L3 AMPLIFIERS

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1. GENERAL

1.01 This section contains a description of the J68816A line and J68816B flat amplifiers used in the L3 coaxial system. These amplifiers are required to pass a band of frequencies from about 300 kilocycles to 8.5 megacycles.

1.02 The line amplifiers are designed to compensate for the loss of the four miles of cable which separate the repeaters; the flat amplifiers are used to compensate for equalizer loss and as transmitting amplifiers. The two types are basically similar, consisting of two feedback amplifiers in tandem separated by an interamplifier network; in the line amplifier this network is variable and is automatically adjusted to compensate for variations in cable temperature and for small deviations from the nominal 4-mile spacing.

1.03 Coupling networks employing high-precision transformers are used to connect the amplifiers to the coaxial cable through the required power separation filters. The low impedance windings of the transformers are center tapped and a balancing network is provided in order to match the cable impedance over the transmitted frequency band. The amplifiers are equipped with plug-in electron tubes of high figure of merit (high transconductance-capacitance ratio) which were developed for this application. A double-triode output stage is used to obtain improved system signal-to-noise performance. Provision is made for preventive maintenance of electron tubes and for a controlled adjustment of gain on an in-service basis.

1.04 All important components of the amplifier are subject to quality control procedures to assure that the average gain of groups of amplifiers will be held within narrow limits and that individual amplifiers will form a normal distribution around the average. This approach is essential in order to meet system equalization and signal-to-noise objectives.

2. TRANSMISSION CONSIDERATIONS

(A) Amplifier Requirements

2.01 In a transmission system such as the L3 coaxial, the degree to which system objectives are achieved is largely dependent on the characteristics of the line amplifiers which compensate for the cable loss. To a considerable extent, the same statement applies to the similar flat gain amplifiers used to make up for the loss of the equalizers at various points along the route.

2.02 The amount of feedback that can be obtained in an amplifier and the signal-to-noise ratio of the system are functions of the figure of merit, modulation coefficient, and life characteristic of the electron tubes used. The ability to meet system requirements require, however, that strict quality control be maintained on the amplifiers at every stage of manufacture, from raw materials to completed amplifiers, to insure that a high degree of reproducibility of amplifier gain and delay characteristics is realized.

(B) Amplifiers and the Equalization Plan

2.03 The equalization plan is based on the assumptions that the gain of the average line amplifier will match the loss of the preceding line section to within 0.15 db and that the average amplifier gain will not vary from one batch of new amplifiers to another by more than about 0.06 db. Under these assumptions, a system equalization plan can be worked out which results in reasonable spacing between equalizers, a tolerable signal-to-noise penalty due to misalignment and equalizer loss, and a practicable procedure for adjusting long systems. Any gross departure from the basic assumptions as to reproducibility of amplifiers seriously compromises these objectives.

2.04 A feature of the amplifier design is the omission of all adjustable elements, or trimmers, to control the transmission. By eliminating gain adjustments, the possibility of adjusting one element to compensate for the shortcomings of another, and the possibility of systematic errors of setting due to faulty or inaccurate adjustment techniques are both eliminated. Either of these possibilities would tend to convert relatively large random effects into smaller but cumulative effects, a conversion which would penalize the system equalization. Obviously, however, the elimination of gain adjusting elements puts a higher premium than ever on the requirement that all elements, including tube capacities, show only small random variations about tightly controlled nominal values.

(C) Design Objectives

2.05 The gain of the line amplifier must be continuously variable, under the control of a regulator circuit, to compensate for differences in lengths of cable sections and for variations of cable loss caused by temperature changes. The shape of the gain change should match the square root of frequency shape of the line loss change over the transmitted band to within a few hundredths of a db. This accuracy of shape should hold over the entire regulation range, which is about $\pm$ 6 db at the top transmitted frequency.

2.06 The input and output impedances of the line amplifier should match the cable impedance in order to minimize the effects, on television transmission, of echoes caused by line irregularities such as splices. Tolerable values of reflection coefficient at amplifier input and output are about 5 per cent at the television carrier and 10 to 15 per cent at upper band edge.

2.07 Feedback consistent with system modulation requirements, shaped across the transmitted band to minimize low-frequency intermodulation products and to give a smooth, easily equalized shape of gain change as tubes age, must be obtained while maintaining adequate margins against singing.

2.08 Other requirements include design and selection of elements to assure as small a change of gain vs ambient temperature as possible, mechanical design provisions for keeping the temperature rise within the unit to a minimum both in order to keep the temperature-gain effect small and to obtain long element life, a sealed housing to avoid damage by humidity in exposed locations, and provision of facilities for testing tubes in service.

3. LINE AMPLIFIER

(A) Configuration

Note: The term "beta circuit" used in the following paragraphs means feedback circuit.

3.01 The circuit configuration of the line amplifier is shown in Fig. 1. It consists of two independent feedback amplifiers with a regulating network between them acting like a 2-terminal interstage. Each of the amplifiers is essentially a 2-stage circuit - the input amplifier literally so and the output amplifier essentially so since the double-triode output circuit acts like a single stage. The input amplifier uses 435A tubes and the output amplifier uses a 436A tube in the input and two 437A triodes in the output stage. The 436A and 437A tubes are tetrodes.

3.02 Each amplifier is connected to the coaxial through a coupling network which consists of a transformer plus gain shaping and impedance-adjusting elements. Since there is no feedback around the coupling networks, they directly affect the insertion gain of the amplifier, as do the two beta circuits and the regulating network. The required shaping of insertion gain across the transmitted band is obtained and controlled by the design of these five networks. Fig. 2A shows the required

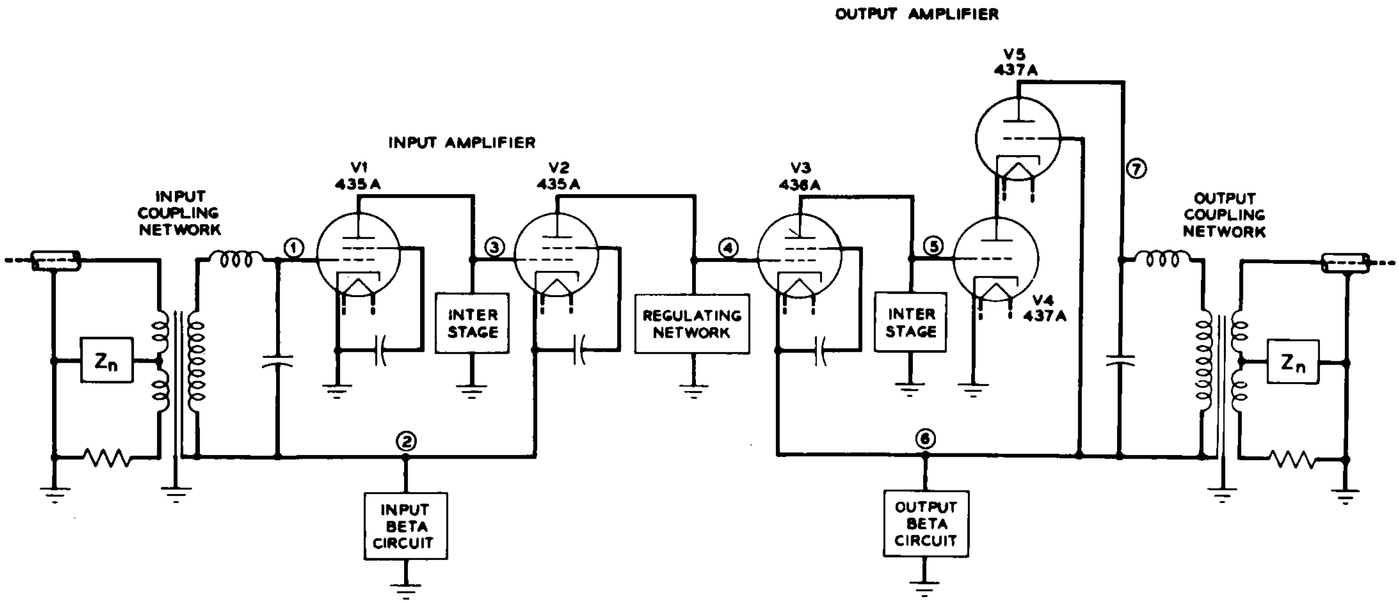

Fig. 1 - L-3 Line Amplifier Configuration

amplifier gain for nominal and extreme thermistor settings; these required gains differ from the line loss by the small losses of the associated repeater components. Fig. 2B shows the difference between the cable loss and the gain that is provided by the average amplifier.

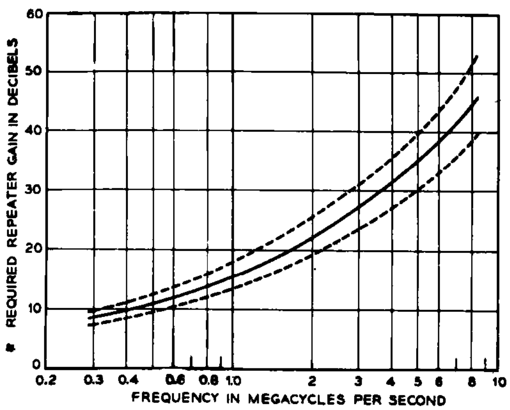

Fig. 2A - Required Line Repeater Gain

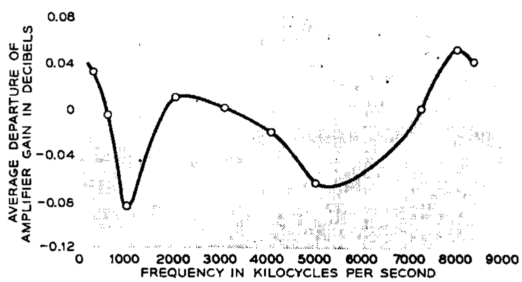

Fig. 2B - Difference between cable loss and actual gain provided by an average L3 repeater.

At midrange thermistor setting about 37 db of gain shaping is needed. The manner in which this shaping is distributed among the five networks has important effects on the feedback which can be obtained and the sensitivity of amplifier gain to element variations.

3.03 An important advantage offered by this configuration is that the regulating network is between the amplifiers. In most other wideband amplifier configurations, the only gain-determining network available for the regulating function is the beta circuit. When the feedback is not infinite, this introduces errors for which it is difficult to compensate, and limits the available feedback by complicating the design. In the configuration used, the impedances which the amplifiers effectively present as shunts across the regulating network are high and can be allowed for in the design so that the regulation error can be made much smaller than the error associated with beta circuit regulation in an amplifier having relatively little feedback. Other major advantages of the configuration used are the superior signal-to-noise performance and the relative simplicity of the feedback loops as compared to alternative designs.

3.04 Another departure from the typical design is that the output section of the amplifier uses two triodes connected in series with a single plate supply so that the tubes operate as a single stage. The output is taken from the plate of the 437A tube on the right triode while the signal is impressed on the grid of the second or other triode as shown in Fig. 1.

This circuit has the advantages of the high gain produced by a triode stage, combined with the high input and output impedance characteristic of a pentode. As an output stage, its signal-to-noise ratio is considerable better than the more usual pentode stage.

(B) Coupling Networks

3.05 The input and output coupling networks are essentially identical. The low side of each transformer is a balanced center-tapped winding which together with the balancing network acts as a hybrid, to produce a good 75-ohm impedance facing the cable. (See Fig. 3.) The use of this type of connection gives a signal-to-noise advantage over the use of a brute-force high-side terminating network. In addition, the use of a hybrid connection permits a good reflection coefficient to be obtained with negligible effect on the insertion gain of the circuit.

3.06 A relatively modest share of the total shaping required is allocated to the coupling networks: 5.5 db each, or 11 db total. One reason for this is that although these networks are outside the feedback loops in the usual sense, nevertheless, the impedances which they present to the amplifiers are important factors in the feedback design, and the effects which they produce must not be allowed to become so severe as to limit the feedback to too low a value.

3.07 A second limitation is that the sensitivity of the insertion gain to variations in the coupling-network elements is increased as the slope is increased. For these reasons not only the slope but also the gain level or efficiency of these networks is kept relatively low.

3.08 The coupling networks are the most important source of manufacturing deviations, but by improved mechanical design and the use of quality control these effects are reduced by an order of magnitude as compared to previous designs. For example, the end capacity of each coupling network is a quartz-disc condenser, and the peaking or splitting coils are tension wound on ceramic forms to give inductances of 1 per cent tolerance with distribution requirements within this range. The windings of the transformers, shown in Fig. 4 are made by plating the turns on threaded forms machined from optical grade quartz or Vycor glass to tolerances of tenths of thousandth of an inch. Leakage inductance and parasitic capacity deviations are thus held to a minimum. Split ferrite cores, which are also held to close tolerances, make it possible to use these methods of fabrication, which previously available types of cores would not have permitted.

(C) Regulating Networks

3.09 Like the coupling networks, the regulating network between the amplifiers is outside the feedback loops, and the gain of the amplifier is very nearly a direct function of the impedance seen looking into the network. This impedance is controlled by a single variable resistance - the thermistor - which is directly heated by the dc output current of the regulator. The output of the regulator, in turn, is a function of the magnitude of main pilot level at the output of the amplifier. The whole forms an AVC circuit which acts to keep the level of the main pilot constant at amplifier output, under the assumption that any changes in this pilot level are caused by line temperature or length deviations. The fixed arms of the regulating network are designed to give the accurate shaping of network impedance vs frequency required so that the amplifier gain change will have the wanted square root of frequency shape.

3.10 Fig. 5 shows the basic configuration of the regulating network. It was selected because it is one of the simplest that gives symmetrical gain changes controlled by a single resistor. It is also capable of absorbing the parasitic interamplifier capacity, and gives

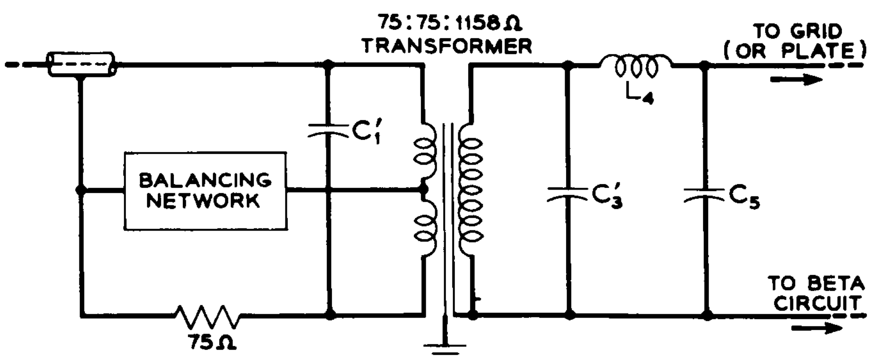

Fig. 3 - Coupling network

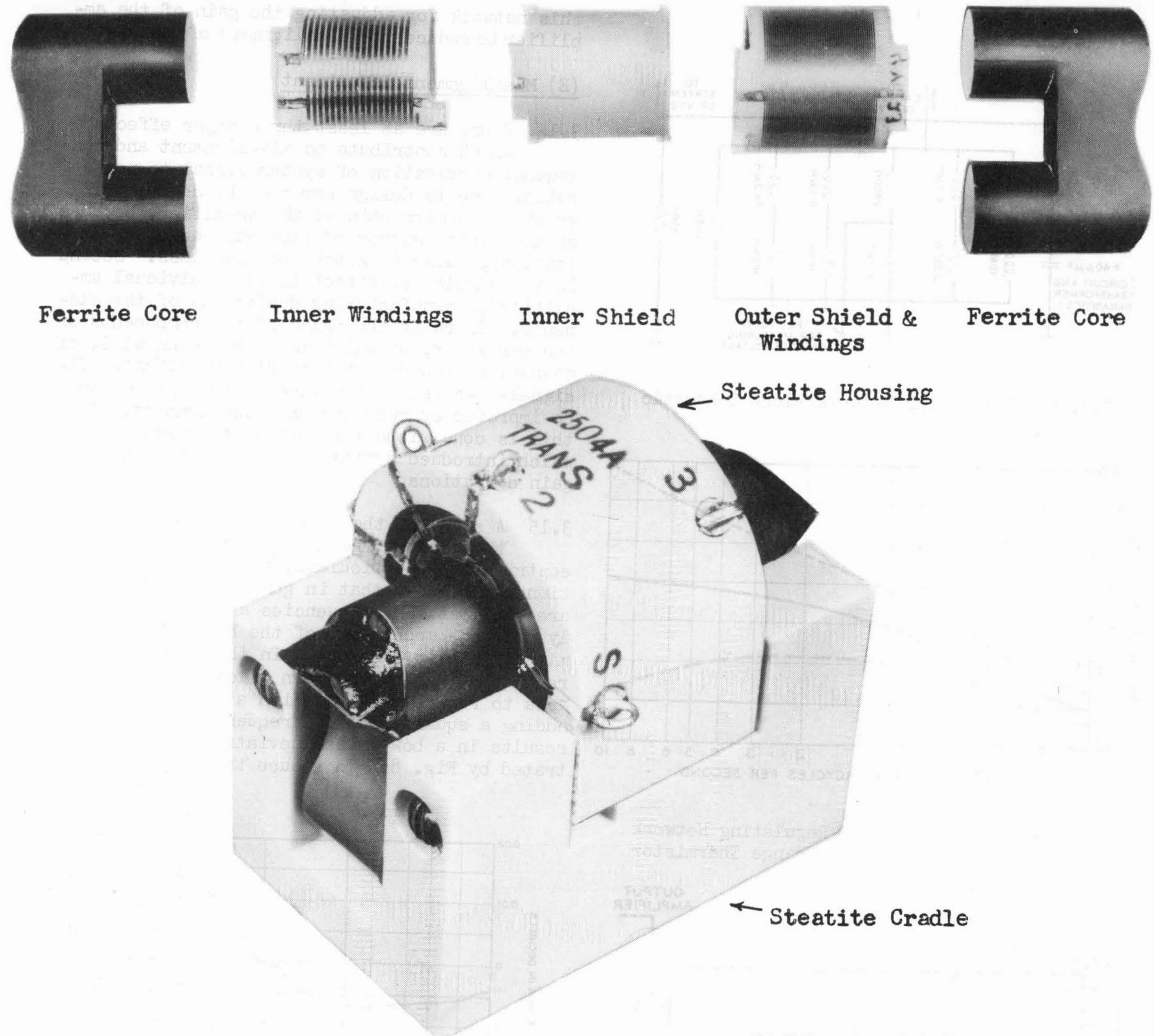

Fig. 4 - Precision transformer, windings, core, assembled unit

some advantageous gain shaping at normal setting, although this shaping is not under design control. Fig. 6 shows the relative gain of the regulating network for extreme and midrange thermistor settings.

(D) Beta Circuits

3.11 Starting from the basic requirement that a slope of 37 db across the transmitted band must be obtained, and noting that the total of the contributions from the coupling networks and regulating network is about 16 db, there remains about 20 db of shaping to be supplied by the beta circuits. The input beta circuit has been designed to supply 17 db and the output beta circuit supplies most of the remaining 3 db.

3.12 Fig. 7 shows the circuit of the input beta network. One of the requirements of the beta circuit is that it have the correct dc resistance to serve as the cathode-bias resistor of the second tube, and that it incorporate provision for metering this bias through suitable decoupling elements which are among the gain-determining elements of the network. The input beta network is used as the mop-up-equalization network of the amplifier, and its element values are adjusted to give the required amplifier gain.

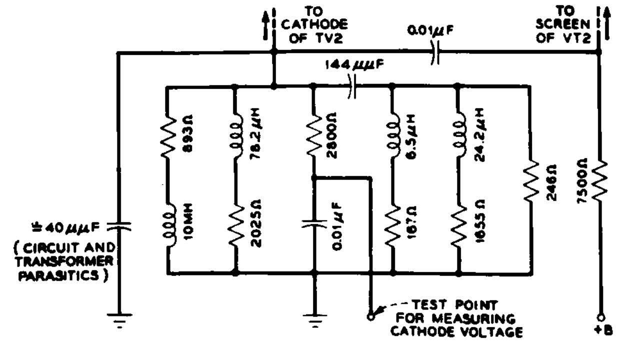

Fig. 5 - Regulating Network Block Schematic

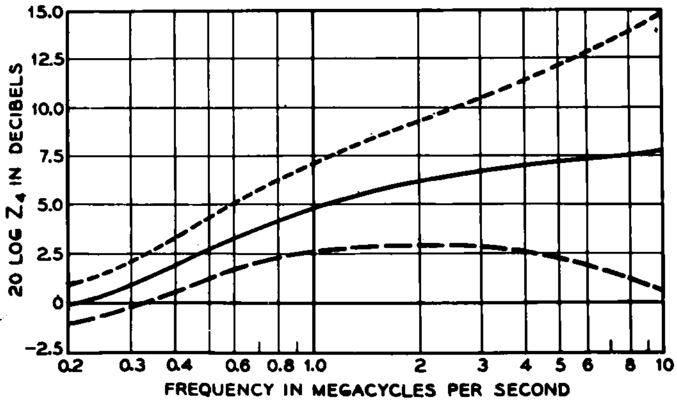

Fig. 6 - Relative Gain of Regulating Network for Extreme and Midrange Thermistor Settings

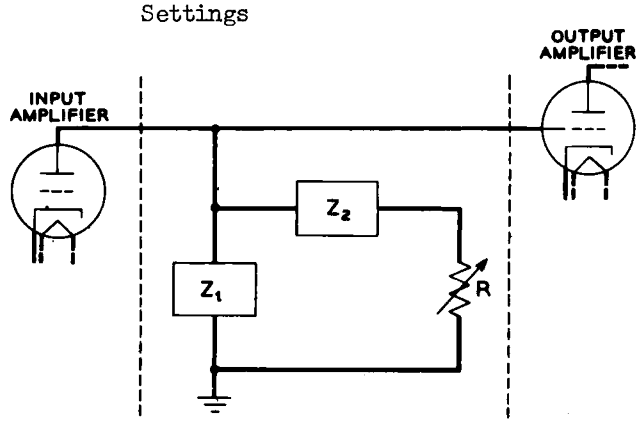

Fig. 7 - Input Beta Circuit Elements - Line Amplifier

3.13 The output beta circuit is relatively flat, which in this case is the optimum condition for signal-to-noise and feedback loop stability considerations. Provision is made in this network for adjusting the gain of the amplifier to reduce the misalignment of the system.

(E) Misalignment Adjustment

3.14 There are at least three major effects which contribute to misalignment and consequent degradation of system signal-to-noise ratio. One is design error - the degree to which the design gain of the amplifier, because of the finite number of elements and other limitations, fails to match the line loss. Second is the cumulative effect in the individual amplifier of manufacturing deviations of the elements. Third is the aging of the components of the amplifier, of which the tube aging will, of course, be the dominant short term effect. The signal-to-noise performance of the system can be improved by reducing the misalignment, if this is done without resorting to measures which introduce systematic instead of random gain deviations.

3.15 A study of the shapes of gain change introduced by the more important deviation contributors, particularly the element variations, has shown that in general the effects are small at low frequencies and increase sharply near the upper edge of the band if the thermistor is held constant. In the system, the regulation around the main pilot automatically acts to reduce the deviation at 7266 kc to 0, adding a square root of frequency curve that results in a bow-shaped deviation as illustrated by Fig. 8. To reduce the misalignment

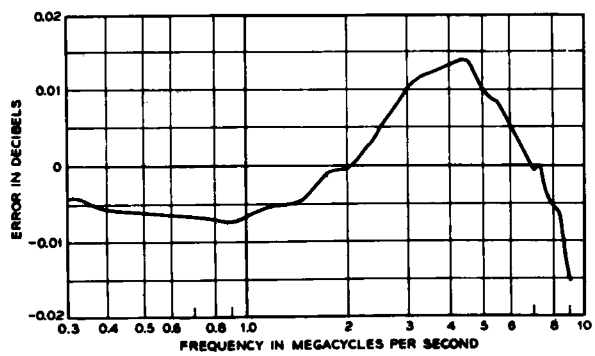

Fig. 8 - Regulation Error per One db Regulation

as much as possible at 4 megacycles, the television carrier frequency in the combined system, the output beta circuit is designed to give varying amounts of this shape, the total range being $\pm$ 0.6 db at 4 megacycles in 0.2 db steps. The successive steps of this gain adjustment are simple multiples of each other, symmetrical in the two directions of adjustment, this puts into the system a single systematic shape, which will be small in magnitude at the equalizing points because the different settings of this control in successive line repeaters will tend to cancel out. This setting of output beta circuit gain is controlled by a GAIN ADJ switch accessible from outside the amplifier housing. The adjustment will be made on an in-service basis as part of normal maintenance procedures, using the level at each repeater of one of the system pilot frequencies (3096 kilocycles) as the index of proper setting.

(F) Dc Feedback

3.16 In addition to the loop feedback at signal frequencies, local dc feedback is used on each stage. The grid of each tube is returned to a +9-volt potential rather than to ground, and about +10 volts is developed across each cathode resistor. The usual stabilizing effects of self-bias are thus obtained to an exaggerated degree, each tube having about 20 db of local dc feedback. Cathode bypass and interstage-coupling condensers are selected with care to accomplish the transition from low-frequency local feedback to in-band loop feedback smoothly without the instability which might be caused if these two feedbacks balanced out in the transition region.

3.17 For maintenance measurements, the 9-volt bias potential and the dc cathode voltage of each tube are brought out to a multipin amplifier test jack through appropriate decoupling filters. Thus the bias on each stage can be measured on an in-service basis. Filament voltage dropping resistors which can be switched in or out of circuit are provided on the repeater panel, so that bias can also be observed for a filament supply voltage 10 per cent below normal. The activity or change in plate current with filament voltage thus measured, or the history of the bias at normal filament voltage, may be used as criteria to determine when amplifiers should be taken out of service for tube replacement.

3.18 The upper triode serves as the plate supply path for the lower triode. Its cathode is, therefore, about 160 volts above ground and its grid is returned to a similarly high potential. About 35 db of dc feedback is obtained in this stage and the same provisions for measurement of bias and activity are made. To avoid excessive filament to cathode voltage, a separate filament supply winding which floats at the +190-volt supply potential is used for this tube.

(G) Loop Feedback

3.19 The feedback built up in the amplifier is limited by the figure of merit of the electron tubes and the circuit capacities. The available feedback is further limited by the multiloop type of circuit used. This type of circuit is advantageous, however, in that it makes the feedback on any given stage relatively insensitive to variations in the transconductances or impedances in another stage. Thus, when the transconductance of a tube starts to decrease, the feedback does not drop as rapidly as it would in a single-loop amplifier.

3.20 Study of the modulation products which will arise in system operation, both for the all telephone case and for the combined telephone-television signal, led to the conclusion that optimum shaping of the feedback for the L3 system would be to maximize the feedback at low frequencies in order to suppress intermodulation products falling in that part of the spectrum in the combined telephone-television case. Shaped feedback, falling off at the higher frequencies, is also consistent with obtaining a smooth and simple shape of gain change as tubes age (known as "mu-beta effect"), which is desirable from the equalization standpoint.

3.21 The loop feedback in the output amplifier is similarly shaped, for the same modulation and equalization reasons. The double triode circuit, sometimes referred to as a "cascode circuit," used in this amplifier has appeared in many contexts in recent years. It serves as a superior output stage in the L3 amplifier largely because the effective transconductance which can be obtained is about 3 db higher than that of a pentode of the same grid-cathode spacing. The effective transconductance, ignoring the division of output current between the load impedance and the internal plate impedance of the upper triode, is very nearly the transconductance of the lower triode. Since no current is lost to a screen, this is higher than that of a pentode of the same spacing. The higher value of transconductance means less grid drive for the same output current, and more obtainable feedback, both contributing to superior modulation performance.

3.22 The modulation of the upper triode, and the changes in transconductance of this tube, are suppressed by approximately the sum, in db, of the local and loop feedback. In consequence, the modulation and mu-beta effect contributions of this tube to the complete amplifier are negligibly small.

3.23 It will be observed that the grid of the upper triode is not connected to ground, but to the top of the beta circuit. In consequence, the grid-plate capacity of the upper triode appears as part of the end capacity of the coupling network rather than as a parasitic capacity to ground.

3.24 The interstage of the output amplifier, which consists simply of the circuit capacity plus a network having the characteristics of a 10 micromicrofarad capacity in the transmitted band is not tuned. Above the transmitted band this network shapes the gain and phase characteristics of the feedback loop to obtain the desired stability margins. The incorporation of this network reduces the in-band feedback by about 3 db, a sacrifice which is necessary to assure stability in the vicinity of 30 megacycles when the thermistor in the regulating network is at its minimum value.

3.25 In the 70-megacycle region there are two almost equally important feedback loops in the output amplifier - one through the transconductance of the lower triode, the other through the grid-plate capacity of this tube. Balances between these feedback paths are observed in the 70-100 megacycle region in the course of measuring the feedback, sometimes accompanied by 180° shifts in the phase of the loop transmission at frequencies above the balance point, an effect which theoretically depends on just how the two vectors go through the balance point. The occurrence of these balances is accompanied by a few degrees loss of phase margin in the 30-megacycle cutoff region, which must also be allowed for in setting the 30-megacycle stability margins, since sufficient control of parasitics to prevent these 70-megacycle effects is out of the question.

3.26 Parasitic resonances between the lead inductances and the capacities of the circuit, which tend to cause instabilities in the very high-frequency region about 200 megacycles are damped by small resistors in the leads, and the lead inductances are kept small by careful mechanical design. In this frequency region, neither measurement nor computation of stability margins can be trusted as anything but a rough guide. On the other hand, adding damping resistors in grid leads and other critical points to prevent 200-megacycle sings causes a phase margin penalty in the 30-megacycle region, so a nice judgment of how much damping to add is called for. Final values of damping were chosen so that typical amplifiers could not be made to sing by increasing critical lead lengths or by substantial increases in parasitic capacity, thus assuring that manufacturing variations of elements and wiring will not cause high-frequency sings.

4. MECHANICAL DESIGN

(A) Accuracy Required

4.01 The severe gain and delay reproducibility objectives also have their effect on the mechanical design of the L3 amplifier. At first sight the unit appears to be a lumped constant structure rather than one in which distributed effects would be of paramount importance. Usually the circuit designer in such a case is interested in the mechanical design only for reasons of neatness and economy, but on close inspection it will be noticed that in the amplifier structure as a whole as well as in the case of certain components, the effects of distributed capacity and inductance could easily defeat the objectives if the mechanical design were not such as to assure precise control of element placement and wiring lengths.

4.02 The order of mechanical accuracy required at the factory is beyond that which can be justified by the accuracy of transmission measurements on individual amplifiers. This striving for mechanical accuracy is carried all the way through, from element piece parts through subassemblies to the assembly on the final amplifier framework. It is expected that by reproducing the amplifiers as exactly as possible, the known elements as well as the many parasitic effects will be controlled to minimize the appearance of shifts in amplifier gain and delay which could be substantial in the system even though difficult to detect in the measurement of individual amplifiers.

(B) Mechanical Assembly

4.03 The mechanical assembly of the amplifier, like the configuration, is divided into three main sections. The input and output amplifiers are mounted on separate chassis which are designed for ready removal from the main base casting. The regulating network is mounted in an enclosed, shielded compartment which also serves to shield the component amplifiers from each other. Figs. 9 and 10 show the assembled amplifier.

4.04 Because of the wide frequency range and close control of parasitic capacity and lead inductance required, the L3 amplifier was designed as an integrated whole, and all networks were designed with, and as part of, the amplifier. In each case circuit elements were placed in space in the best possible position for optimum electrical performance, and supporting structures were then designed to maintain the desired space relationships. These supporting structures are made as separate units which mount on the amplifier chassis, so that the networks can be individually tested before

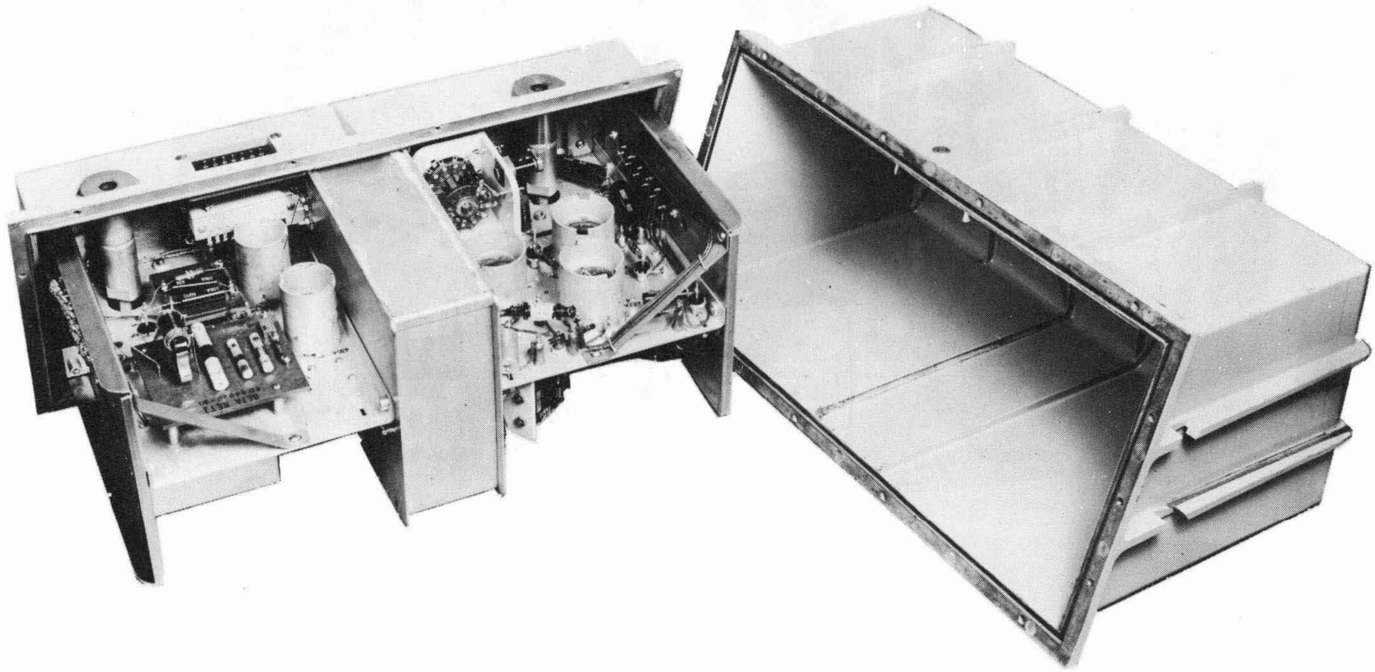

Fig. 9 - Line amplifier and housing

final assembly into the amplifiers, and can be removed for repair or replacement if necessary.

4.05 Heretofore, this method of design has been impracticable because of the very complicated supporting structures which resulted. It was feasible in this case because of the availability of a cold casting resin which allows the parts to be produced in a cheap phenolic mold. Since the process is practically equivalent to the sand-casting of metals, complex parts can be economically manufactured even in the relatively small quantities required for L3 production. Where necessary to assure accurate location or orientation of parts, the cast resin frameworks are milled or spot faced. The structure used in the input interstage, shown in Fig. 11 is an example. Circuit elements are wired to pins driven into the casting or, in some cases, to wires imbedded in the material. All wiring can thus be made direct with a minimum of bending and no doubling back, resulting in a reproducible and uniform product.

4.06 The entire amplifier is housed in a sealed die-cast container to protect the components from humidity damage. Dessicant is enclosed in each amplifier. It would have been desirable to make this housing of aluminum, but the high melting point of this metal makes it impractical for such a large casting to meet the air-tightness requirement. A zinc-base die-casting alloy was therefore used. Sealing is accomplished by rubber gaskets at all openings for connections and at the joint between the two parts of the housing. The removable part of the casting which serves as a cover is made as large a part of the total housing as possible, in order to provide maximum accessibility for maintenance of the units mounted on

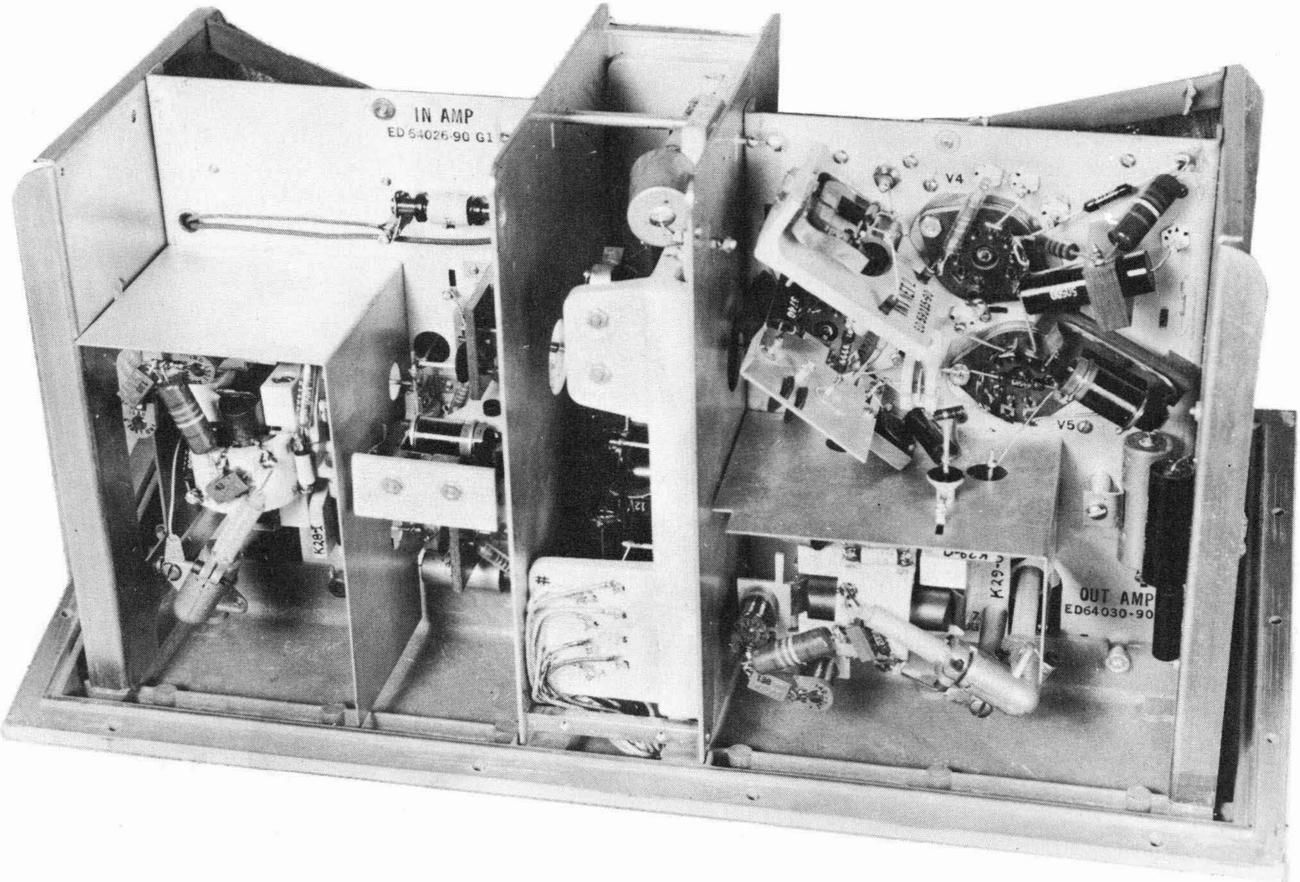

Fig. 10 - Line amplifier, wiring side

the base. The entire housed unit is arranged to mount on a relay rack mounted panel by means of slides which are self-locking. Signal and power connections are made by means of flexible cords which are available on the panel to plug into the unit after it is in place on the slides.

5. ELECTRON TUBES

(A) Requirements

5.01 The amplifier needed to compensate for the cable attenuation in the L3 system must meet very exacting requirements with respect to gain frequency characteristics, stability, noise, and linearity.

(B) Newly Developed Types

5.02 The design features necessary to provide suitable electron tubes for use in the L3 amplifiers are closely related to the requirements mentioned above for the amplifiers. In general terms, the tube design objectives are: (1) high transconductance-capacitance ratio (figure of merit), (2) minimum excess phase shift or phase delay, (3) low noise, (4) well controlled modulation, (5) long life, (6) interchangeability. In the material which follows, each of these objectives will be discussed briefly.

5.03 Figure of Merit: This is a direct measure of the bandwidth over which the required amplification can be obtained. In general, a given factor of improvement in the figure of merit can be translated directly into a wider transmission band providing more communication channels.

5.04 Tube design factors which influence the figure of merit include grid-cathode spacing, grid-screen spacing, screen-plate spacing, and grid-wire diameter.

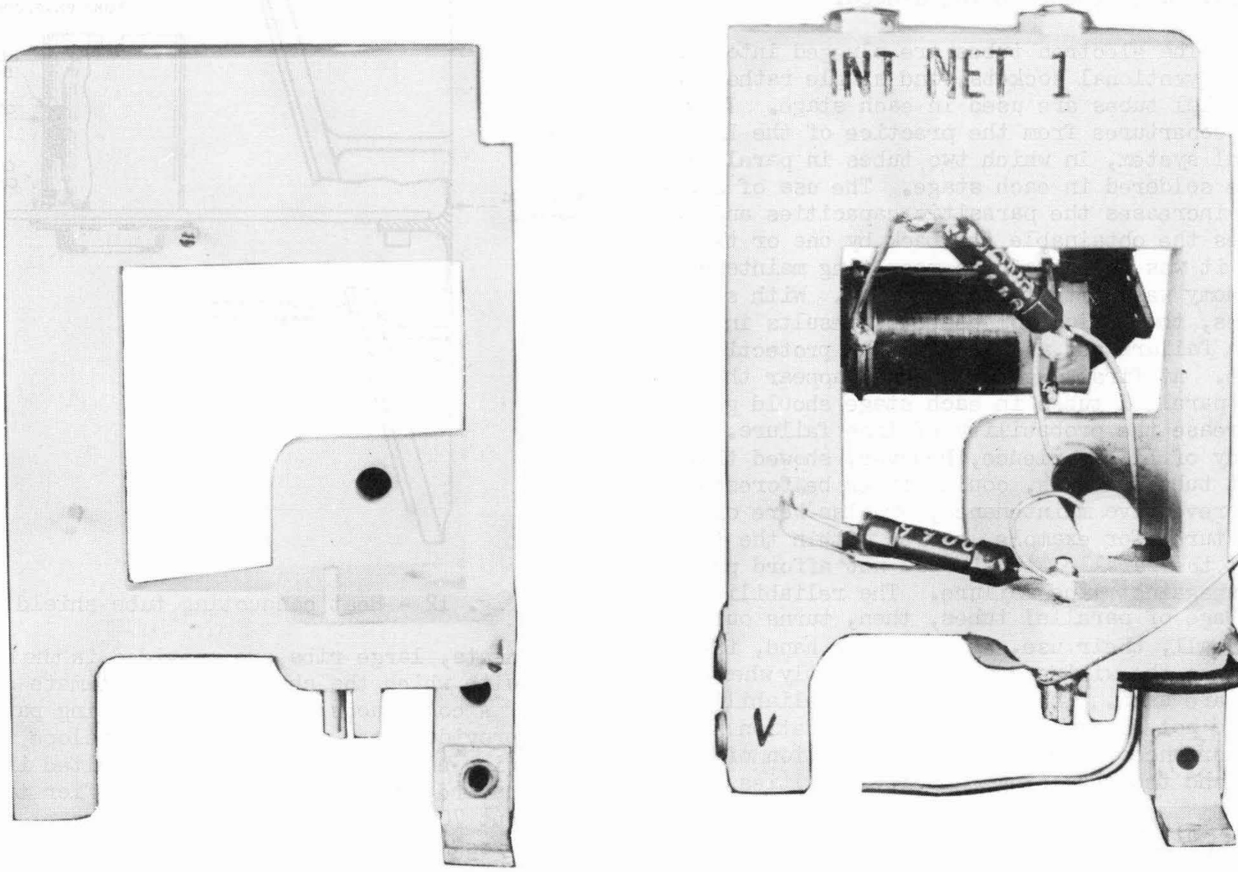

Fig. 11 - Input interstage, illustrating use of case resin frameworks

5.05 Minimum Excess Phase Shift or Phase Delay: The effects of electron transit time and lead inductance in the tubes must be taken into account in order to meet the amplifier requirements with respect to phase margin. In order to maintain stable operation over the desired transmission band, the gain and phase characteristics must be controlled up to about 200 megacycles.

5.06 Low Noise: Low-frequency noise components such as microphonics, power frequency hum, and "sputter noise" are kept to a minimum by tube and circuit design. Fluctuation noise is an important factor in the W.E. 435A used in the first stage of the input amplifier and in the W.E. 436A used in the first stage of the output amplifier. The fluctuation noise is minimized in the design of the tube by adopting an optimum value of cathode temperature and current density.

5.07 Well Controlled Modulation: Since a major purpose of using feedback is to reduce the modulation products arising in the amplifiers, the more nearly an ideal linear transfer characteristic can be approached in the tube design the better, because less feedback is required to obtain a given grade of system performance. The most important factors involved in controlling the variation in modulation from tube to tube are grid-cathode spacing, uniformity of grid pitch, and cathode activity.

5.08 Long Life: Long tube life is a very important requirement in the L3 system. The most important consideration is the effect on the reliability of the system. Also maintenance costs are reduced through long tube life. Laboratory life tests predict that a tube life of at least 15,000 hours may be expected in the L3 system.

5.09 Interchangeability: In Paragraph 2.04 there is a statement "omission of all adjustable elements, or trimmers, to control the transmission." It then follows that tube characteristics should be sufficiently uniform so that tubes may be replaced at will without circuit adjustments being needed.

5.10 The electron tubes are plugged into conventional sockets, and single rather than parallel tubes are used in each stage. These are departures from the practice of the L1 coaxial system, in which two tubes in parallel were soldered in each stage. The use of sockets increases the parasitic capacities and reduces the obtainable feedback by one or two db, but it was felt that the resulting maintenance economy was worth this sacrifice. With single tubes, the failure of one tube results in a line failure and a switch to the protection line. At first sight, it would appear that using parallel tubes in each stage should greatly decrease the probability of line failure. A study of L1 experience, however, showed that most tube failures, could either be forestalled by preventive maintenance, or else were of such a nature (for example, shorts within the tube) that the parallel tube would not afford protection against line failure. The reliability advantage of parallel tubes, then, turns out to be small, their use, on the other hand, increases the wiring complexity greatly when sockets are used. The small gain in reliability would not compensate for the degradation in performance caused by the complication of wiring and the resulting capacity penalties.

(C) Heat Dissipation

5.11 In common with many modern designs with high gain vacuum tubes, the problem of heat dissipation was acute in the L3 amplifier. The amplifier is enclosed in a sealed housing of sufficient size to dissipate readily the heat generated. However, with the usual types of chassis and tube shield construction, electron tube envelope temperatures were so high that long tube life could not be assured. Consequently, a new type of tube shield was developed. This shield is of heavy copper tubing equipped with internal helical springs mounted in such a manner that each turn of the spring makes contact with both the glass tube envelope and with the copper tube as shown in Fig. 12. Thus each turn of the spring provides two metallic heat conducting paths to carry away the heat from the tube envelope. A total of 480 conducting paths are provided for each of the large tubes used in the output amplifier by the use of these springs. Good contact is made between the copper tubes and the chassis, so that heat generated within the electron tube is efficiently conducted through metallic paths to the copper chassis of the amplifier. In order not to raise the temperature of the chassis and consequently the temperature of the circuit

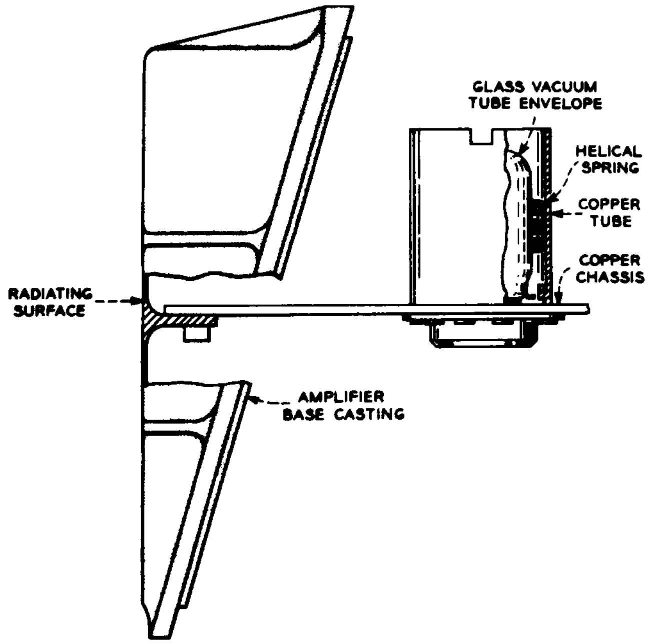

Fig. 12 - Heat conducting tube shield

components, large ribs are provided in the housing, with which the chassis make intimate contact. A continuous metallic conducting path is thus provided from electron tube envelope to amplifier housing. This design resulted in a temperature drop in the output amplifier tubes of about 70° C without any temperature rise in the chassis or circuit elements over that produced when ordinary types of shields were used. The smaller electron tubes in the input amplifier do not ordinarily run as hot as those in the output amplifier and a temperature drop of only about 55° C was attained by these methods.

6. SIGNAL LEVELS, MODULATION, AND NOISE

6.01 As a result of using the input beta circuit to give so much of the shaping of amplifier gain, the input amplifier has little gain at low frequencies. In consequence, the input tube of the output amplifier and the regulating network are important thermal noise sources at low frequencies. The relative magnitudes of the noise sources are shown in Fig. 13, which gives the noise at amplifier output as a function of frequency.

6.02 Typical amplifier modulation values are given in Table 2. Computations using the measured feedback and the performance of single tubes without feedback check the measured values of amplifier modulation to within a couple of db if the third order coefficient of the tube is corrected to take account of the fact that some third order modulation is generated by the

TABLE 1

Power Requirements of Amplifier Unit

6.3 volts (grounded)	1.5 amperes
6.3 volts (190v off ground)	0.45 amperes
+100 volts regulated	0.5 milliamps
+190 volts	68 milliamps
+315 volts	41 milliamps

TABLE 2

Modulation products, in db below one milliwatt at amplifier output, for fundamentals 5 db above one milliwatt at amplifier output.

Type	Fundamentals MC	Product MC	Product -dbm
2F	.5	1.0	72
	1.0	2.0	65
	3.0	6.0	55
	4.0	8.0	51.5
3F	.25	.75	95
	.667	2.0	97
	2.0	6.0	87.5
	2.66	8.0	81.5

interaction of the fundamentals and the feedback second order products. In general, the effective third order coefficient of the tubes is approximately equal to the voltage sum of the tube's uncorrected third order coefficient and a coefficient 6 db worse than the square of the tube's second order coefficient. If this interaction correction is not taken into account, the correlation of tube modulation, feedback and amplifier modulation is unsatisfactory.

7. FLAT AMPLIFIER

7.01 The flat gain amplifier, which is used as a transmitting amplifier and to make up for equalizer loss at various points in the system, is basically the same as the line amplifier, with only the obviously necessary modifications. The input beta circuit is nearly flat, the regulating network has been replaced by a fixed gain network which contains a single variable element whose adjustment at the factory compensates to some extent for variations in the coupling networks, and the input coupling network has been modified so that the peaking used in the line amplifier is replaced by a drop in the high-frequency gain of this network. The output beta circuit has been modified to give flat gain control of ± 1.0 db in 0.2 db steps. The interstage designs are changed to readjust the feedback so that the modulation suppression and the change in gain as tubes age will be nearly the same as in the line amplifier. Somewhat more feedback is obtained in the output amplifier since no network is needed in the output amplifier interstage to adjust the 30-megacycle phase for an unfavorable regulating network setting.

7.02 The nominal gain of the flat gain amplifier has been set at 34 db and is flat to within ± 0.2 db over the transmitted band. The amplifier circuit capacities are low enough so that the interamplifier network could be built to give considerably more gain than this; the limit has been set so that flat gain amplifier noise contributions to the complete system noise will not exceed about 1.0 db at the television carrier.