V4 } TYPE 5702
V7, V9 & V10 } TYPE 5702
V5 & V6 ---- TYPE 5784

RED DOT



V8 ---- TYPE 5704

RED DOT

Figure 13. Model V assembly and wiring layout. - Continued

also to provide anchor points to which interconnecting component leads may be soldered. Additional wiring is required in a few places, such as for power supply buss bars, connections to plug-in terminals, etc. In these cases uninsulated tinned wire is used, and small-diameter steatite tubes are slipped over the wire in the few places that insulation is required. In the input network a 1/16-in.-diameter steatite tube with a printed circuit on it is utilized to provide several interconnections.

A high-melting-point solder, 95 percent of tin and 5 percent of silver, is used throughout. This composition is not difficult to use, provides good mechanical and electrical bonds, will not soften below about 210° C, and the silver content retards alloying of fired-on silver during soldering operations.

(c) Assembly

The stage assembly is quite simple. Two separate subassemblies are first prepared. The first one is prepared by: (1) soldering the decoupling filters and/or bypass capacitors into the semicircular grooves of the chassis plates, (2) soldering the tube clip into the slot provided in the chassis plate, and (3) snapping the tube into its clip, adjusting its orientation, and soldering the appropriate tube leads to the bypass capacitors or into the hole provided in the chassis plate for ground connections. The second subassembly consists of the inductor form with its printed circuitry, wound and impregnated as required, with the appropriate resistors, capacitors (if any), and tuning slug in place.

The inductor assembly is then placed under the clamps provided for it on the chassis plate, and is soldered at the clamps, thereby uniting the two subassemblies. Finally, the remaining tube connections are made to the inductor form, and the stage assembly is complete. The completed assembly is pictorially illustrated in figure 13.

Certain constructional features of operational significance are to be noted.

1. The chassis plates act as interstage shields, and, except for small openings provided for the stage interconnections, give complete compartmentation of the amplifier. Therefore, in addition to providing shielding, the chassis plates prevent any waveguide propagation within the amplifier.

2. The tube clip secures the vacuum tube at its hottest part (surrounding the plate) and is soldered to the chassis plate. The chassis plates are in turn well bonded to the case. Thus the danger of hot spots developing within the amplifier is minimized.

3. The individual stage assembly design lends itself to good isolation of i-f ground return circuits.

The case is made of 1/64 in.-thick brass and is cadmium plated. Despite its light construction, the assembly is an extremely rigid unit when the amplifier, liner, and base plate are installed. Because under certain conditions it might be desirable to have this amplifier hermetically sealed, all connections are made through glass-Kovar terminals in the base plate, so that sealing the entire unit would merely entail a single soldering operation (i.e., soldering the base plate to the case). While the present case has two additional seams due to the method of forming (the ends are spot-welded and the seams solder-filled), these would not be present in the deep-drawn case, which is recommended for production It might be desirable in certain installations to use a case cast with integral cooling fins, or in event of liquid cooling, to provide an integral cooling jacket.

A 0.004-in.-thick silver case liner is placed about the amplifier. This liner serves two functions. First, it prevents damage to the amplifier during installation and removal of the case. The liner edges hook over the 1/8-in.-thick base plate, and this combination provides rigidity to the amplifier, which would not otherwise be present when it is not installed in the case. The second

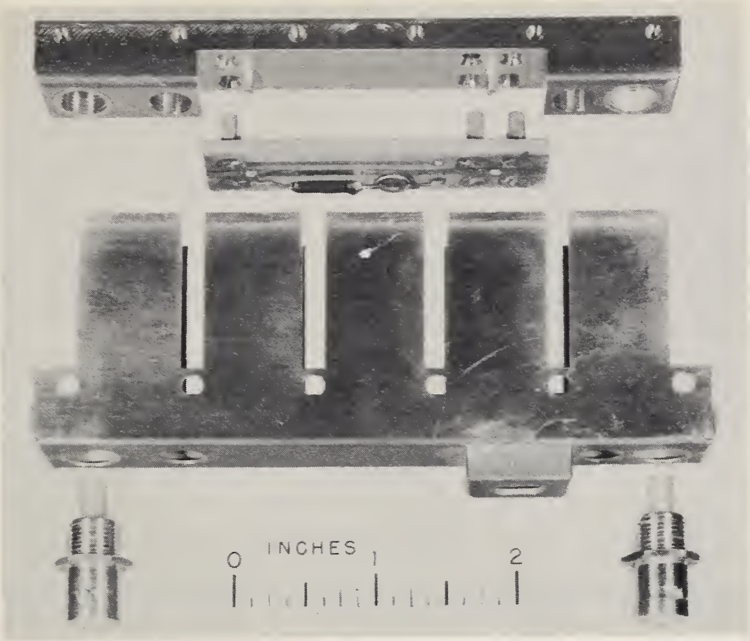


Figure 14. Model V socket detail.

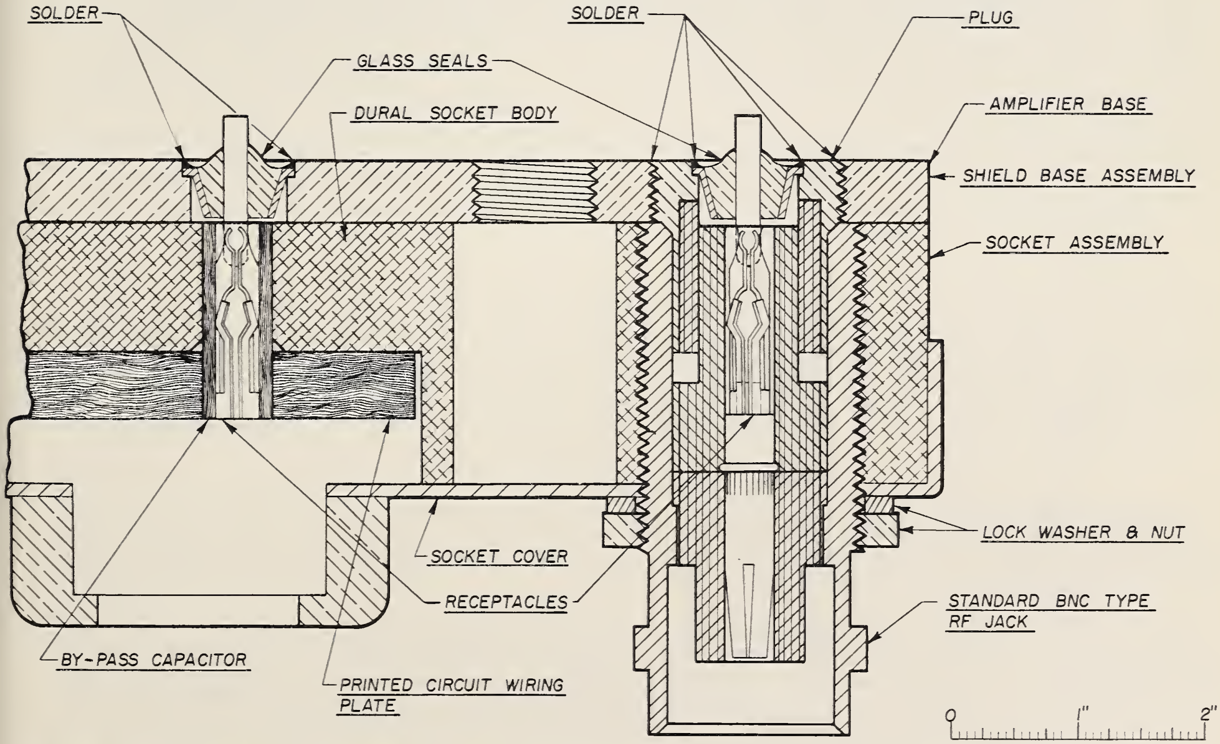


Figure 15. Detail of power (left) and coaxial (right) plugs and receptacles for model V amplifier.

function of the liner is to provide a complete ground return circuit for all the stages (which have no other common ground). The use of a silver liner eliminates the necessity of silver plating the inside of the case in order to assure good electrical conductance. For this reason, a variety of finishes may be applied to the case, but they must withstand high temperature. A black silicone paint, which is suitable for amplifier operation in ambients of 100° C, is available for installations where good radiation from the case can be utilized to cool the amplifier. Under certain conditions, use of this paint has reduced the internal temperature by as much as 20 deg C when operating in an ambient of 85° C.

The base plate is made 1/8 in.-thick in order to provide for tapped holes about its periphery in the screw-assembled unit. In a hermetically sealed unit, the base plate would be 1/16 in.-thick or less. It is made of brass in order that the glass-Kovar plug-in terminals may be soldered into place. The input and output connectors are coaxial-type plugs, the insulators and center conductors of which are the same type glass-Kovar plug-in terminals used for the other connections. Electrically, the input and output connectors are very similar to standard r-f BNC-type connectors. Two exhaust tubes are provided, which also act as guide pins to prevent improper insertion of the amplifier into the socket. To provide positive retention of the fittings, the tubes and coaxial fittings are solder-tinned and then screwed together while hot. The assembly is then silver-plated in order to provide good electrical contacts to all the terminals. (The insulated terminals are wired to the base plate just before the electroplating.)

The socket shown in figure 14 consists of a 1/2-in.-sq body the length of the amplifier, with appropriate fittings. It is so designed that there is no need to solder to the body, which therefore is made of dural. Silver-plated inserts are press fitted into holes provided at each end of the socket body. Special type BNC r-f jacks are threaded into these inserts. These jacks also secure the socket cover in place. Grounding fingers for the amplifier are formed by extensions of the socket cover.

The dural socket body is milled out to accommodate a printed-circuit-wiring plate, by means of which the various power and gain control terminals are connected to the power cable. Each receptacle (other than for the coaxial connections) in the socket is mounted within a ceramic tube, which is of steatite where minimum stray capacity (about 5 μμf) is desired, and of high-dielectric-constant material where bypassing is desired(about 1,000 μμf). The capacitors and receptacles are solder assembled to the wiring plate, which is then soldered to two studs that have been screwed into the socket body. Details of the power and coaxial plugs and receptacles are illustrated in figure 15. In certain cases, decoupling chokes, disk capacitors, and/or resistors may also be included in the socket wiring.

The socket also serves as a good heat-transfer medium and therefore aids in cooling the amplifier. However, the socket itself becomes very hot, so that it is necessary to use glass and teflon-insulated multiconductor and coaxial cables for socket installation. The coaxial cable is a high-temperature equivalent of RG-59/U (72-ohm impedance), but a multistrand center conductor is used to provide long life under constant flexing.

(d) Circuitry

Circuit design has been engineered in two distinct phases. The first phase covers the general i-f and video circuitry, and the second the low-noise front-end circuitry.

One of the common i-f configurations is the stagger-tuned system. This system has been used, as in earlier National Bureau of Standards i-f miniaturization work and for the same reasons. Briefly, these are the large number of stages which would be required in the synchronous (peaked) system where a bandwidth of 5 Mc. or greater is required, the difficulty of controlling feedback and of maintaining low stray capacity of the feedback chain when the inverse feedback

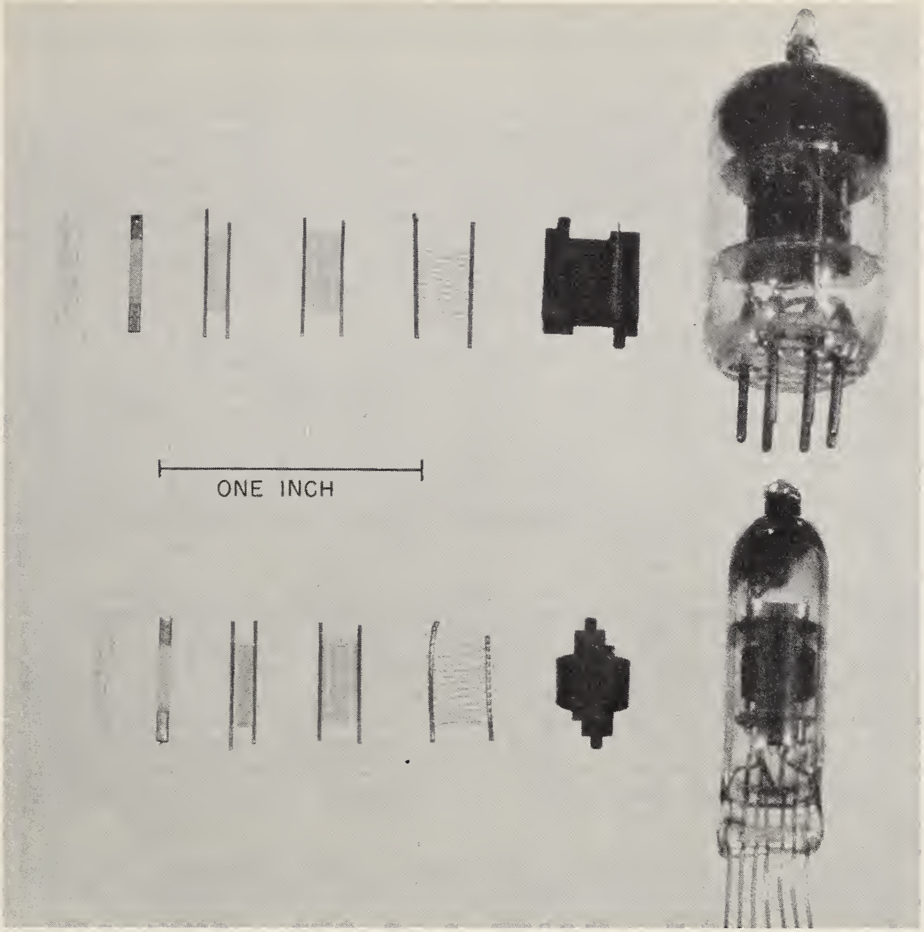


Figure 16. Electrode comparison of equivalent miniature and subminiature tube.

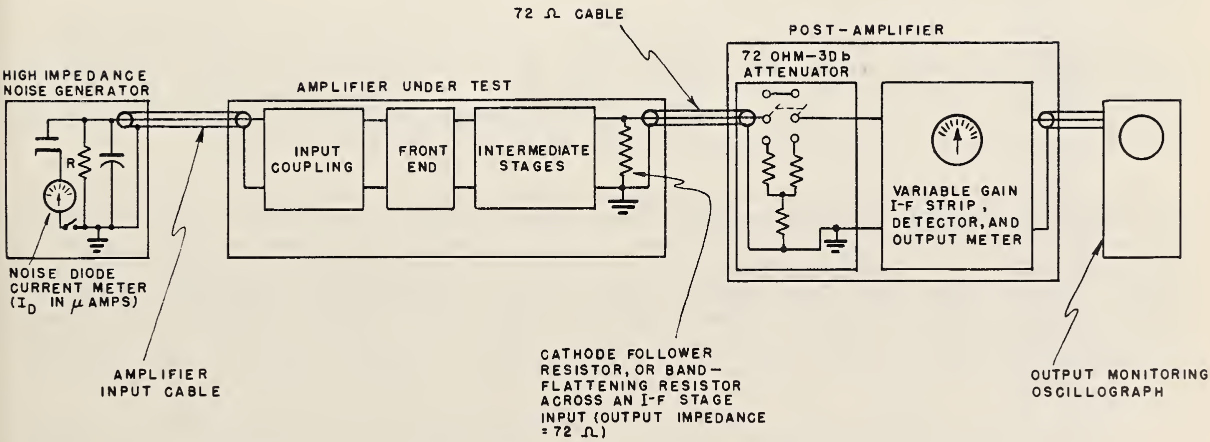


Figure 17. Block diagram; noise-figure measurement.

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system is miniaturized, and the difficulty of designing and reproducing transformers within required tolerances when the double-tuned system is miniaturized.

The single-tuned staggered system was therefore chosen for the model V amplifier. Similarly, circuit layout simplicity makes the bifilar coupling system most attractive, especially in view of the fact that breakdown due to electrolysis is not anticipated because teflon and ceramic insulated wire (which is required for high temperature operation) is used. However, it might be mentioned that where special application indicates the use of another i-f system, or of stagger-tuned system utilizing unifilar inductors with coupling capacitors, these alternatives may also be employed.

Three staggered pairs are used instead of two staggered triples because sufficient gain is obtainable with the doubles, alinement is simplified, the bandpass characteristic is less subject to alteration by slight circuitry changes due to shock, aging, etc., and the difficulty of obtaining the relatively high-Q circuits required in triples is avoided. The first pair consists of the low-noise circuit (i.e., the first two i-f stages, which, for the purposes of amplification, are equivalent to a single pentode stage) and the third i-f stage. (Individual stage design, and alinement procedures follow the methods of H. Wallman.[2])

AGC (automatic gain control) voltage is applied to the low-noise circuit and to the third and fourth i-f stages by means of grid bias. Control of three stages is required to obtain a minimum of 80 db AGC range. Since the AGC voltage also supplies operating bias to these three stages, cathode bias is not required. Small un-bypassed resistors are placed in the cathode circuits of these stages in order to minimize changes in input capacitance due to changes in bias voltage (Miller effect). The fifth and sixth stages utilized tubes whose suppressor grids have good control of tube transconductance. By this means MGC is applied to these two tubes. The seventh stage is a fixed-gain i-f amplifier.

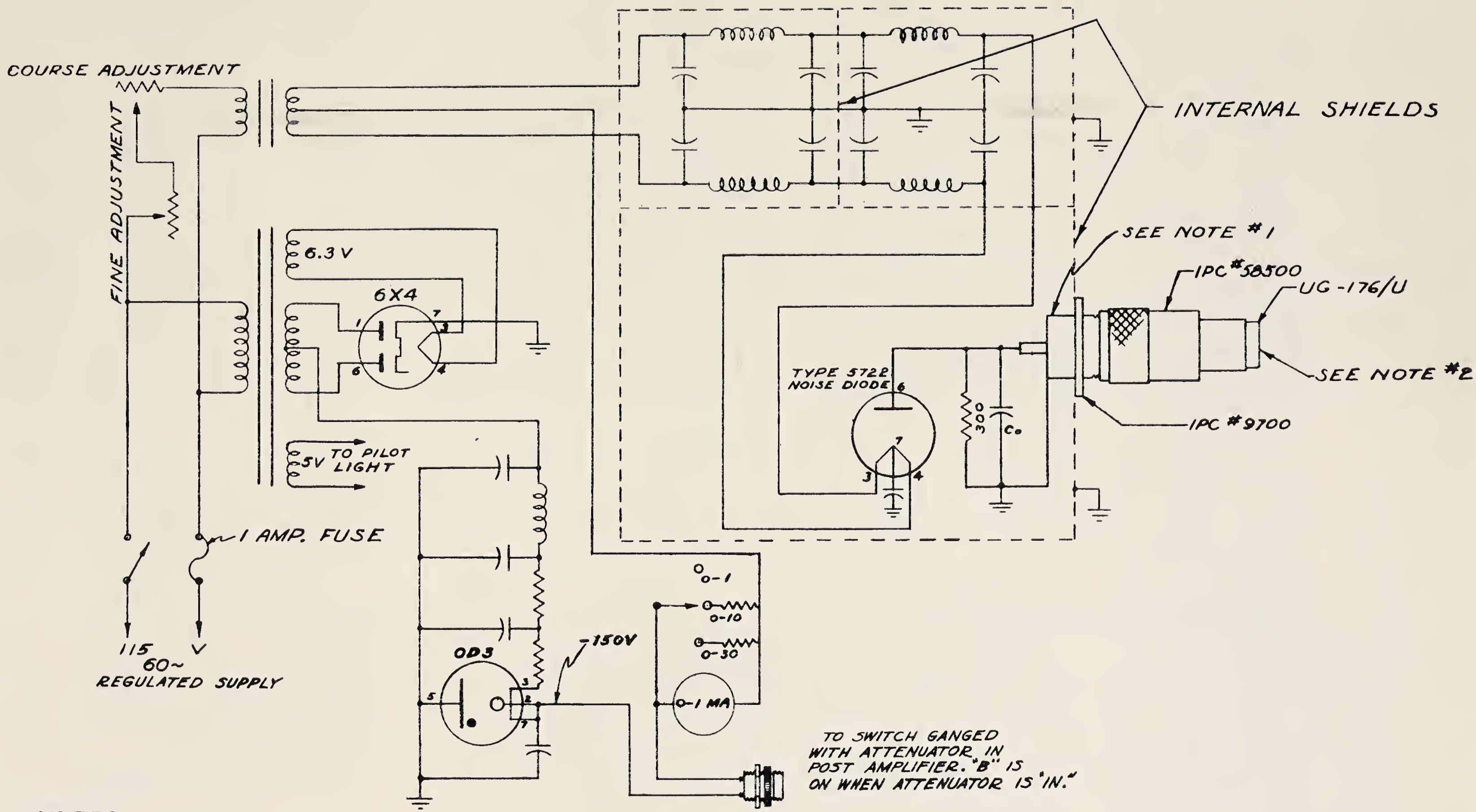
The i-f section is followed by the usual diode detector. As the AGC voltage is supplied external to the i-f amplifier, the detector circuit is very simple. It is coupled to the video amplifier through an i-f filter choke. The video circuitry is also standard, includes a peaking inductor, and is coupled to a triode-connected cathode-follower output stage.

Amplifiers have been built with both chain-type heater and plate supply decoupling and with individual "pi" decoupling filters in each stage. In the latter case, a single choke is placed in the heater and plate supply busses between the third and fourth stages. The chain filters give better decoupling with an apparently simpler design, but have more voltage drop. Due to difficulty in constructing a mechanically suitable chain choke to fit in the available space, the individual decoupling chokes are used in most of the model V amplifiers built to date.

Although it would have been feasible to use a conventional low-noise-type front-end utilizing miniature tubes, this would have substantially increased the size of the amplifier and, more important, probably given it an irregular shape due to the large tube diameter. Therefore, it was decided to investigate the applicability of subminiature tubes to this type of circuit.

Five basic considerations appeared at the outset of this work. First, the thought was prevalent that subminiature tubes might prove to be noisy compared to the more familiar miniature types. This widespread belief is surprising in view of the very slight difference in structure between, for example, the 6AK5 and the 5702 WA. The smaller size of the subminiature tubes is largely attained by elimination of unused space. Figure 16 shows a comparison between the two tube types, and it is to be noted that all active elements, with the exception of the plates, appear to be identical. Second, due to the lower Q

[2]George E. Valley, Jr. and Henry Wallman, Vacuum tube amplifiers, MIT Radiation Laboratory Series, vol. 18, chap. 4, 7, 13, and 14 (1948)



NOTES:

1. Co IS SELECTED SO THAT CAPACITY MEASURED AT THIS POINT IS 21 μμf. MEASURE OUTPUT CABLE LENGTH FROM THIS POINT.
2. USE RG-59/U CABLE. TERMINATE IN UG-260/U CONNECTOR.
3. USE 2 CONDUCTOR SHIELDED CABLE FOR "B" CONNECTING CABLE TO POST AMPLIFIER.

Figure 18. Circuit diagram of noise generator.

obtainable with the smaller inductors and transformers, some deterioration of noise figure due to circuit losses was expected. Third, the basic problems of miniaturization; fourth, the additional miniaturization problems due to the increased complexity of the specialized circuitry; and fifth, the problem of performing experiments with and making measurements on the compact assemblies presented difficulties.

The first problem was quickly found to be nonexistent by substituting subminiature tubes in circuits that were designed for 6AK5 tubes. The deterioration of noise figure was no more than would be expected due to change of tube type, and a little circuit adjustment permitted use of subminiature tubes without any deterioration of noise figure. The second doubt was also dispelled when inductors and transformers with Q's in the range of 60 to 90 proved to be suitable for the input coupling network, and even lower Q's were tolerable for the neutralization inductor. The added complexity simply called for care in evolving the intricate mechanical layout of the circuit components.

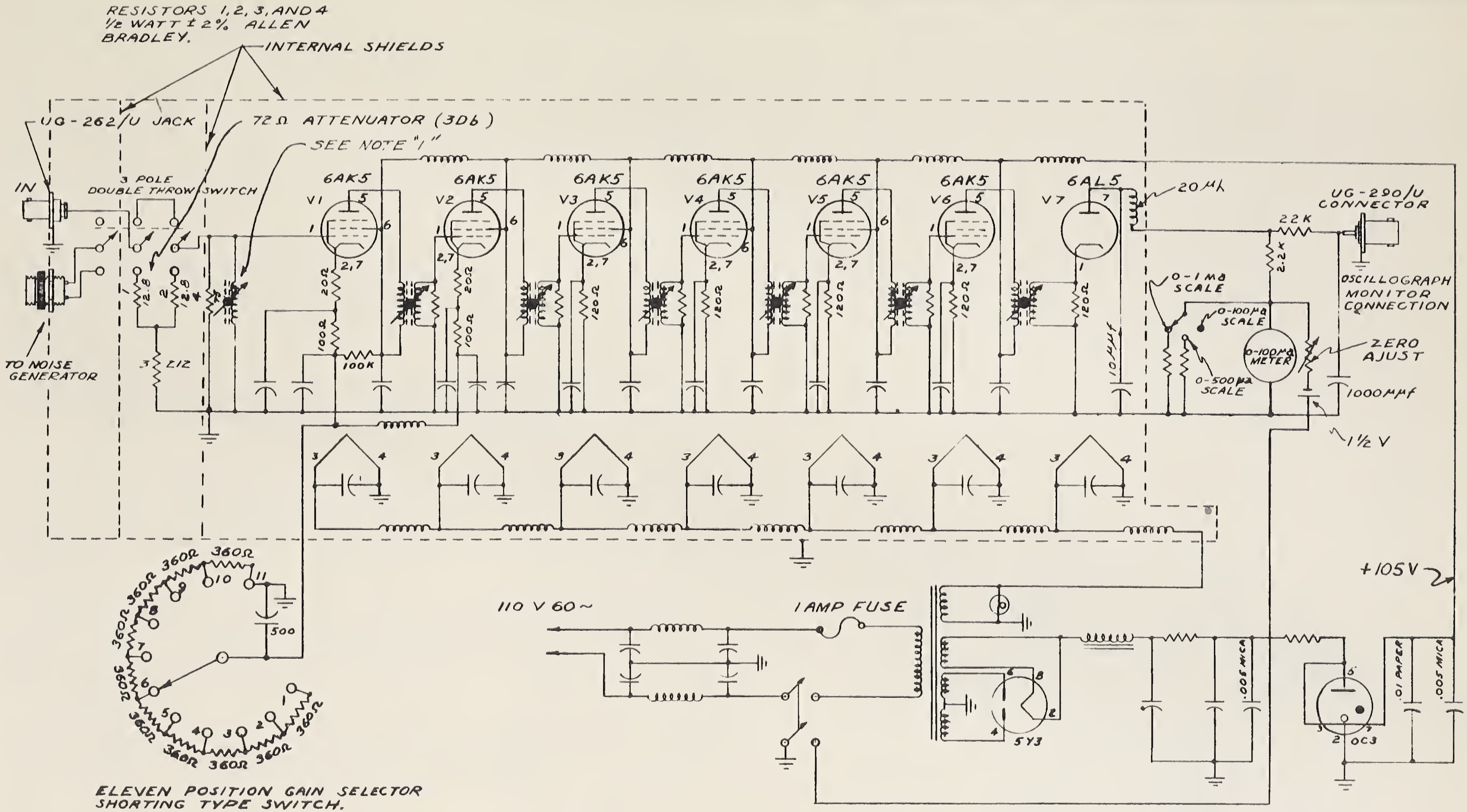
Due to the inaccessibility of test points within the miniature amplifier, it was apparent that special noise-figure measurement equipment and techniques would be required for the development of a suitable low-noise front-end. It was decided to use a noise generator and post-amplifier measurement technique similar to that described by Wallman (see footnote) because this appeared to be a versatile and reliable method. A block diagram of the setup and circuit diagrams of these equipments are shown in figures 17, 18, and 19. A high-impedance-type noise generator was selected because the required capacity was greater than the inherent noise-generator capacity. By using an amplifier input cable, difficulties associated with generator coupling lead length are avoided. The use of a high-impedance generator has the advantage of having a small noise-diode current for a given noise output, thereby assuring long diode life. The type 5722 miniature noise-generating diode is used.

Although the noise generator is of conventional construction, the post-amplifier is rather unusual in that it has a maximum gain of about 60 db. This large gain makes possible measurements on only a few stages of the i-f amplifier, thereby eliminating much of the difficulty of making these measurements. In addition, the noise-generator bandwidth (centered at 60 Mc) is greater than 10 Mc. For detailed construction and use of the equipment, the reader is again referred to Wallman. One point deserves additional comment. Experience at the National Bureau of Standards indicates that the need for shielding the post-amplifier and noise generator cannot be overemphasized. It is much less time-consuming in the long run to provide adequate and perhaps excess filtering and shielding while constructing equipment than to locate and alleviate conditions resulting from inadequate attention to this problem. Accordingly, a setup was made in which the high-signal-level end was so well shielded that it was possible to pursue the development of the front-end circuitry without any shielding of the experimental front-end whatsoever, and with no sign of regeneration, despite an over-all system gain in excess of 100 db.

An additional problem arose from the fact that despite the care taken in shielding the noise generator, certain large pulses in the laboratory reached the noise-generating diode and caused high and inconsistent noise-figure measurements. This difficulty was eliminated by placing an additional shield about the noise-generating diode itself.

The front-end circuitry, which consists of an "L" network followed by the cascaded grounded-cathode triode and grounded-grid triode low-noise circuit, is shown in figure 20. The choice of bifilar transformers for the interstage coupling between the grounded-cathode and grounded-grid triodes is merely in keeping with the construction of this particular amplifier. Coupling capacitors might just as well have been used. The scheme of heater and high-voltage supply decoupling is that used in the succeeding stages.

The input network consists of a bifilar shunt winding of 6 turns and a separate series winding of 14 turns, both of No. 26 gage Ceroc-ST wire. A bifilar transformer is used for the shunt branch because it provides d-c isolation between the mixer and the i-f input stage in order that AGC



NOTES:

1. ADJUST TO RESONATE WITH INPUT CAPACITANCE OF V1 AT 60 Mc/Sec.
2. USE 72 Ω INPUT CABLE FROM LOW IMPEDANCE AMPLIFIER OUTPUT.

Figure 19. Circuit diagram of post-amplifier.

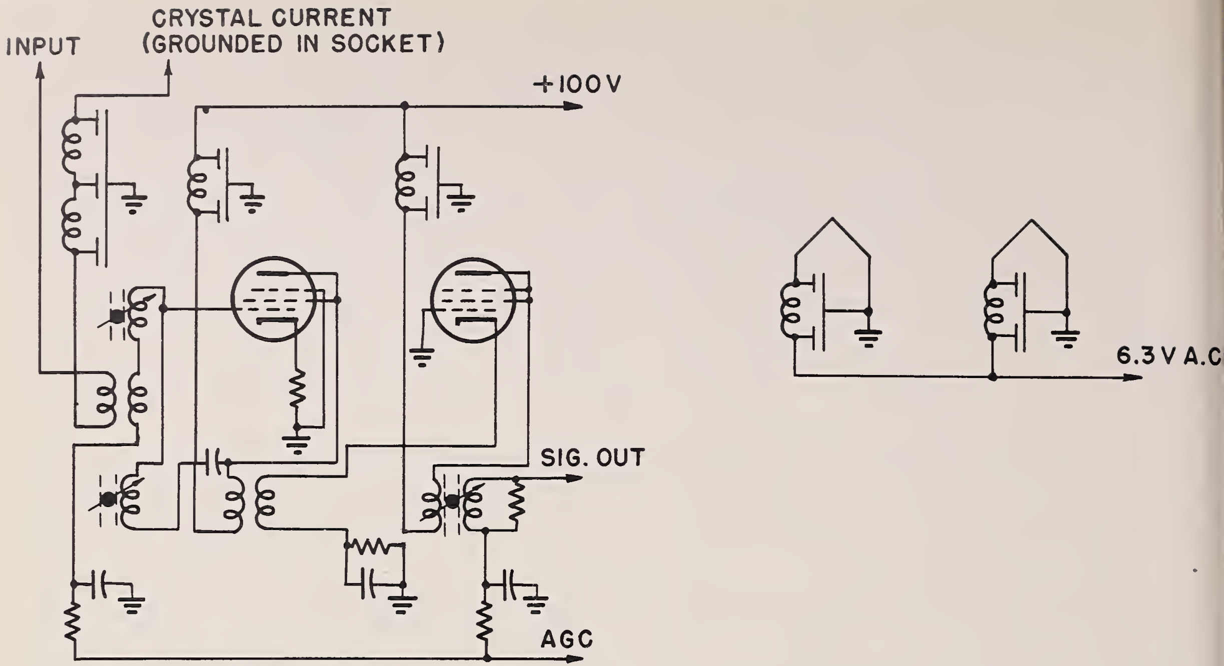


Figure 20. Low-noise front-end circuitry for model V amplifier.

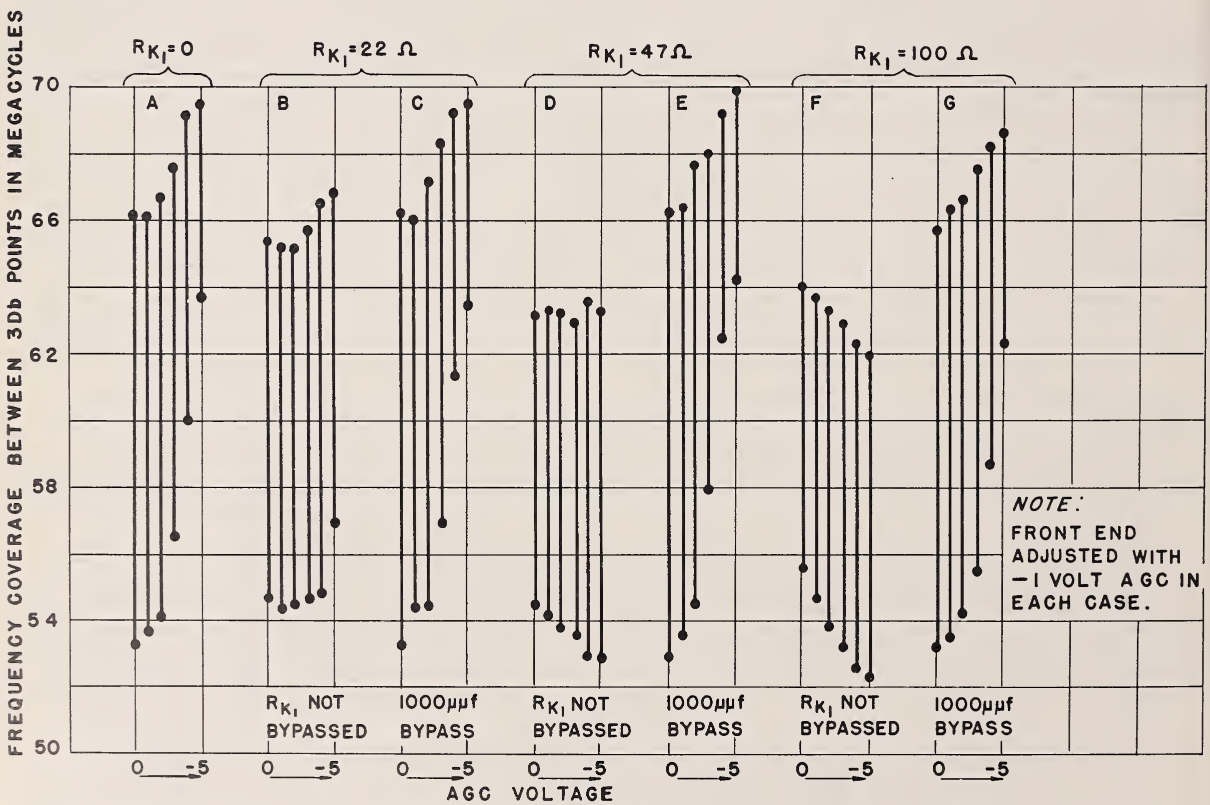


Figure 21. Effect of various cathode resistors on bandpass of model V amplifier.

voltage can be applied to the first i-f stage without biasing the mixer. This low-level application of AGC is necessitated by the very large input signals sometimes applied to this i-f input. The mixer crystal current is returned through a two section "pi" filter so that it may be brought out of the i-f strip without causing regeneration. In this way, crystal current may be measured, and if it is desired to bias the mixer crystal in order to improve the over-all receiver noise figure, the bias may be applied through this lead.

Adjustment of the input circuit for minimum noise figure does not necessarily coincide with the adjustment for maximum output. In wideband applications, however, the adjustment is the same for practical purposes.

The cathode resistor used in the input stage has several purposes. It serves as a protective device in case of loss of AGC bias supply (which is external to the i-f strip). Not only does it limit the cathode current to a value only slightly higher than the maximum rated value for this tube type, but it prevents serious deterioration of noise figure due to grid current that would flow if all bias were removed. The resistor is not shunted by a bypass capacitor because it is also used to compensate for variations in bandpass characteristics, which usually occur when bias is varied, due to change of input capacity of the tube. It is desirable to use as small a resistance as possible in order to maintain maximum gain, and also because an increase in noise figure is caused by a resistor that is not bypassed. The resistor is therefore chosen to be as small as possible consistent with good bandpass characteristics. Figure 21 shows the effect of AGC bias on bandpass characteristic with various cathode resistors. The bandpass shown is for the entire front-end, but as the bandwidth of the interstage coupling is very great (due to heavy loading by the grounded-grid stage), the over-all response is essentially that of the input network.

In figure 21 the uncompensated (R_k = 0) circuit, or circuits with bypassed resistors, show serious narrowing of bandwidth and increase of center frequency as AGC voltage is applied. Where a bypassed cathode resistor is used, the effect of AGC voltage on bandpass characteristics is substantially independent of the resistor value, but in this case the noise figure may be maintained (within limits) despite the biasing. However, if an unbypassed resistor is used to prevent change of bandpass characteristics as AGC voltage is applied, deterioration of noise figure occurs. For this reason, R_k should be kept as small as possible. However, it is clear that a stage may be overcompensated by use of a large cathode resistor. Note that for R_k = 100 ohms the trend is actually reversed and there is a decrease in center frequency for an increase in AGC bias. Therefore, if the largest value of input stage cathode resistor consistent with good noise figure does not give sufficient compensation, a later stage (to which AGC bias is also applied and where noise figure is no problem) may be overcompensated in order to maintain a constant bandpass characteristic for the over-all amplifier.

Neutralization of the grid-to-plate capacity of the first tube seems to be of little value from the point of view of improving noise figure. Due to the comparatively large inductance required, the neutralizing inductor must be wound with many turns of fine wire, (about 30 turns of No. 40 Ceroc-ST), and therefore has a low Q, which results in a very small and inconsistent improvement in noise figure. The reason for including a neutralizing inductor is not primarily to improve the noise figure, but rather to make more effective the operation of the AGC circuit. This comes about because the range of gain control for a single stage is equal to the maximum gain of that stage plus the attenuation of the stage when maximum negative gain control voltage is applied. Since this input stage has a maximum gain of about unity, it has a smaller control range than either of the other two controlled stages. This range (of attenuation) may be nearly doubled, however, by resonating "out" the grid-to-plate capacity, as is done in this circuit. It is to be noted that the input network design is influenced by whether or not the input stage is neutralized, and that the neutralizing inductor and input network adjustments are not independent of each other. However, the adjustment procedure is very simple. The shunt member of the input network is not adjustable, and for the correctly designed network, it is necessary only to tune the series inductor for maximum output at the center frequency. This assumes that minimum noise figure is obtained when the circuit is adjusted for maximum output. As pointed out above, this is true, (for practical purposes) for wide-band amplifiers. The neutralizing inductor is tuned by applying sufficient AGC voltage to nearly cut off the input tube, applying a large input signal at the center frequency, and adjusting the neutralizing inductor for minimum output.

An advantage of the type 5702 WA subminiature tube over the 6AK5 is that the suppressor grid is not tied to the cathode internally. Therefore, the subminiature tube is more suitable for the grounded-grid stage (due to lower cathode-plate capacity). In the case of the grounded-cathode stage the grid-to-plate capacitance is further reduced by using the suppressor grid as a grounded shield. Incidently, slightly more gain is realized with this connection than with the suppressor grid tied to the plate.

The input circuit triode-connected tubes are of the same type as the pentodes used in the balance of the i-f and video stages. Since this subminiature tube type gives the best noise figure of all those investigated, its choice for the input circuit was quite logical. The good results with this type are not surprising in view of earlier experience with the 6AK5, and the similarity between the two types. However, the use of this tube in the input was a factor in its selection for the other i-f stages, for which other types are available. In general, of course, it is desirable to use as few tube types in an assembly as possible. There is the additional possibility of selecting individual tubes for the input circuit in order to get the best possible noise figure. This matter has often been discussed, and many engineers consider it impractical to select tubes for the front-end in any large-scale production. This would be true in a case where a special tube is used in the input stage, as it would involve selection of a few tubes and perhaps discarding large numbers of unsuitable tubes, but where the input stage is one of a number using the same tube type, there is small chance of economic loss in selecting the better tubes for use in the input stage. Once a standard has been set up, the selection of tubes is a simple operation requiring no special skill; it may be done on a "go, no go" metering basis. It appears that such selection may prove to be unwarranted in view of the uniformity of the relatively few tubes of the type used in this circuit that have been examined to date.

Operating potentials of the low-noise input stage are usually selected from the point of view of good noise figure. An exception is the addition of the small unbypassed cathode resistor. Figure 22 illustrates the effect of operating potentials on noise figure. It is apparent that for fixed bias operation, the plate supply voltage is not critical, as the same minimum noise figure may be attained for each plate voltage, provided this voltage does not fall below about 75 volts. Where AGC voltage is not applied, it is desirable to apply a small amount of bias (usually cathode bias), in order to prevent the noise-figure deterioration that results from zero bias operation (in part due to grid-current flow). Where AGC voltage is applied, fixed bias sufficient to avoid a zero bias condition is usually present due to a "threshold" AGC voltage in the region of 1/4 to 1 volt; the higher the supply voltage, the better the noise-vs-AGC characteristic. Fortunately, this relationship is not critical, and therefore the supply voltage in the amplifier may usually be used for the input stage. If a higher voltage is used, care must be taken that the tubes are not damaged during operation with minimum AGC voltage applied.

In cases where an occasional large input signal requires that AGC voltage be applied to the first tube, a very large AGC range will undoubtedly be needed. For example, the model V amplifier has three stages under AGC, resulting in an AGC range in excess of 80 db. When a large input signal is applied, the noise figure of the input stage is rather unimportant. A 100-volt plate supply is used in the model V amplifier, and the noise figure does not fall off appreciably under these conditions until an AGC of more than 2 volts is applied.

As a result of these investigations the following conclusions have been reached:

1. For radar-type i-f amplifiers, low-noise circuits using subminiature tubes are attainable with performance comparable to those using miniature tubes.

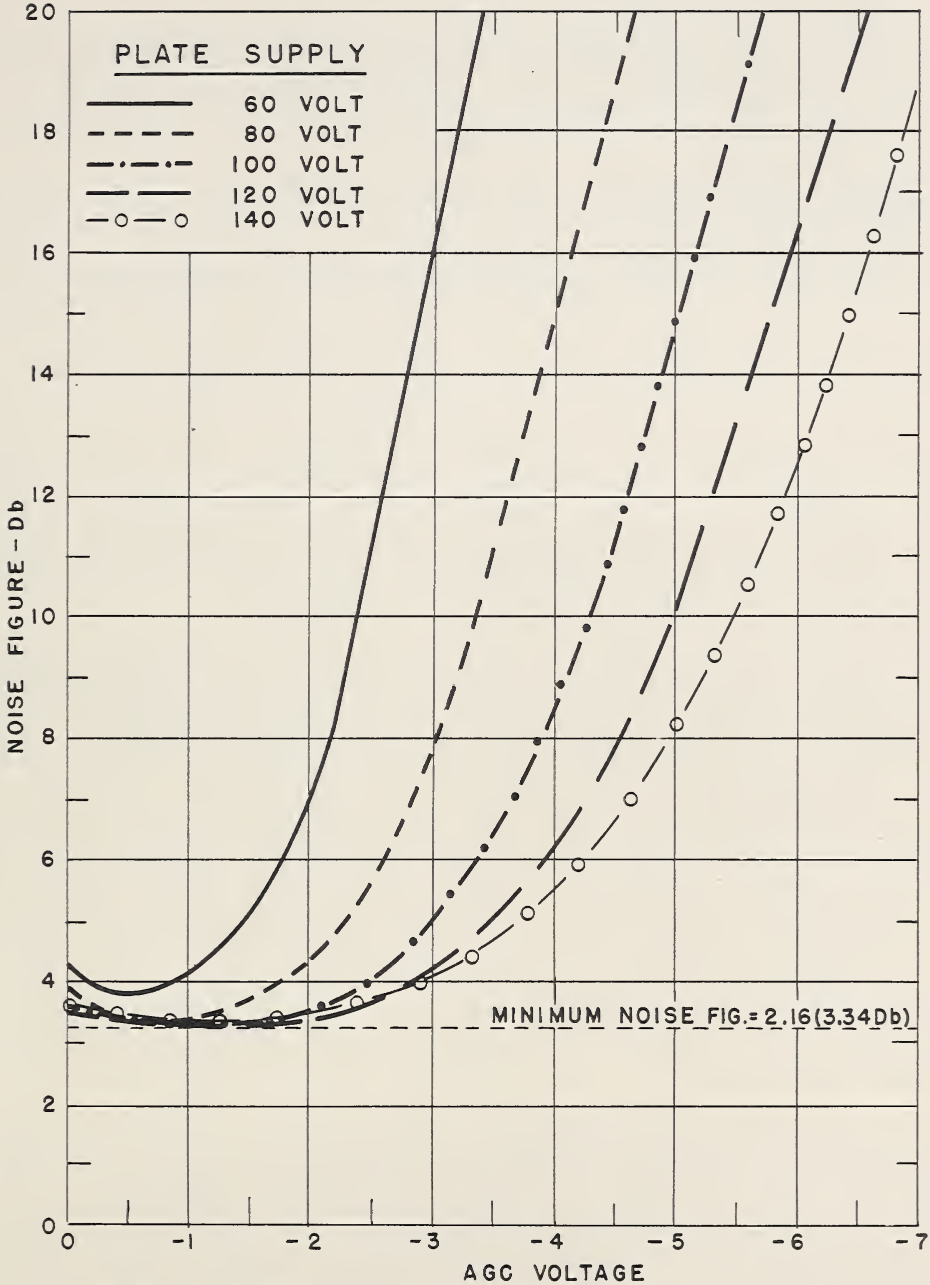


Figure 22. Model V amplifier noise figure as a function of AGC voltage.

Noise figures as low as 2.1 have been obtained with the circuit used.

2. Automatic gain control may be incorporated into the low-noise circuit without deterioration of the noise figure.

3. Operating voltages are not critical.

4. Substantial size reduction is attained by the use of subminiature tubes in the low-noise input circuit.

(e) Tests

Heat problems are so intimately related to useful life of miniature equipments that the consideration of either problem without reference to the other is meaningless. Various data with reference to high-temperature operation of miniature assemblies have been accumulated during the past 2 years. Previous work has established that the maximum short-period operating temperature for most of the materials used is in the region of 200° C. The vacuum tubes are rated by the manufacturer at a 500-hour life for a bulb temperature of 250° C. Measurements made at National Bureau of Standards show that at an 85° C ambient temperature, the maximum tube bulb temperature in the model V unit is only 200° C.

Due to the excellent thermal bonding, there appears to be a very small temperature spread within the amplifier, perhaps 25 deg at most. It is almost impossible to measure accurately the temperature of each component within the amplifier; therefore, it is difficult to predict the maximum safe operating temperature of the amplifier with any great accuracy from data on the components. Specifications call for an 85° C temperature, but a study of data shows that operation at 100° C is probably obtainable in this unit.

In order to obtain data on the minimum useful life, a test was run on one of the model V units. The unit chosen was the second (final) developmental model, which had already operated for 127 hours. This unit was operated for 506 hours (including the 127 hours of development time) at room temperature. During this 379-hour period of continuous operation (at maximum gain) the unit showed practically no change in its gain-bandpass characteristics. The unit was then placed in a thermostatically controlled oven equipped with a circulatory blower, and operation was continued for more than 300 additional hours at an ambient temperature of 85° C. During this period the bandpass characteristic remained substantially the same, as shown in figure 23, whereas the gain slowly decreased. This loss of gain is attributed to normal aging of the tubes. The gain could be returned to the original value at any time by resetting either the AGC or MGC, or both. At the start of the test the gain adjustments had been brought to the point where further bias reduction would not increase gain any further. It is believed that the maximum obtainable gain is limited by regeneration rather than by the figure of merit of the tubes. The fact that the gain could be restored to the same maximum, by reduction of tube bias, after many hours of operation, substantiates this belief.

Some time between 800 and 822 hours of total operation, the oven thermostat jammed, resulting in the ambient temperature rising to 115° C. At this temperature the amplifier was very unstable both in bandpass and in gain characteristics. The temperature was lowered to 100° C, and after several hours the bandpass characteristic appeared normal, but the gain was down somewhat. Currents and voltages all remained normal. It was then decided to continue operating the strip up to a total of 1,000 hours, at 100° C, in order to gather information concerning operation at 100° C. There was little change in gain or bandpass characteristic during the remainder of the test.

At 1,011 hours the amplifier was taken off life test and removed from its housing. The internal structure appeared clean, but it was noted that considerable resin had volatilized and condensed on cooler parts of the amplifier. Although there was some oxidation on the spring fingers of the chassis plates, they still maintained their spring qualities, and apparently the grounding of the chassis plates to the case liner remained unimpaired throughout the test.

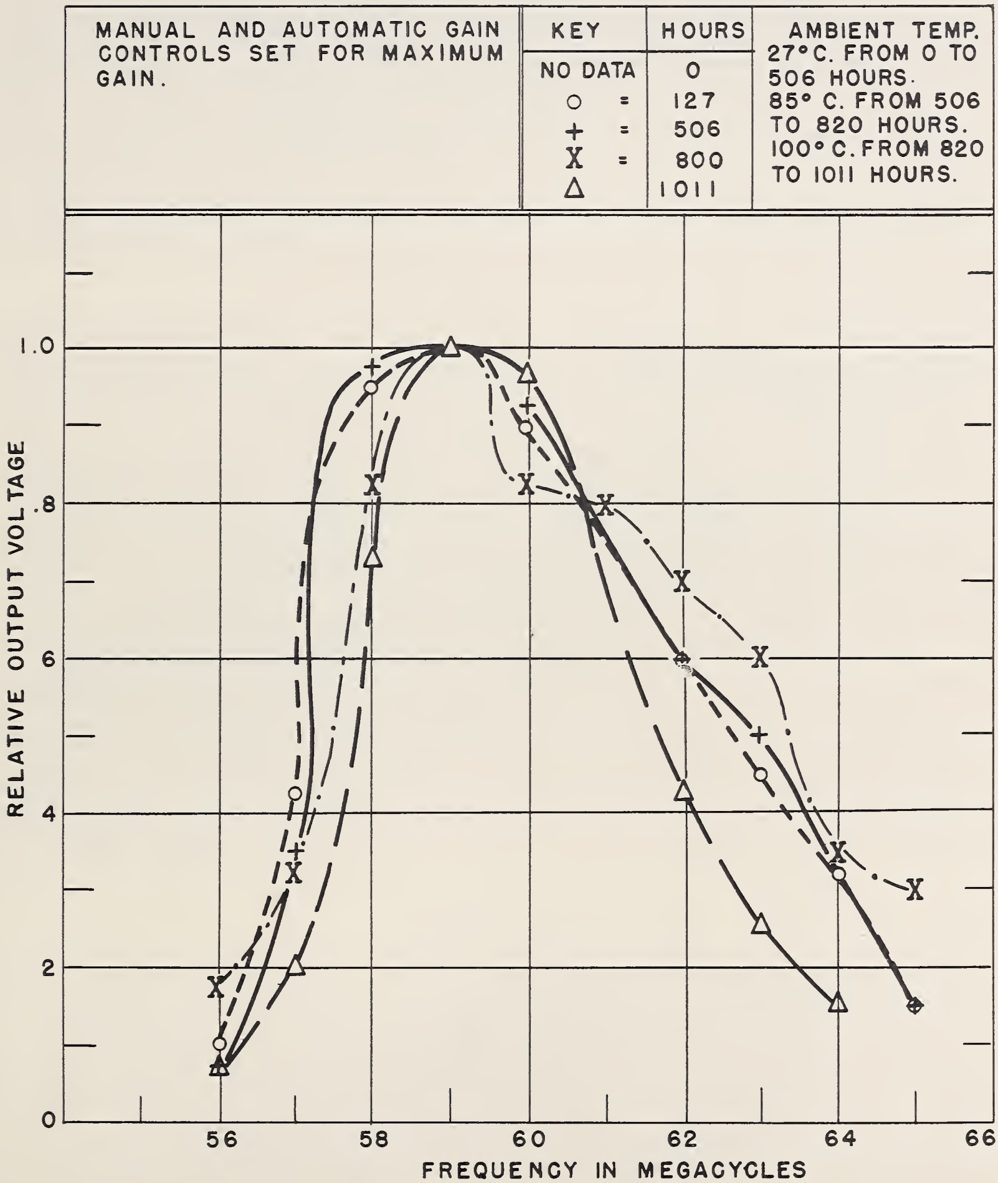


Figure 23. Heat-life test bandpass characteristics of model V amplifier.

Slight deterioration of the higher-value resistors was noted, but this was not accompanied by any great impairment of amplifier characteristics. This may have been due to resin condensing on the resistors. Further study is indicated in order to find means of preventing flux condensation on electronic components.

The noise figure was also measured and found to be 3.3, as compared to 2.7 at the start of the test.

As a result of these tests, together with information previously acquired, the following is now believed to be a resonable estimate of life for the model V i-f amplifier and for other equipments having similar heat-dissipation characteristics in assemblies of similar size.

1. At room temperature (20° to 30° C), 1,000-hour life should be easily obtainable.

2. At an ambient of 85° C, 500-hour life should be obtainable. This is an estimate based on the life expectancy of the vacuum tubes (500 hours at 250° C bulb temperature) as stated by their manufacturer. Up to 85° C, the vacuum tubes appear to be the shortest-lived component.

3. Operation for short periods at 100° C ambient temperature is practicable. At present, 100° C appears to be the maximum safe operating temperature. It is expected that additional tests would show that a life of several hundred hours, perhaps even 500 hours, is feasible at this temperature.

4. With improved components, the model V might eventually be operated in as high as 125° C ambient temperatures. However, nearly every component and material in the amplifier would then be operating close to or at its own maximum temperature. For operation in ambient temperature above 125° C, an entirely new approach to electronic miniaturization appears to be necessary.

3.2. Model VI Intermediate-Frequency Amplifier

(a) General Description

The following characteristics were specified for the model VI amplifier:

1. Center frequency: 20 to 100 Mc

2. Bandwidth: 2 to 10 Mc

3. Volume (per stage): Equal or less than that of the model V i-f amplifier. (Not more than 1 cubic inch per stage.)

4. Shape: To be governed by the equipment in which it is to be incorporated.

5. The final design to be adaptable to straightforward manufacture.

6. Production models to have uniform characteristics within narrow limits.

7. The production amplifier to have satisfactory stability during operation.

Because experience with previous amplifiers indicated that the components would have to withstand high-temperature operation, and in view of the severe space limitation, little attempt was made to utilize commercial components except for standard subminiature electron tubes.

New components were designed, where necessary, to meet the requirements of the model VI assembly. Consideration was given to the availability of materials and where feasible, the components were designed so that their use would not be limited to this particular application. Manufacturers were consulted during the design period to insure that the components would be readily adaptable to straightforward manufacture. Action was also taken to interest manufacturers in the commercial production of these components.

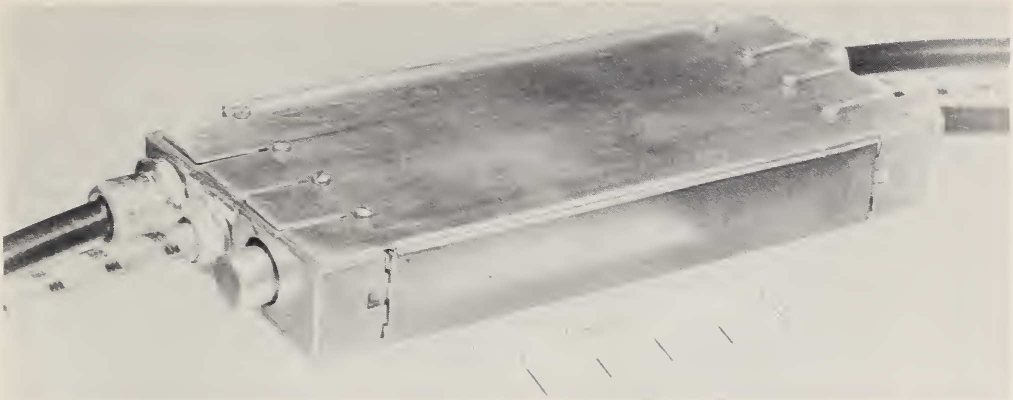


Figure 24. Model VI plug-in case and plugs (assembled).

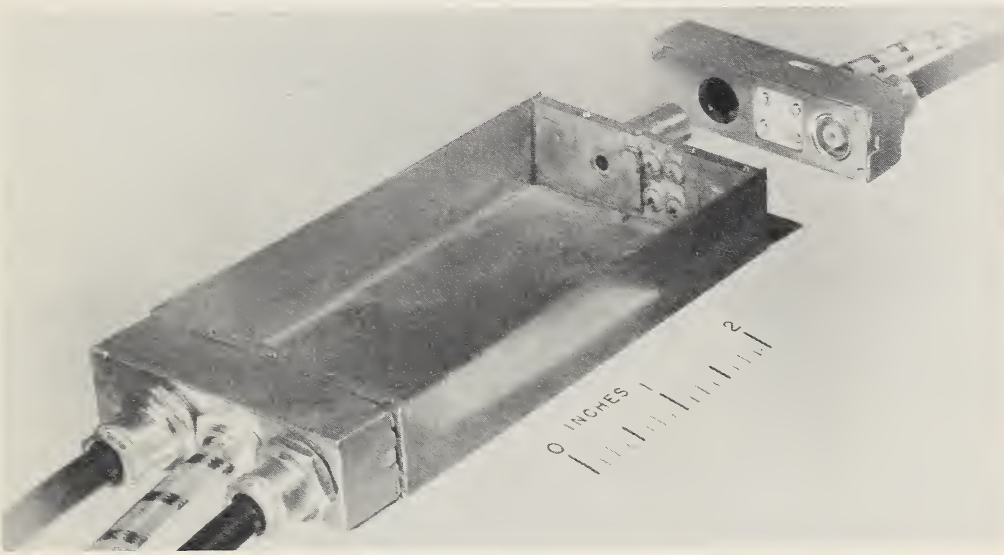


Figure 25. Model VI plug-in case and plugs (disassembled).

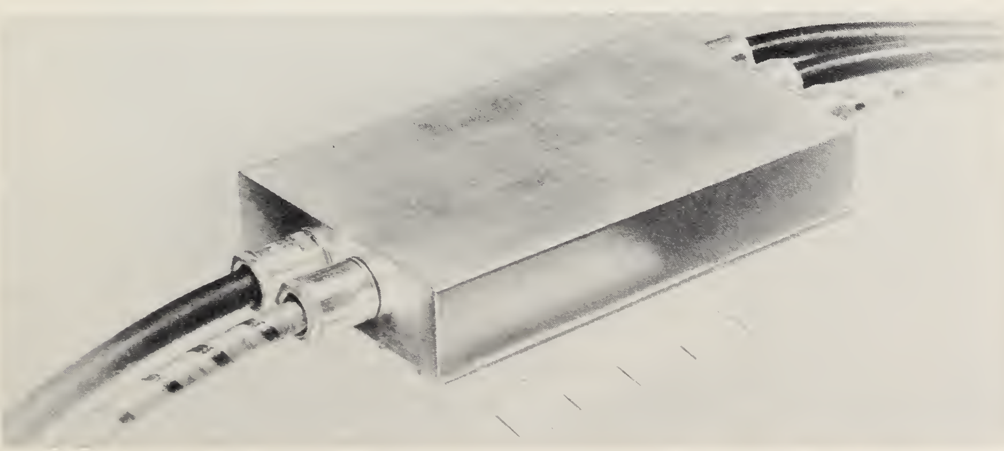


Figure 26. Model VI case having attached cables.

It was considered desirable to design the amplifier case to permit hermetic sealing. Sealing the amplifier in an inert atmosphere contributes to stable operation and long-life expectancy by retarding the rapid deterioration of components resulting from the high internal temperatures encountered during amplifier operation.

To facilitate production, the design of components was kept simple and a number of subassemblies were utilized. Also, the basic design of the unit is such that all connections are easily accessible both during and after assembly.

Flexibility of design was maintained in the choice of components. For example, any one of three resistor types may be accommodated by the unit with almost equal facility. The type of resistor to be utilized in production depends upon which best meets the requirements of stability, temperature, and life. Similarly, either of two capacitor subassembly types may be accommodated. With either type of capacitor, all the bypass capacitors for the amplifier are included in one subassembly. The only additional capacitors required are coupling capacitors used in the input circuitry.

Two housing types were designed. A plug-in type shown in figures 24 and 25, with its advantage of easy replacement may be used where space permits. Where space is limited, a simple nonplug-in unit shown in figure 26 is available. The over-all dimensions of the plug-in type amplifier, including its two plugs, are 4-3/4 by 2-1/8 by 21/32 in. When the cables are brought out of the amplifier without the use of plugs the dimensions are 3-3/4 by 2-1/8 by 21/32 in. The total volume of the smaller case is then 5-1/4 in.^{3}, with an average stage volume of about 7/8 in.^{3}.

(b) Internal Structure: Component Parts

The components and materials used in the model VI amplifier have been selected (wherever possible) to withstand continuous operation at a temperature of 200° C. A solder of 95 percent tin and 5 percent silver, with a melting point of about 217° C, was used throughout, except for the case assembly. In the case assembly, a silver solder was used to give the desired mechanical strength.

Only one subminiature-type electron tube, the 5702 WA, is used in the model VI amplifier. Of this type, six tubes are required to meet the particular gain-bandwidth requirement. In the two stages comprising the low-noise input circuit, the tubes are triode connected. In the remaining stages, the tubes function as pentodes.

No single-resistor type was available which was completely satisfactory for the amplifier. For this reason, three resistor types were considered, and the design made so that any of these can be utilized. The first is the conventional carbon-composition 1/4-watt resistor of nominal physical dimensions, 3/8 in. long by 9/64 in. in diameter. (Figure 27 shows a unit with such resistors installed.) Resistors of this type will not withstand the temperatures encountered within the amplifier for the desired length of time. The second type is the cracked-carbon on ceramic resistor 3/8 in. in length and 1/16 in. in diameter (shown installed in fig. 28). This type of resistor will withstand the temperatures involved, but in this small size it is not entirely satisfactory due to its fragility. Model VI amplifiers employing the two types of resistors have been constructed. The third general resistor type that this amplifier design will accommodate, is of the printed or NBS tape type, which may be applied and fired on a suitable base material. This type has perhaps the greatest promise from the standpoint of space saving and unitized assembly because the entire resistor complement of the amplifier may be applied upon one steatite mounting plate. No amplifier model was built utilizing this type resistor because the required resistance values were not available at the time those models were being fabricated.

Amplifiers have been constructed utilizing two capacitor types. With either of these types, one preassembled capacitor subassembly includes all the bypass

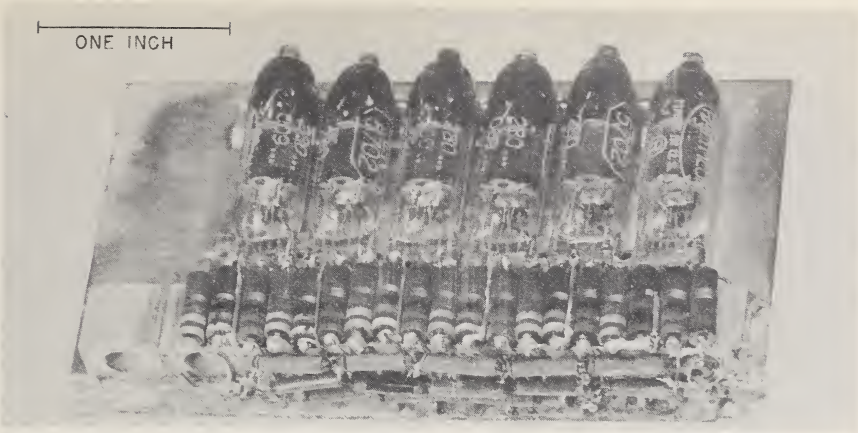


Figure 27. Model VI amplifier unit utilizing conventional resistors.

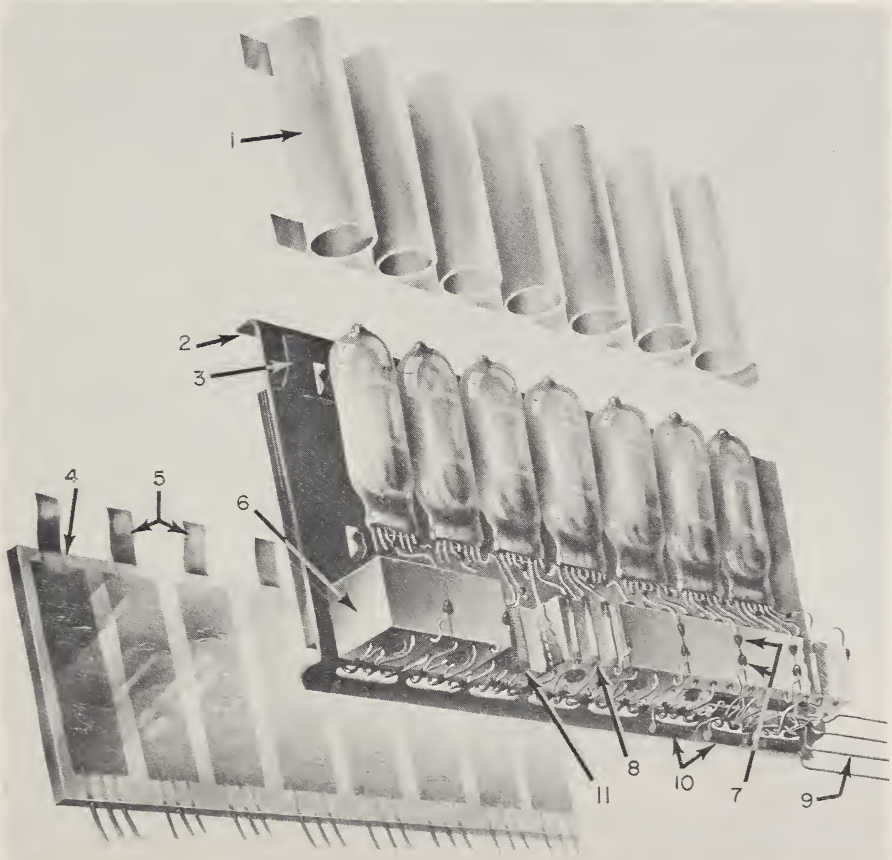


Figure 28. Model VI amplifier assembly and wiring layout.

(1) Tube shield subassembly; (2) Amplifier chassis; (3) Fingers which engage tube shield; (4) Capacitor subassembly, multiple glass dielectric type; (5) Common ground leads for triple capacitor sections of multiple unit capacitor; (6) Steatite inductor mounts; (7) Solder points connecting ground leads to metallized surface of inductor mounts; (8) Resistors, cracked carbon on steatite, high temperature miniature type; (9) Power, control, and signal leads; (10) Chokes, lower row-plate supply chain, center row-heater supply chain, upper row automatic gain control chain; (11) Inductor, bifilar wound on powdered iron core.

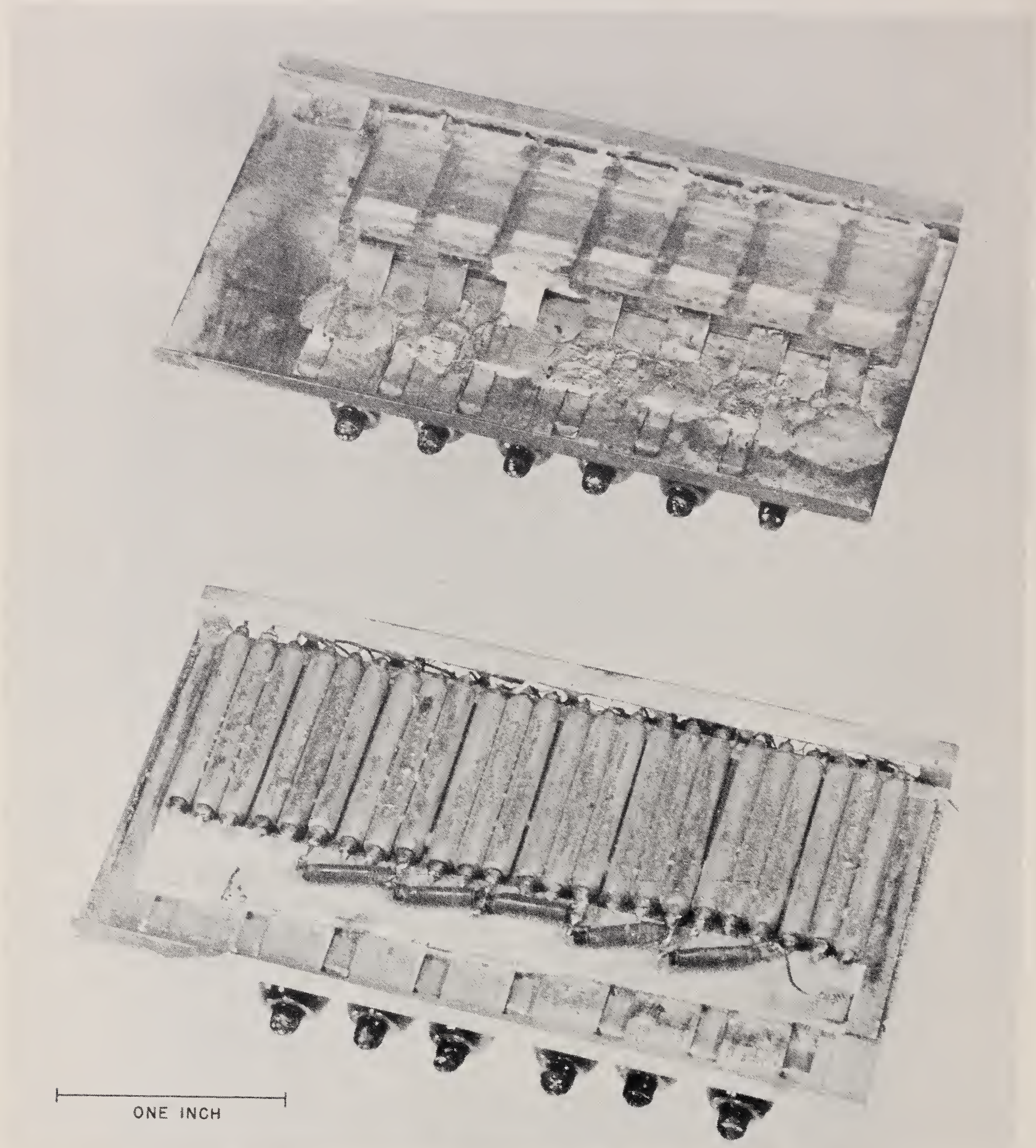


Figure 29. Model VI capacitor subassemblies.

capacitors required in the amplifier. Figure 29 shows a comparison of these two installations.

One bypass subassembly is of a new glass-dielectric type, wherein the individual capacitors are arranged in groups of three (heater, plate supply, and AGC bypass) having a common ground connection. A number of these groups of three capacitors are encased in one glass unit, giving a completely sealed and insulated capacitor subassembly. This unit for the model VI amplifier has 7 groups of 3 capacitors, for a total of 21 capacitors, each capacitor having a capacity of approximately 1,500 $\mu\mu$fd. The dimensions of the unitized subassembly are 3-7/16 by 1-3/8 by 1/10 in. The common ground leads are brought out from one edge of the unit and are of metal foil 3/16 by .0015 in.; the other leads are of No. 28 wire and are brought out through the opposite edge of the capacitor. This capacitor subassembly has proved quite satisfactory. It provides ample capacity and dielectric strength in a relatively small volume. It has a low capacitance temperature coefficient, and its losses are low so that is can be used for other than bypass applications.

The multiple glass-dielectric capacitor subassembly has been specially developed for this application and is not yet in production. (The glass-dielectric capacitor is a development of Corning Glass Works.) For this reason, the alternative-type multiple capacitor was designed. In this unit high-K ceramic tubes of 0.100-in. outer diameter are utilized. The capacitor plates are provided by a metallized surface of silver paint fired onto the ceramic. The outer plate is grounded directly by soldering the tubes to a chassis and connections are made to the inner capacitor plates by soldering metal inserts into place within the tubes. The required number of these individual capacitors are soldered to a metal strip to form the capacitor subassembly. The inserts are soldered into place and the capacitors to the metal strip in a single operation.

Approximately the same space utilization is obtained through the use of either of these multiple capacitor subassemblies.

When the glass-dielectric type is used, it is desirable to place 10-ohm resistors in series with the screen grids of the electron tubes in order to prevent parasitic oscillations.

All interstage inductors for the amplifier are of a uniform type, bifilar-wound to eliminate the need for coupling capacitors. To obtain the necessary inductance value in as small a space as possible, the coils are wound directly upon the tubular powdered iron cores. An intervening layer of Teflon tape, 0.004 in. thick, assures a sufficiently high Q. Silicone resin is used to cement the windings in place, and an additional layer of Teflon tape is cemented over the windings to provide extra protection during insertion into the inductor mounts. Tuning is accomplished by inserting 1/16-in.-diameter ferrite rods into the center of the tubular powdered iron cores (fig. 30). By adjusting the length of insertion of the ferrite cores, a tuning range of 2 to 3 Mc is obtained. At the time of final tuning, the ferrite rod is cemented in place with silicone resin, and the protruding portion is broken off.

The inductor mounts are ceramic blocks having holes to accept the bifilar-wound inductor assemblies. When the inductors are ready for mounting they are given an additional coating of silicone resin to cement them in place within their mounts. The outer surfaces of the mounts are metallized by applying silver paint, which is then fired on at 700° C. The metallizing provides good electrical shielding for the inductors as well as a surface to which solder will adhere. In a single operation all the inductor mounts are soldered in a row to the chassis (fig. 31), when the inductors are cemented in place to provide a single unitized inductor subassembly.

The inductors are wound with No. 36 Ceroc-ST wire. This insulation will withstand the high temperatures and gives a good margin of safety against voltage breakdown.

The r-f chokes are wound directly upon ferrite cores 3/8 in. long and 1/16 in. in diameter, thus giving a maximum inductance in the allotted space. The winding

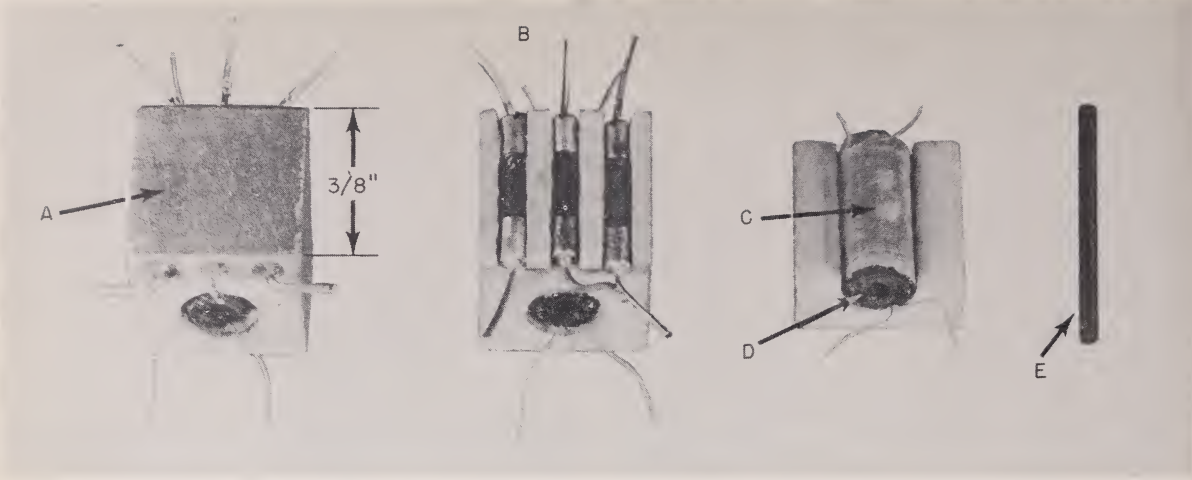


Figure 30. Model VI miniature intermediate-frequency amplifier.

A. Housing; B. Resistors; C. Bifilar inductor;
D. Powdered iron core; E. Ferrite trimming rod.

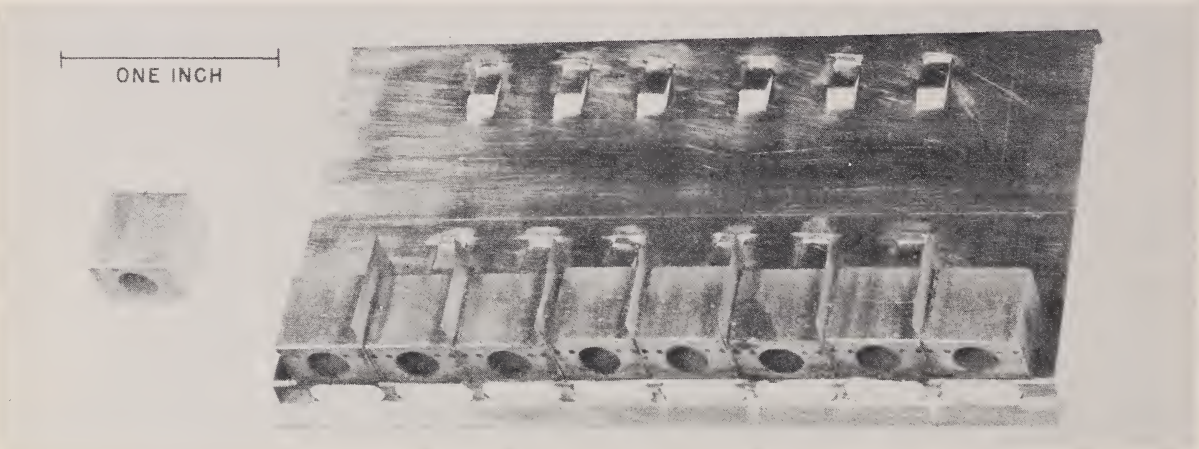


Figure 31. Subassembled inductor mounts for model VI amplifier.

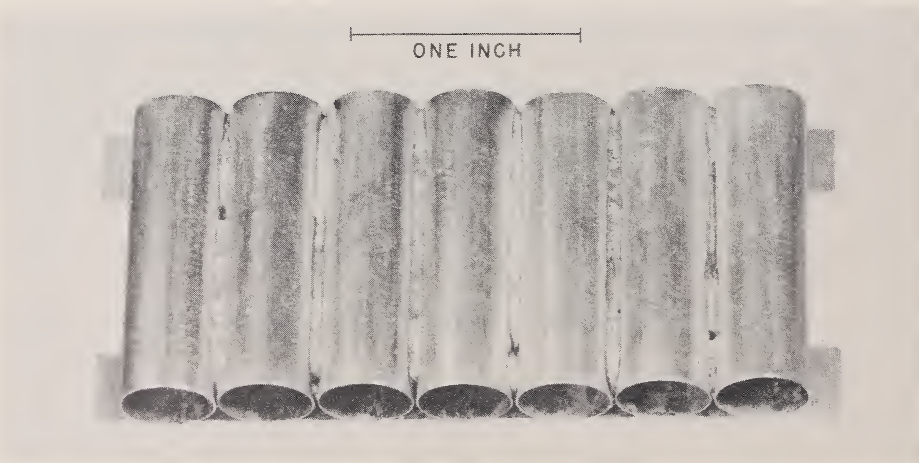


Figure 32. Tube shield subassembly for model VI amplifier.

itself is brought off radially at each end to provide leads without adding to the over-all length. Finally, the choke is vacuum impregnated with silicone resin and cured at 200° C. This coating provides the necessary mechanical support for the winding. The chokes are also wound with Ceroc-ST insulated wire to withstand the high temperatures. Choke chains are used in the plate, heater, and automatic gain-control voltage supply leads of the model VI amplifier.

Figure 27 shows a unit with the chokes installed and figure 29 shows an alternative placement of heater chokes when the tubular ceramic bypass capacitors are used.

Brass tubes, 1-3/8 in. long, 0.400 in. in diameter, and a 0.010-in. wall thickness, are used to shield the electron tubes electrically. A number of these brass tubes, one to accommodate each electron tube, are placed side by side and joined in a single jigged soldering operation to form the tube shield subassembly (fig. 32). In the same operation, two runners are soldered along the length of the shield assembly. The chassis is provided with spring fingers that will engage these runners and hold the shield subassembly firmly to it when the shield is slid into position. The pressure maintained by these fingers assures good electrical grounding contact between shield and chassis.

The clip-on design of the tube shield subassembly permits easy removal, thus assuring ready access to the connections at the tube bases.

(c) Assembly

The final assembly of the model VI miniature i-f amplifier is considerably facilitated by the use of the preassembled units. It consists of wiring-in the capacitor and inductor subassemblies and adding the tubes, chokes, and resistors. When tape resistors or resistors printed on a ceramic plate are used, the entire resistor complement is likewise included in a single subassembly. Thus, resistor mounting is accomplished in a single operation.

The capacitor subassembly nests beneath the chassis (fig. 29). When tubular capacitors are used, the metal plate on which they are mounted is soldered to the chassis. When the glass-dielectric capacitor subassembly is used, its foil-type ground leads are soldered to the chassis and provide adequate support at one end; at the other end, the 24 "hot" capacitor leads are tied to the inductor and resistor subassemblies and provide sufficient support.

The electron tubes are wired with their bases adjacent to the inductor mounts (fig. 27). The tubes lie close together, their separation being only the 0.025 in. allotted to the tube shields, thus the diameter and number of the vacuum tubes determine the length of the amplifier.

All connections are easily accessible, thus simplifying the wiring, Most connections are made in but two regions, one below the inductor forms where there is nothing to impede the wiring, the other between the inductors and the tube bases. In this second region the shape of the tube base press is such that the connections are readily made when the tube shield subassembly is unclipped and slid back from its normal position.

Component leads are used exclusively for wiring the amplifier. This may be done because the layout is such that the conductors required are extremely short. The need for lead insulation is also obviated in most cases, the very short leads having sufficient rigidity to keep them from wandering and shorting.

As already mentioned, two alternative case assemblies were designed for the amplifier. One provides for simple installation or removal of the amplifier through a plug arrangement (figs. 24 and 25). With the other case, the power and signal cables are attached directly to the amplifier, thus effecting a space saving through elimination of the plugs (fig. 26).

The plug-in case is designed so that all connections are made to the amplifier by two plugs, one of which inserts into each end of the amplifier case. The input plug provides connection for the input and crystal current cables. The output plug accommodates the output cable and a multiconductor cable that supplies plate, heater, and AGC voltages.

These cables are terminated in the plugs in fittings that mate with the hermetically sealed fittings mounted in the ends of the case. Both the coaxial terminations and the steatite insulator that holds the receptacles terminating the individual conductors of the multiconductor cable, mount on the plug end plate. A sheet-metal cover shields and protects the entire plug.

The case and cover are made of 0.015-in.-thick phosphor-bronze. The case is formed around, and silver soldered to, 1/8-in. brass end pieces on which the hermetically sealed fittings are mounted. Phosphor-bronze is used to give sufficient spring action so that extensions of the case and cover over the end plates may serve as alinement and grounding fingers for the plugs.

Feed-throughs and coaxial connector fittings utilizing glass-Kovar seals are soldered into the case end pieces. (These may be seen installed at the output end of the case in fig. 25.) They provide hermetically sealed connections between the amplifier proper and the receptacles in the plugs when the plugs are inserted.

The case is provided with a copper tube, that permits evacuation and filling with inert gas. When this is done, the tube is clipped off and sealed. Then a cylindrical cap is screwed in place over the protruding portion to provide additional alinement for insertion of the plug. (This is shown at the output end of case in fig. 25.)

The alternative case assembly provides a saving of 1 in. in the length of the amplifier due to the elimination of the plugs at the two ends (fig. 26). In short-life applications, or where the assurance of a sufficiently low maximum ambient temperature makes hermetic sealing unnecessary, the cable termination fittings may screw directly into the brass end plates of the amplifier. The cable conductors are then soldered within the case to the proper amplifier terminals. When hermetic sealing is necessary, cable termination fittings utilizing glass-Kovar seals are installed and solder sealed to the case end plates. The coaxial and multiconductor cables are then terminated outside the case on these fittings.

(d) Circuitry

The model VI i-f amplifier consists of six stages, plus input and output coupling networks. Figure 33 shows the schematic diagram of the amplifier. The first two stages comprise the low-noise input. Following the input there are four synchronously tuned (peaked) stages. A model VI amplifier having a center frequency of 30 Mc has a bandwidth of approximately 6 Mc for each stage, and the combined effect of the six stages gives an over-all bandwidth of approximately 2.5 Mc.

In the experimental model shown, the detector is omitted, and the intermediate frequency signal is coupled from the output of the amplifier to the succeeding unit by means of a 93-ohm link coupling. If desired, a standard detector and succeeding video stages could be included within the amplifier.

At both input and output of the amplifier, tightly coupled transformers are used with the turns ratio being such as to transform the tube impedances to the relatively low impedance of the coaxial cables. As with the other inductors in the amplifier, these transformers are wound directly on their powdered-iron cores. In order to achieve as tight coupling as possible, the windings that connect to the coaxial cables are wound midway between the ends of the powdered-iron slugs and beneath the other winding of the transformers.

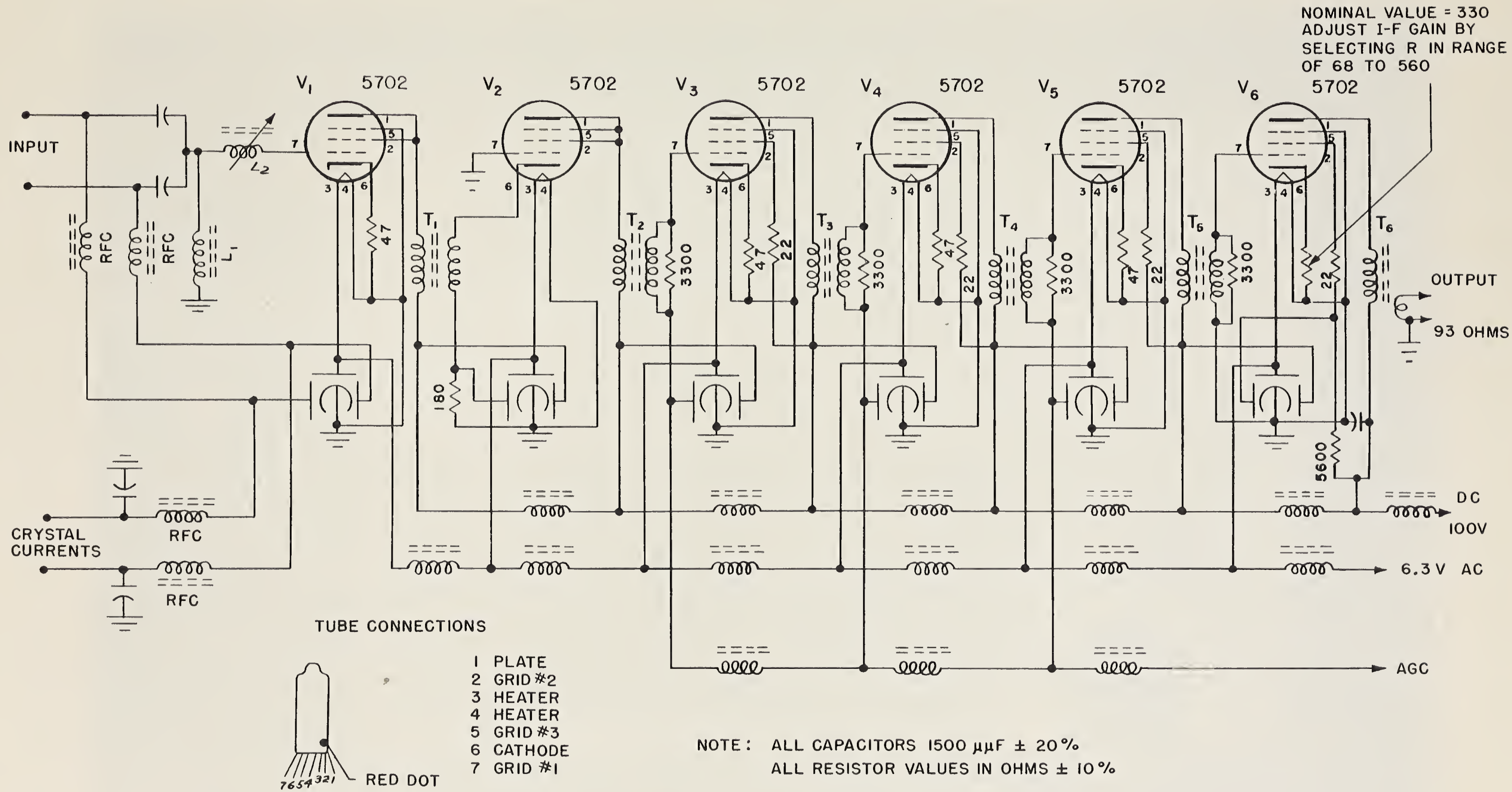


Figure 33. Circuit diagram for model VI amplifier.

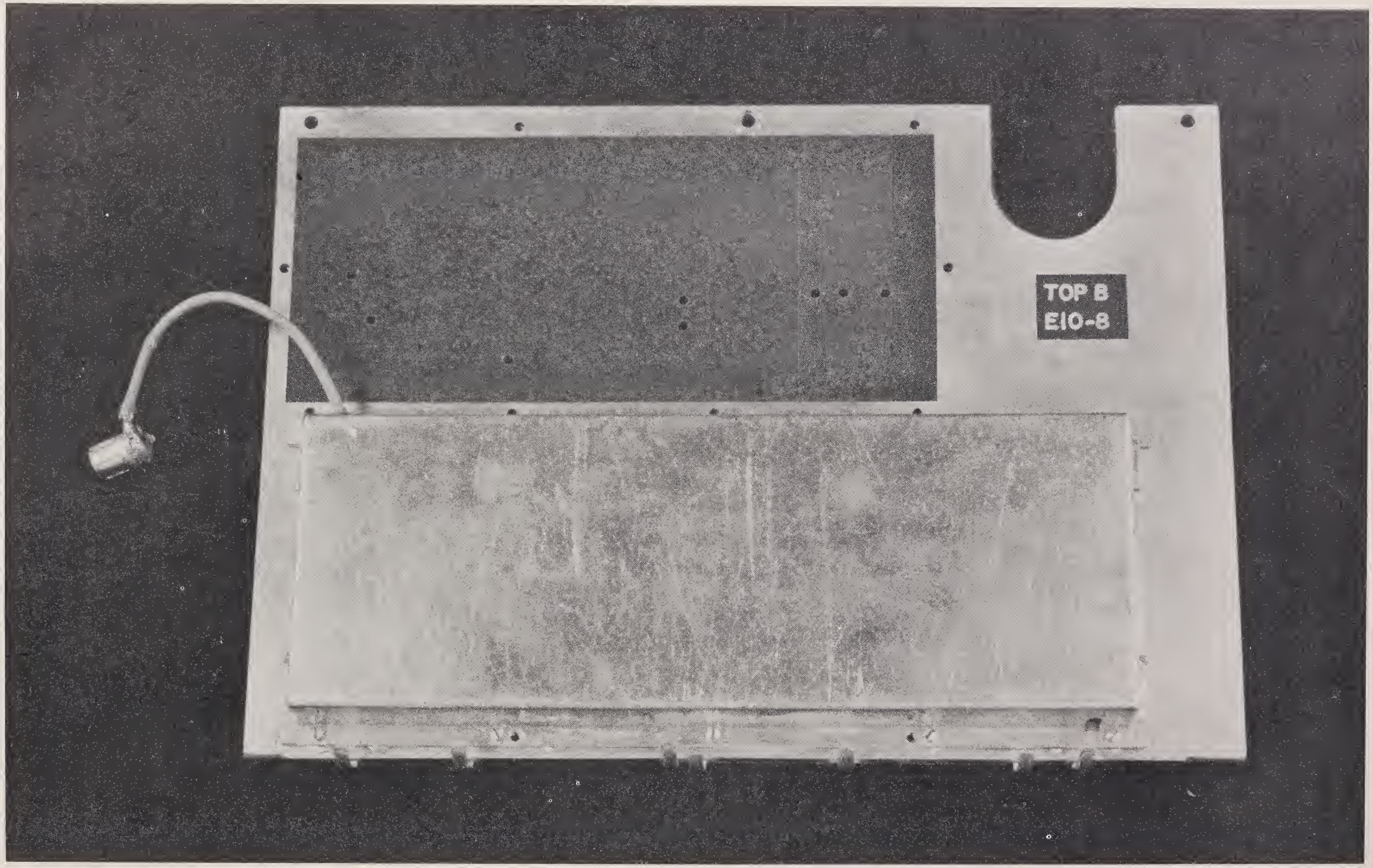


Figure 34. Model VII amplifier mounted on base plate.

3.3. Model VII Intermediate-Frequency Amplifier

(a) General Description

The characteristics specified for the model VII amplifier were similar to those specified for the model VI, with the following exceptions:

1. The volume (per stage) was to be governed by the equipment for which it was intended, and this was greater than the model V or VI, although still considerably smaller than conventionally built amplifiers.

2. The ease of construction was to be comparable with that of a conventional amplifier.

3. The appearance of new high-temperature components since the development of the model VI, and the larger allowable volume, made it possible to use a larger percentage of commercially available components in the model VII amplifier.

4. As the model VII was intended for use in a pressurized equipment, it was not necessary to provide a hermetically sealed housing. Of course, if other equipments require it, such a housing could be provided.

The significant advances in the model VII amplifier include the use of a processed plate for the amplifier chassis, a single piece for the cover, and a design that allows one set of screws both to hold the cover in place and to mount the amplifier to the equipment chassis. In the particular equipment for which this amplifier was designed, the chassis to which the amplifier mounts is also the chassis for the automatic frequency-control unit and consists of a simple assembly of two 1/16-in.-thick processed plates. These plates are removable from the equipment, as an assembly that plugs into a main chassis baseplate. The assembly is shown in figure 34 with the i-f amplifier mounted in place (the afc unit has been removed).

(b) Internal Structure: Component Parts

As in the model VI, the components and materials used in the model VII have been selected (wherever possible) to withstand continuous operation at a temperature of 200° C. However, in the interest of reliability, the installation has been designed so that the maximum internal temperature, even under the most severe conditions specified for the equipment, will not exceed 175° C. The same high-melting-point solder used in the earlier amplifiers is used. Although the melting point of low-temperature (conventional) solder probably would never be reached in this assembly, it has been found that such solder, nevertheless, does deteriorate after long operation at elevated temperature, whereas the 95-percent-tin and 5-percent-silver solder shows no signs of deterioration.

The same tube types are used in the model VII as in the earlier models except that the 6110 high reliability dual diode is used as the detector. The model VII includes both a video amplifier and a cathode follower output stage, combined in a 6112 high reliability dual triode.

Standard carbon-film-type resistors are used throughout this amplifier. Because the amplifier is not hermetically sealed, the smaller uncoated resistors used in models V and VI are not suitable for the model VII.

The glass-dielectric-type capacitors described in connection with the model VI amplifier are used throughout the model VII. The triple units are also used for bypassing each stage.

This amplifier is constructed on a single 1/16-in.-thick processed plate, which is shown with the components mounted in figure 35. The plates used in the developmental models are etched from silver-plated copper-clad laminate.

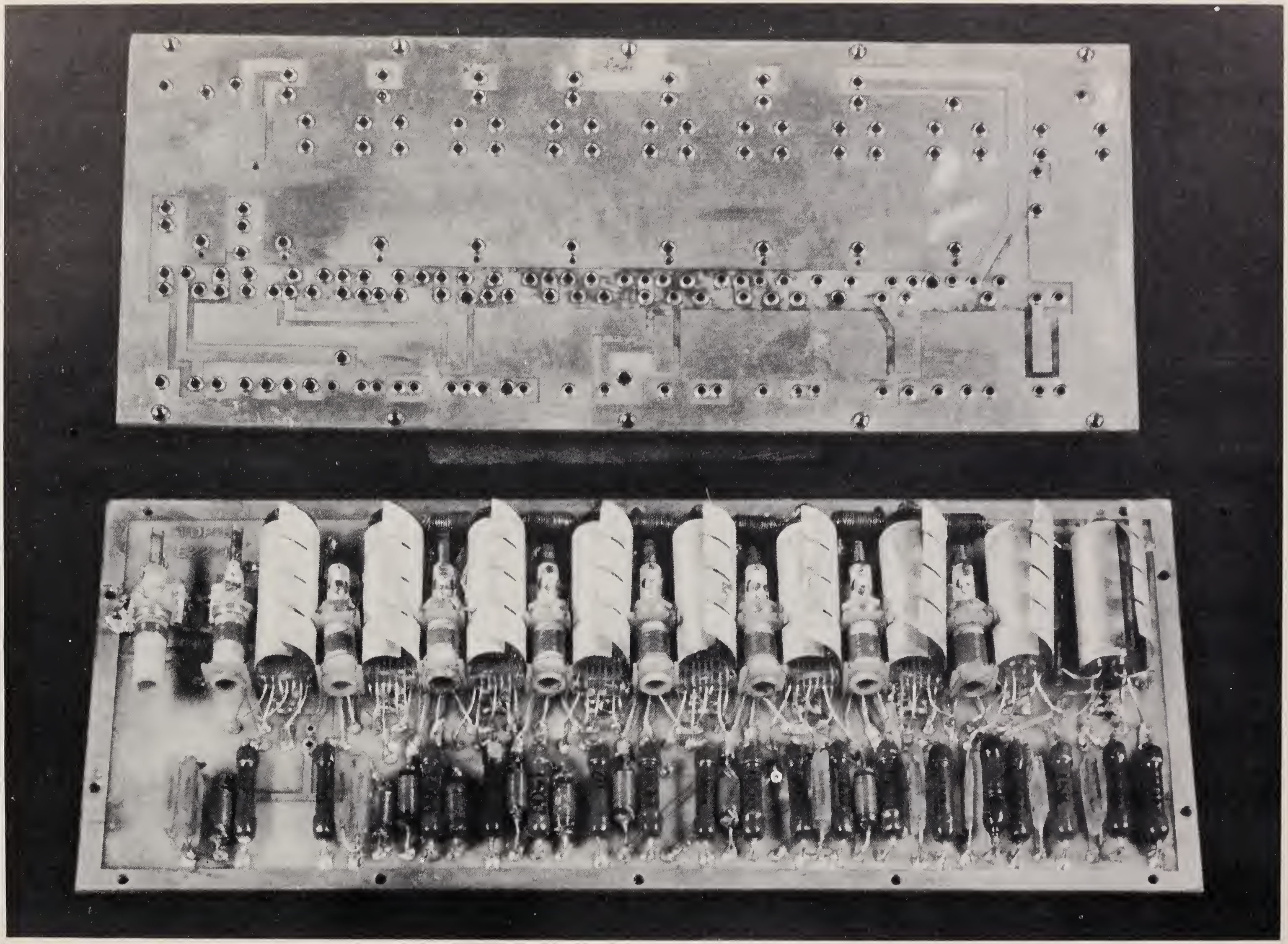


Figure 35. Model VII amplifier.

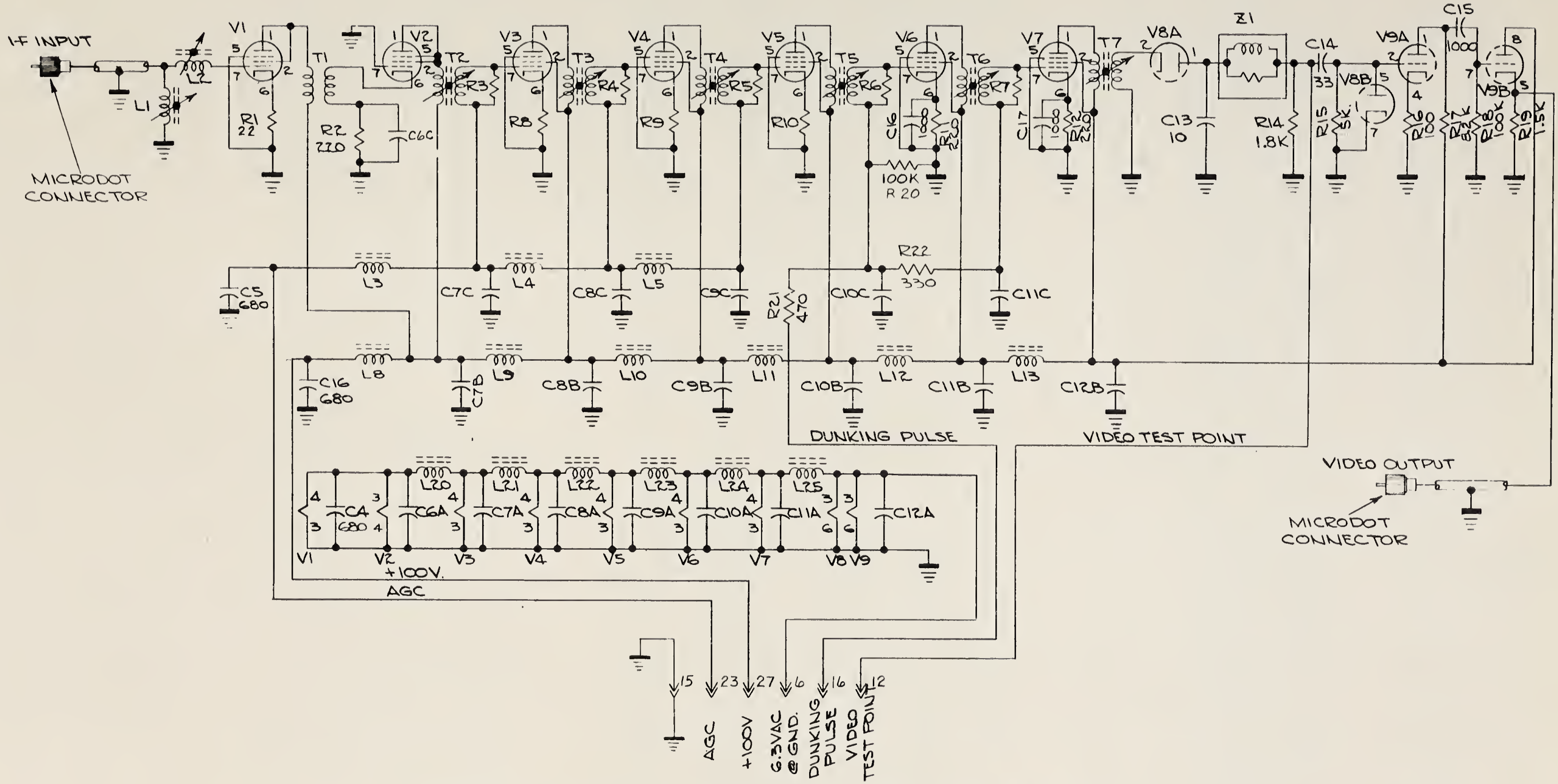


Figure 36. Circuit diagram for model VII amplifier.

Silver plating is used in order to minimize impedance in the high-frequency circuitry, to facilitate soldering, to protect the copper, and to provide good contact to the amplifier cover, the inside of which is also silver-plated (the cover is fabricated of 1/32-in.-thick aluminum). Additional moisture protection to the processed plate may be obtained by coating with silicone resin. The laminate itself is silicone-impregnated glass fiber. However, a number of other suitable materials, such as those made with Epoxy resin, are now becoming available.

The inductors are wound upon standard commercial coil forms, which have powdered-iron slugs, adjustable within the ceramic body, for tuning. While for ease of laboratory construction, the use of bifilar inductors is continued, it now appears that for any large-scale production a small double-tuned, fixed-tuned transformer should be used. With proper design of the amplifier and inductor, it is now practical to produce such amplifiers without the necessity of individually tuning the inductors. The inductors are wound with Ceroc-ST wire.

The decoupling chokes are similar to those used in the earlier amplifier models.

(c) Assembly

In assembly, the individual metal parts are riveted to the main chassis plate, to constitute the complete chassis. While in laboratory models, eyelets are often installed in all the component lead holes in the processed plate in order to make possible frequent soldering to this plate, it is believed that such eyelets should be omitted in production units. With certain processes, a limited number of eyelets would, nevertheless, be required to complete circuitry connections between the two sides of the plate; other processes include means for connecting between the two sides without eyelets. One such means is a method for direct plating through the holes. Where eyelets are used in electric circuits, it is always essential that the eyelet be soldered to the processed circuitry pattern. No matter how good contact is attained by mechanical means, high resistance will always develop in some of the pressure contacts, during high-temperature operation.

Once all the metal parts have been attached, the electronic parts may be installed and soldered. This type of construction facilitates the use of dip-soldering for production.

(d) Circuitry

The model VII i-f amplifier consists of nine stages, plus an input coupling network. Figure 36 shows the schematic diagram of this amplifier. The first two stages comprise the low-noise input circuit. This circuit is followed by five synchronously tuned (peaked) stages. A model VII amplifier having a center frequency of 60 Mc has a bandwidth of approximately 2.5 Mc, over-all. The i-f section proper is followed by the detector stage, a video amplifier stage, and a cathode follower output stage. In the particular model shown, both AGC and dunking voltages are applied to the i-f section proper, the AGC voltage being applied to three low-level stages, and dunking to two high-level stages. Manual control is applied through a manual setting of the AGC reference voltage.

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. . . 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.

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. . . 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 of all uncommon materials and equipment used. The book contains 5 chapters, 32 figures, and 1 table that amply illustrate the text.

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