THE USE OF INTEGRATED CIRCUITS IN CABLE TELEVISION

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Cable television systems began with single channel amplifiers operating in a low VHF band. As the demand for cable television grew, along with technology, amplifiers were designed to cover more than two octaves and performed several additional functions, including automatic slope and gain controls.

The use of integrated circuits to satisfy some of these requirements has been limited in modern cable television amplifiers. This paper examines some of the present-day and future uses of IC's in cable television equipment in view of cost, performance, and reliability.

The development of cable television system techniques--such as the method of ALC control, tilt mode, operating level, gain, etc., together with the time consuming proof-of-feasibility for each approach--has been too dynamic to warrant any costly IC designs.

This limitation has been particularly true at VHF frequencies with physically large components which are not compatible with thin film IC's. In addition, the operating levels normally encountered in cable television amplifier output stages are beyond the present state of the art for IC's.

To determine the feasibility of thick films at VHF, a thick film broadband amplifier is shown. Using this technique, components can be trimmed to precise tolerances on low cost replaceable modules.

With the flexibility of thick film hybrid integrated circuits, utilization of these devices in cable television equipment can be expected within the next few years.

APPLICATION OF INTEGRATED CIRCUITS IN CABLE TELEVISION SYSTEMS

INTRODUCTION

The cable television industry has had a fascinating history. Cable television technology was not the product of a large electronic R and D effort or government sponsored research program. Rather, it grew out of a need and countless novel approaches, many of which produced surprising results. Fifteen years ago, few people took cable television seriously. After a 25% annual growth over the past decade together with the EIA,[1] FCC, and Justice Department favorable attitudes during 1969, cable television is becoming a major communications media. As a significant electronics industry considerable equipment refinements can be expected. Along with increased demand and competition, new functional and reliability requirements will introduce new technology including the use of integrated circuits.

It is the purpose of this discussion to examine some of cable television circuit requirements in view of hybrid integrated circuit technology, and to project some future uses of IC's for both RF amplification and low frequency control functions.

BROADBAND AMPLIFIERS

Most of the amplifiers used in early cable television systems were "broadband" in the sense that they covered a 6 MHZ bandwidth. They served to amplify the signal at the same frequency--just enough to overcome cable losses. Early systems had very few amplifiers in cascade. With nominal requirements the amplifiers did not require significantly greater dynamic range than that of the receiver front end.

As systems developed, it became necessary to carry several channels requiring broadband amplifiers. Amplifiers in the low TV band were built to accommodate up to three non-adjacent channels. Distant stations, many of which were on adjacent channels, in addition to high band channels converted for the low band system, soon filled all the available channels on the cable. This introduced a new problem for the system--that of adjacent channel interference. Television receivers, not designed for adjacent channel reception, did not have adequate selectivity to reject the next lower channel sound carrier. Reducing the sound carrier at the strip amplifiers or converters by 15 to 20 DB corrected the problem. Thus the major effort continued to be developing means to carry more channels over greater distances.

[1]FCC Docket 18397, Part V, Industrial Electronics Division, Electronic Industries Association, Washington, D.C., October 1969.

In order to achieve wide bandwidths several types of circuitry were used among which was distributed amplification.[2] The technique increased the gain bandwidth product of the tubes in addition to increasing the amplifier reliability. Since tubes in the distributed amplifiers were operated effectively in parallel rather than cascade, the failure of one tube merely resulted in reduced gain and not complete failure.

Transistor distributed amplifiers could not realize the full potential of the technique. The loading effect of the transistors on the input transmission line, limited designs to three transistor stages for the VHF band.[3] Although 3 DB more output power was obtained by this method, it was not enough to handle the power levels normally encountered in cable systems. Operation over +48 DBMV (about 1 MW) drove the output stages into the non-linear region which resulted in distortion. The effects of temperature on gain variations added to the design problem.

In spite of the initial shortcomings, transistor amplifiers had the potential to reduce the current requirements for cable powered amplifiers and to reduce the physical size to permit mounting on the messenger cable. The possibilities of transistor amplifiers for cable television encouraged development.

A variation of the distributed amplifier resulted in the distributed pair configuration[4] see Figure 1. The dual amplifying sections eliminated the output line reverse termination which resulted in higher output power than that of a conventional distributed amplifier. The circuit is essentially two stages in parallel, except that the input impedance remained nearly constant, about 85 ohms, over the entire VHF range.

Feedback was used around several stages to obtain gain over the 50 to 500 MHZ range. From the amplifier shown in Figure 2 it can be observed that no tuning capacitors were used. Tuning was accomplished by adjusting the air wound coils. The four-stage unit amplifiers provide 24 DB gain with 1 DB ripple and was stable from -20^{o}c to +70^{o}c.

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[2] Ginzton, Hewlett, Jasberg, Noe, "Distributed Amplification," Proceedings of the IRE, Vol. 36, pp. 956-969, August 1948.

[3] L. F. Roeshot, "Transistor Distributed Amplifiers," Masters Thesis, The Pennsylvania State University, February 1960.

[4] L. F. Roeshot, "Distributed Pair Amplification," Electronic Design News, January 1963.

The gain bandwidth product of available transistors required circuit novelty to achieve reasonable gain over two octaves. Both the distributed amplifier and the distributed pair achieve broadband gain up to the f_{max} rating. As transistor gain bandwidth products increased, circuits were simplified. Maximum gain in the simpler circuits was traded for ease of alignment, repeatability and tolerance for transistor parameter variations.

Present day cable television amplifiers use variations of the circuit shown in Figure 3. In this circuit the collector-to-base feedback compensates for flat frequency response. The output power using this technique is greater at high frequencies than at low frequencies because of the mismatch.

In normal operation, amplifiers in a cable system are operated well below their maximum output levels. As amplifiers are cascaded, the third order distortion builds up in proportion to the number of amplifiers (10 log N).

System cross modulation is required to be at least -46 DB below the signal. For a single amplifier then, the cross modulation must be significantly lower. Cross modulation is reduced by using emitter degeneration. The negative feedback is made to vary with frequency by using several sections as shown in Figure 3. Using this scheme, greater emitter degeneration is obtained at low frequencies, where cross modulation improvement is needed most. The low Q adjustment of the resistor-capacitor combination is predictable and aids in obtaining positive slope response.

THE USE OF INTEGRATED CIRCUITS

Integrated circuits are not used in CATV amplifier designs except for ALC (Automatic Level Control) DC amplifiers. Integrated circuits for RF frequencies have been slow in development for a number of reasons. Standards are not yet firm. The many philosophical approaches in design, including the method of gain and slope control, operating level, and non-standard band usage has resulted in a number of design changes and field modifications. The power level used in broadband cable television amplifiers requires special design considerations. RF integrated circuits need closer tolerances than 10 and 20%, common in monolithic logic circuits. Typically, a cable television amplifier must control gain variations to less than $\pm$.25 DB in an outdoor environment.

The VHF frequency range has been a transition range for integrated circuits. At low frequencies, monolithic IC's are designed as resistance coupled circuits. In the microwave region, short wave lengths permit the use of strip line techniques for circuit functions. At VHF, neither technique is efficient. The lack of suitable broadband inductors has especially limited the use of IC's at VHF.

THICK FILM HYBRID IC'S

Thick film hybrid IC's have found wide acceptance where external inductors or other precision components must be added to the circuit. Costs are comparable to those of printed circuits, and in some instances can be less. RF circuits on PC boards often require additional components to compensate for stray effects. By using smaller geometries on a low loss substrate stray effects can be reduced which results in simpler circuits.

With present thick film technology, resistors can be screened and fired to an accuracy of about ±10 per cent. Abrasion timing can be used for ±1 per cent, or even ±.1 per cent accuracy. The temperature co-efficient of screened resistors ranges from 200 PPM/°c to 50 PPM/°c. Both resistors and capacitors can be screened or discrete components can be mixed in thick film circuits.

Discrete capacitators, available in a wide range of values, temperature co-efficients, and physical configurations, lend considerable versatility to the VHF hybrid circuits.[5]

Screened as well as thin film spiral inductors have been limited to values of a few tenths of a microhenry. For larger values, the distributed capacitance of spiral inductors results in self resonant frequencies of about 100 MHZ. Several manufacturers produce microminiature coil inductors suitable for attachment to thick film circuits. Typical inductors or .82 microhenry are .175 inches long with self resonant frequencies of 300 MHZ. Slightly larger sizes are adjustable over a two to one inductance range.

The behavior of an inductor over a broad frequency range is largely dependent on the type of fabrication. Self resonant frequency (SRF) is reached when the inductance resonates with the distributed capacitance. For spiral inductors the distributed capacitance is emperically determined and depends on the line width, the number of turns and the method of processing. For thin film spirals, this capacitance is typically .25 pf for four turns. For inductances greater that 100 uh, (needed for VHF), inductance increases about 50 uh per turn while the distributed capacitance remains relatively constant. The increased inductance lowers the SRF which degrades the high frequency performance of the coil. The equivalent inductance of the coil is a function of frequency is given by:

$$L_{equiv.} = \frac{L}{(1-K)^2}$$

where

$$K = \frac{f}{SRF}$$

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[5]D. W. Hamer, "Reduced Titanate Capacitor Chip for Thick Film Hybrid IC's," International Hybrid Microelectronics Symposium, pp. 256-264, October 1968.

and the equivalent series resistance is

$$R_{equiv.} = \frac{R}{(1-K^2)^2}$$

For a spiral inductor with a SRF of 300 MHZ the inductance doubles at the high end of the VHF TV band, while the resistance increases four times. These effects are desirable in a circuit when used for shunt compensation. However, when uniform inductance is necessary over a broad band, inductors with resonant frequencies of at least four times higher than the upper frequency should be chosen.

The economies of monolithic IC and thin film circuits are best realized when the size of the circuit is reduced as much as possible. For VHF frequencies, inductors limit the reduction in size. The inductance per unit area of microminiature coils is more than ten times that of spiral inductors.

A BROADBAND THICK FILM AMPLIFIER

A broadband thick film circuit has been fabricated as shown in Figure 4. The schematic of the two-stage circuit is shown in Figure 5. Emitter degeneration was used on the first stage, while the second stage consists of collector-to-base feedback along with a tapped emitter resistor. The proper tap is selected during the bonding process of micro-soldering operation. Additional resistor adjustments are made provided by heat treating, abrasive trimming or localized heating. All of the components except the transistors and feedback inductor were screened components.

The capacitors, with values of about 470 pf, require a large amount of real estate and could be more efficiently replaced by multi-layer chip capacitors. However, the main purpose of the experiment was to screen as many components as possible. In an effort to reduce pinhole shorts the dielectric was screened twice. The resulting thickness decreases the capacitance per unit area.

A computer was used to draw the screen patterns. The four patterns, 1) first metalization, 2) dielectric, 3) resistors, and 4) second metalization, were drawn separately for independent modification. Circuit revisions are accomplished by specifying a coordinate change on a data card. After debugging the program the total drawing time was 48 minutes for the four patterns.

The frequency response of the amplifier is flat up to about 200 MHZ. Beyond this frequency, the response is highly dependent on the ground plane. These results were sufficient to evaluate the preliminary design, since the final package will largely influence the high frequency response. The cost for the basic thick film circuit without testing or packaging has been estimated to be under three dollars.

Hybrid IC modules permit amplifiers size reduction limited by the connectors. Figure 6 compares models of a conventional bridging amplifier and an IC modular unit.

A layout model for a trunk amplifier is shown in Figure 7. The four rectangular plug-in modules depict the equalizer, amplifier, power amplifier and power supply. By substituting the power amplifier module with a matching network, the unit becomes a low power line amplifier. Amplifier functions are illustrated in Figure 8.

A 7.5 watt broadband stud mounted amplifier has been developed by RCA.[6] The frequency range of 265 to 400 MHZ is just beyond the required range, but it represents the type of throw-away high power module needed for cable television applications.

FUTURE USE OF HYBRID CIRCUITS

Several television receiver manufacturers have adopted thick film technology. Oak Manufacturing has developed a TV tuner with a plug-in module using thick films.[7] This method was selected over a printed circuit or a monolithic approach on the basis of cost, performance and circuit optimization. Zenith has developed a hybrid thick film chroma demodulator.[8] RCA has announced that by 1973 color sets will be made up of seven modules.[9] The development of thick film technology for the amplification and processing of television signals is certain to have an influence on the cable television industry.

Cable television systems of the future, more clearly described as a BCN (Broadband Communication Network)[10] will perform a number of other services in addition to that of television. Many of these services will require bi-directional communications.

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[6] W. E. Poole, "UHF Integrated Power Amplifiers," IEEE International Solid State Circuits Conference, Philadelphia, Pa., February 1969.

[7] K. S. Williams, "A Plug-In Thick Film Hybrid Circuit Module," Hybrid Microelectronics Symposium, pp. 497-505, October 1968.

[8] C. M. Engel, et. al, "A Hybrid Thick Film Chroma Demodulator and Color Difference Amplifier," Hybrid Microelectronics Symposium, pp. 487-496 October 1968.

[9] R. Sarnoff, "Bob Sarnoff Runs a New Game," Business Week, p. 89, January 1970.

[10] EIA, Op. Cit., Reference 1.

The RF spectrum used on the cable system has been proposed to be divided as shown in Table 1.[11] The simplified functional diagram of the amplifying unit is shown in Figure 8.

Proposed Frequency Plan

Frequency Allocation	Use	Channels TV
60 kHz to 5 MHz	Wideband Data & Trunk Carrier Two-Way	
5.5 to 48 MHz	Customer to Distribution Point One-Way	6 to 7
54 to 88 MHz	Distribution Point to Customers' CATV/ITV--One-Way	5
88 to 108 MHz	Distribution Point to Customers' FM plus	50 FM Channels
Music--One-Way		
112 to 170 MHz	Distribution Point to Customers' Additional TV or Other Private Line Services--One-Way	At least 2 TV Channels
174 to 216 MHz	Distribution Point to Customers' CATV/ITV--One-Way	7
220 to 270 MHz	Distribution Point to Customers' Additional TV or Other Private Line Service--One-Way	8

In future systems, the circuitry required for data conversion, telemetery, coding and performance monitoring will far overshadow the amplifier circuits. Functional modules provide the greatest flexibility for modification on field repair.

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[11] J. O. Norback, "Modern Concepts for Cable Transmission Systems," Communication News, February 1970.

CONCLUSION

Cable television amplifiers evolved within an industry having an uncertain future. The practicality of cascading many broadband amplifiers out of doors, while preserving picture fidelity had to be proven. Having solved this technical problem, cable system designs in the future can be expected to grow more complicated with increased reliability demands.

Replacement modules have become standard in the industry. The next consideration is to make wider use of integrated circuits within the modules. An attempt was made here to describe some of the advantages and limitations of using hybrid circuits for VHF broadband amplifiers. Some details of an experimental thick film VHF amplifier were given together with a mock up to illustrate adaptation for cable television. More development is needed to include other circuit functions within the modules.

In light of the reliability, cost, and flexibility, thick film hybrids appear to be the most suitable type of integrated circuit for cable television amplifiers.

LIST OF FIGURES

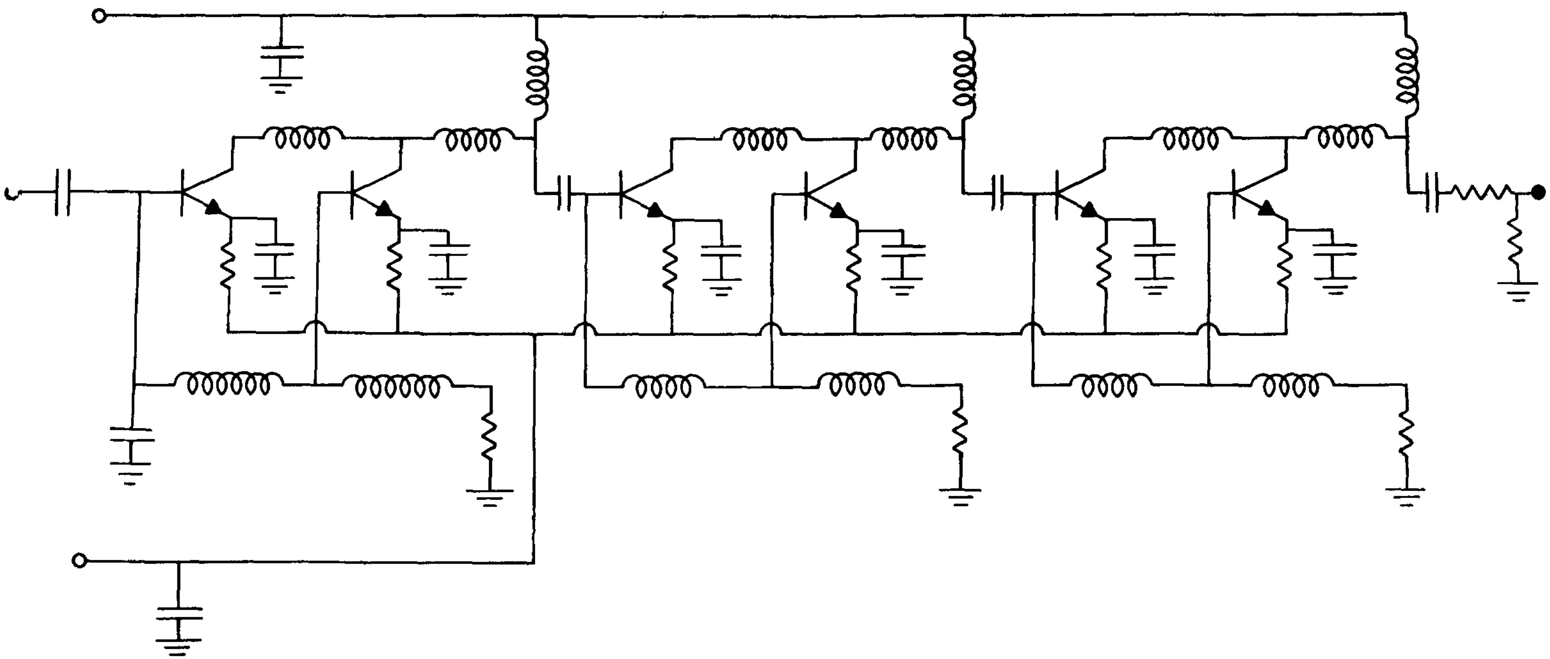

FIGURE 1. Schematic Diagram of a Distributed Pair Amplifier.

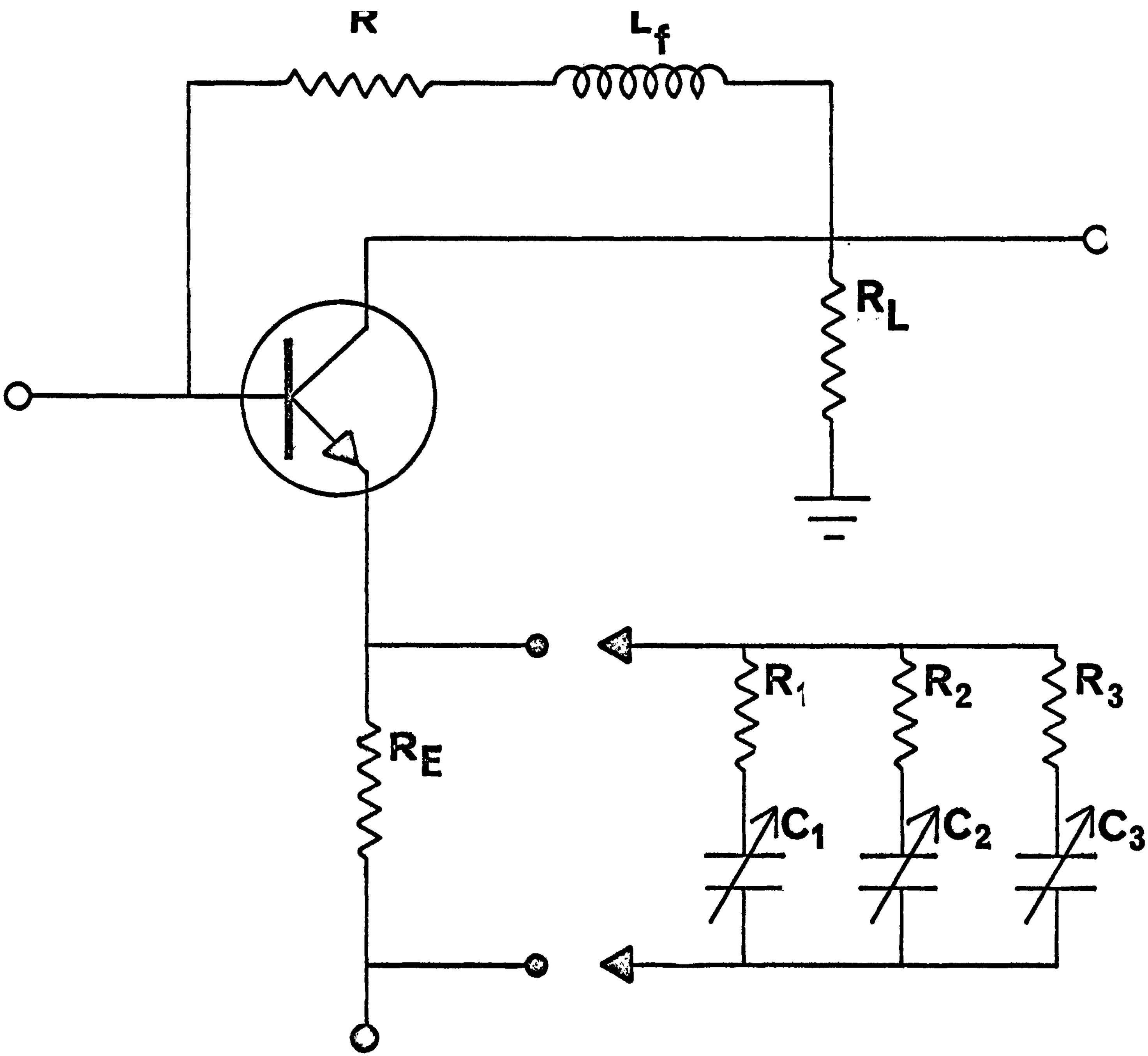

FIGURE 3. Basic Circuit for Obtaining Broadband Response in Cable Television Amplifiers.

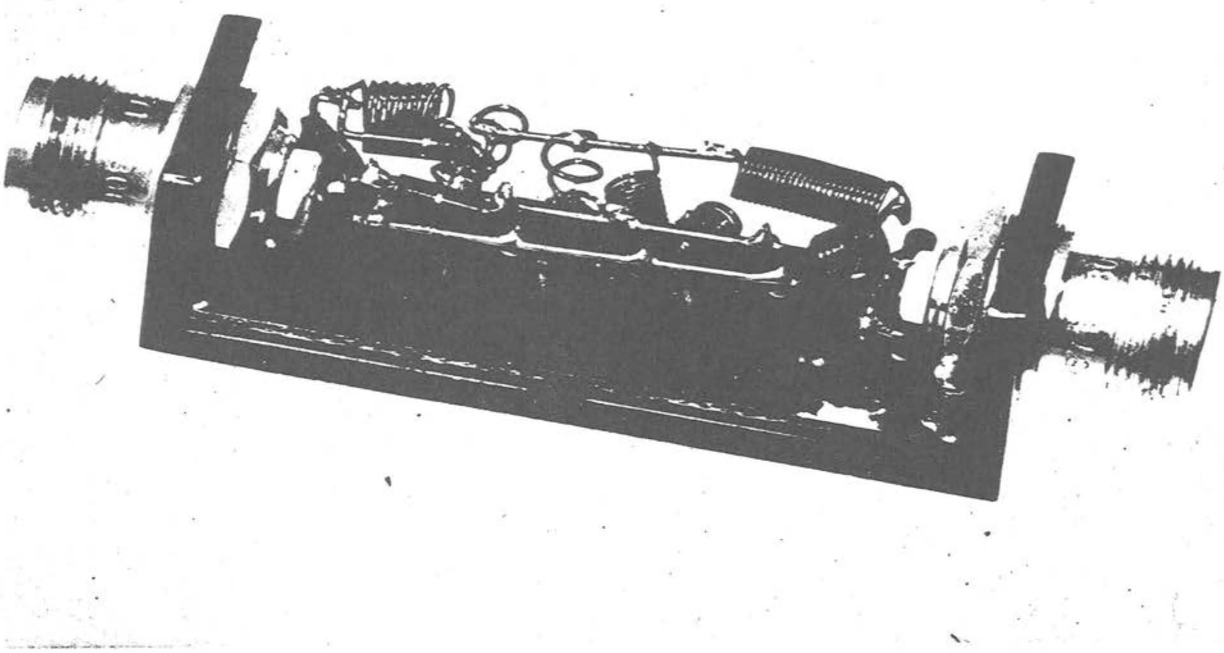

FIGURE 2. A Miniature Amplifier Covering the 50 MHZ to 500 MHZ Frequency Range.

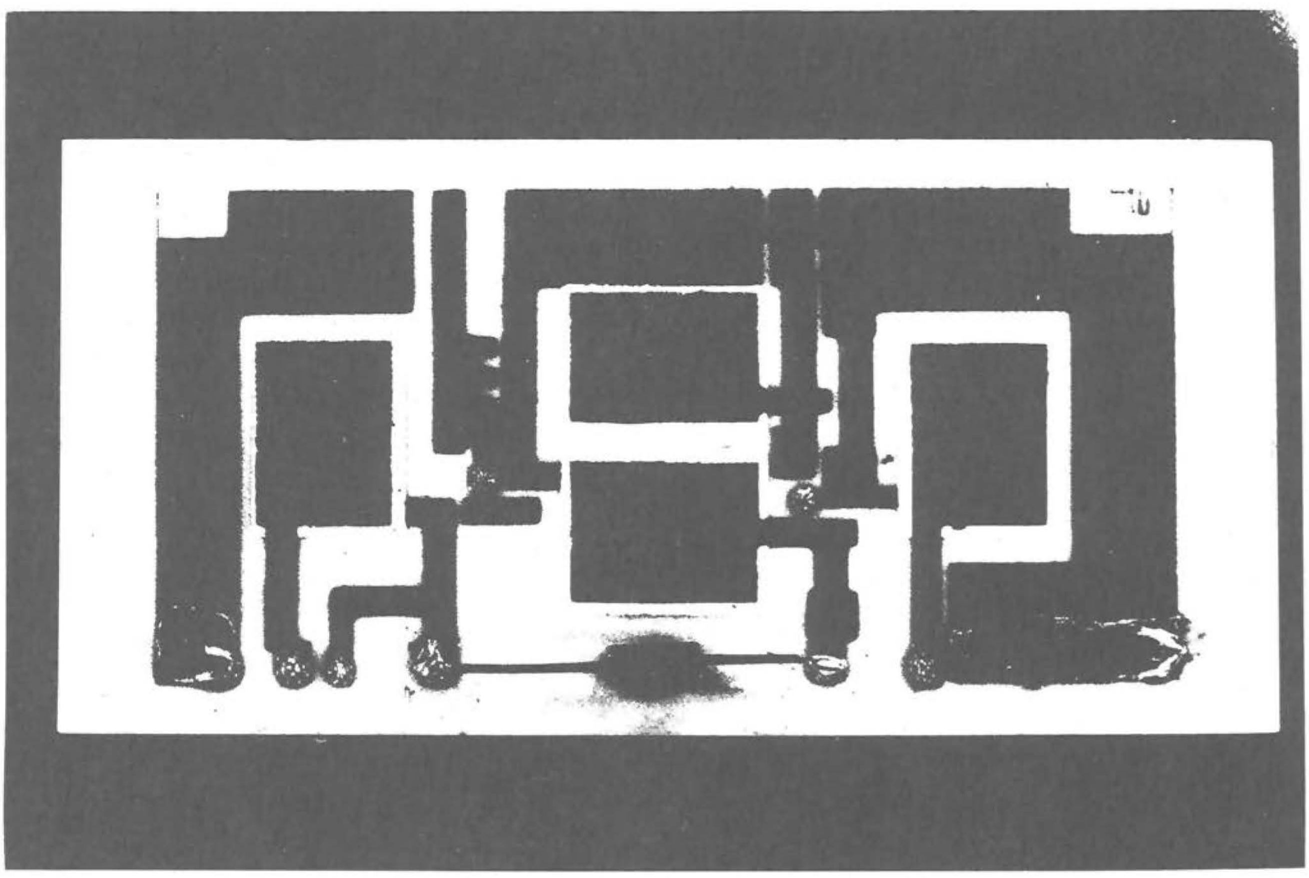

FIGURE 4 A Thick Film Broadband Amplifier

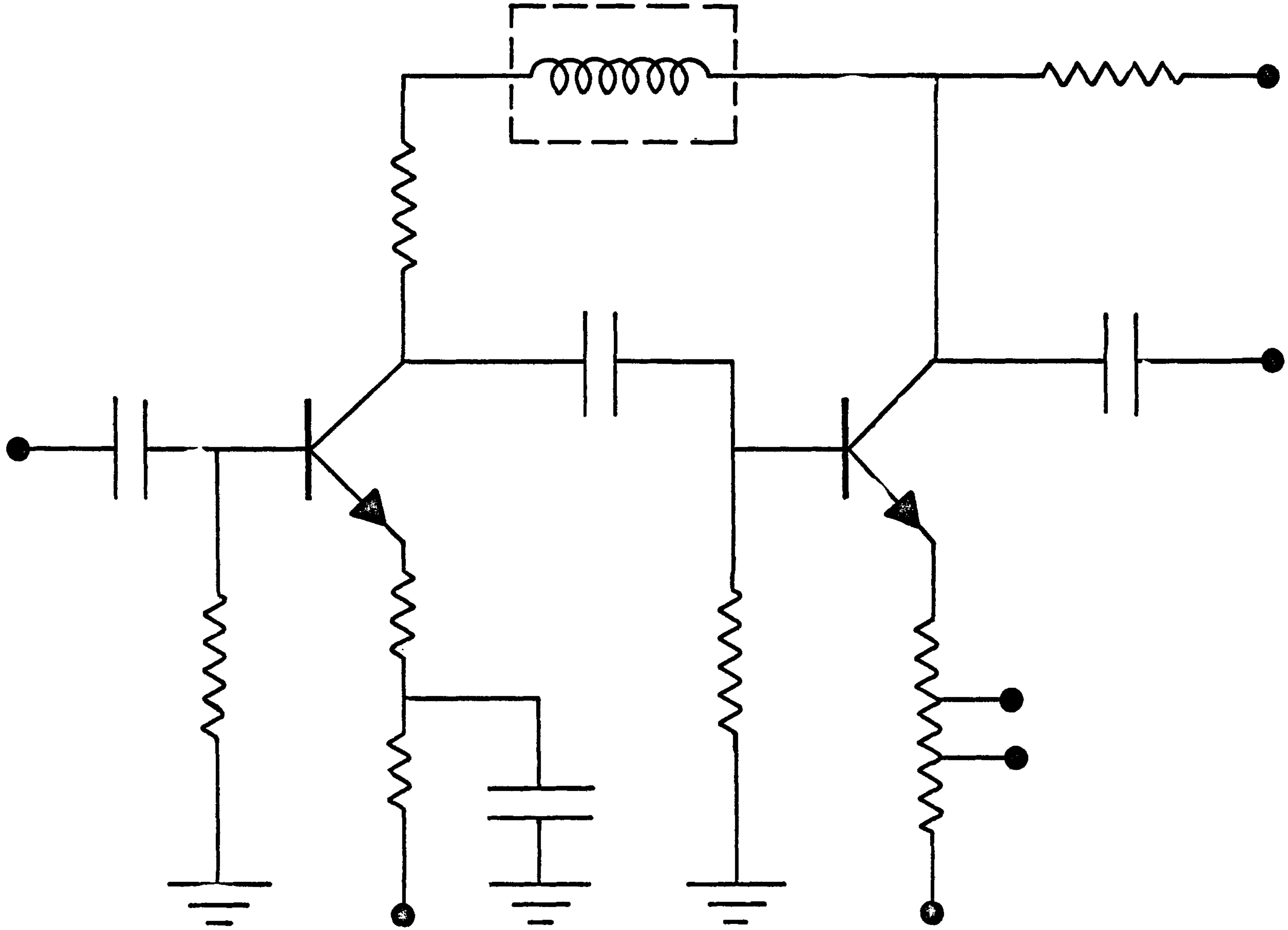

FIGURE 5. Schematic Diagram of the Thick Film Amplifier.

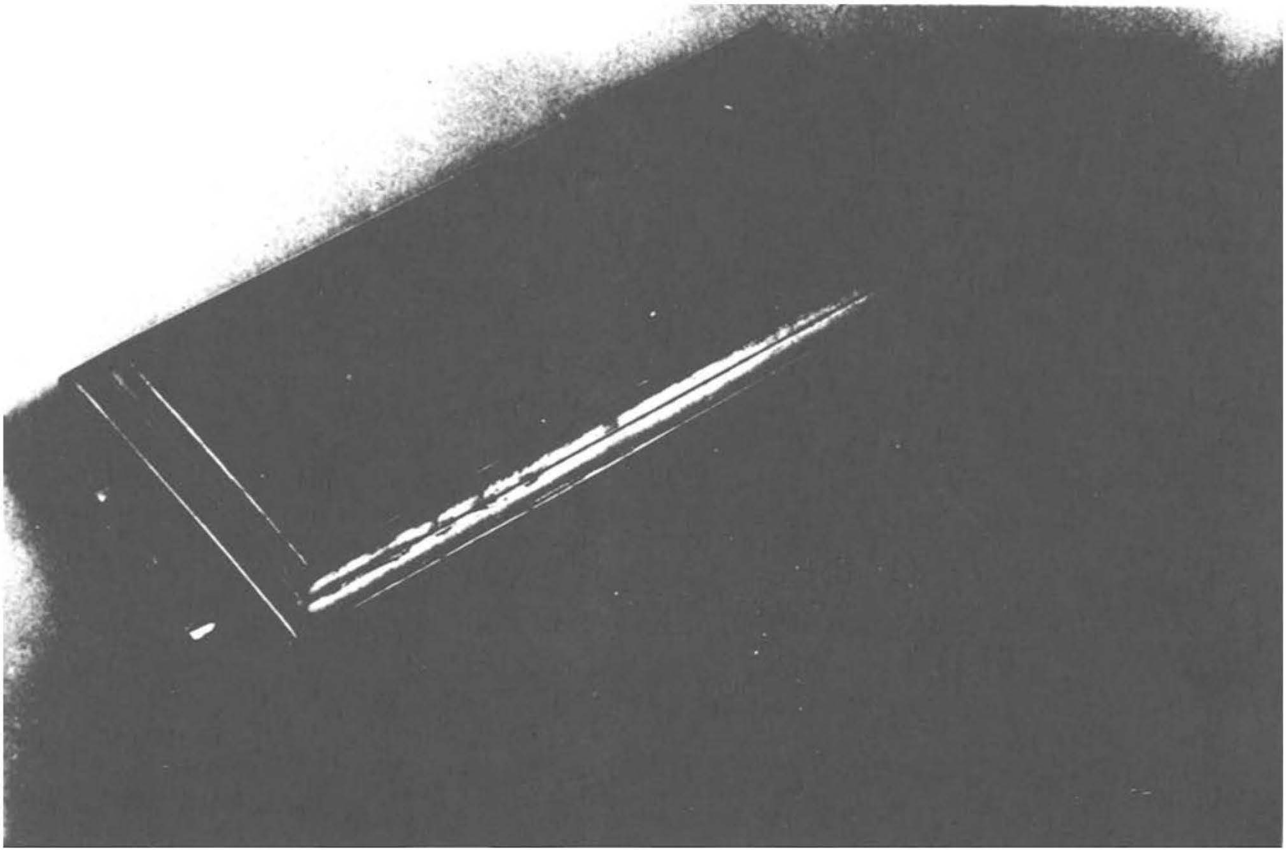

FIGURE 6. Size Comparison Between Conventional and Modular Distribution Amplifiers.

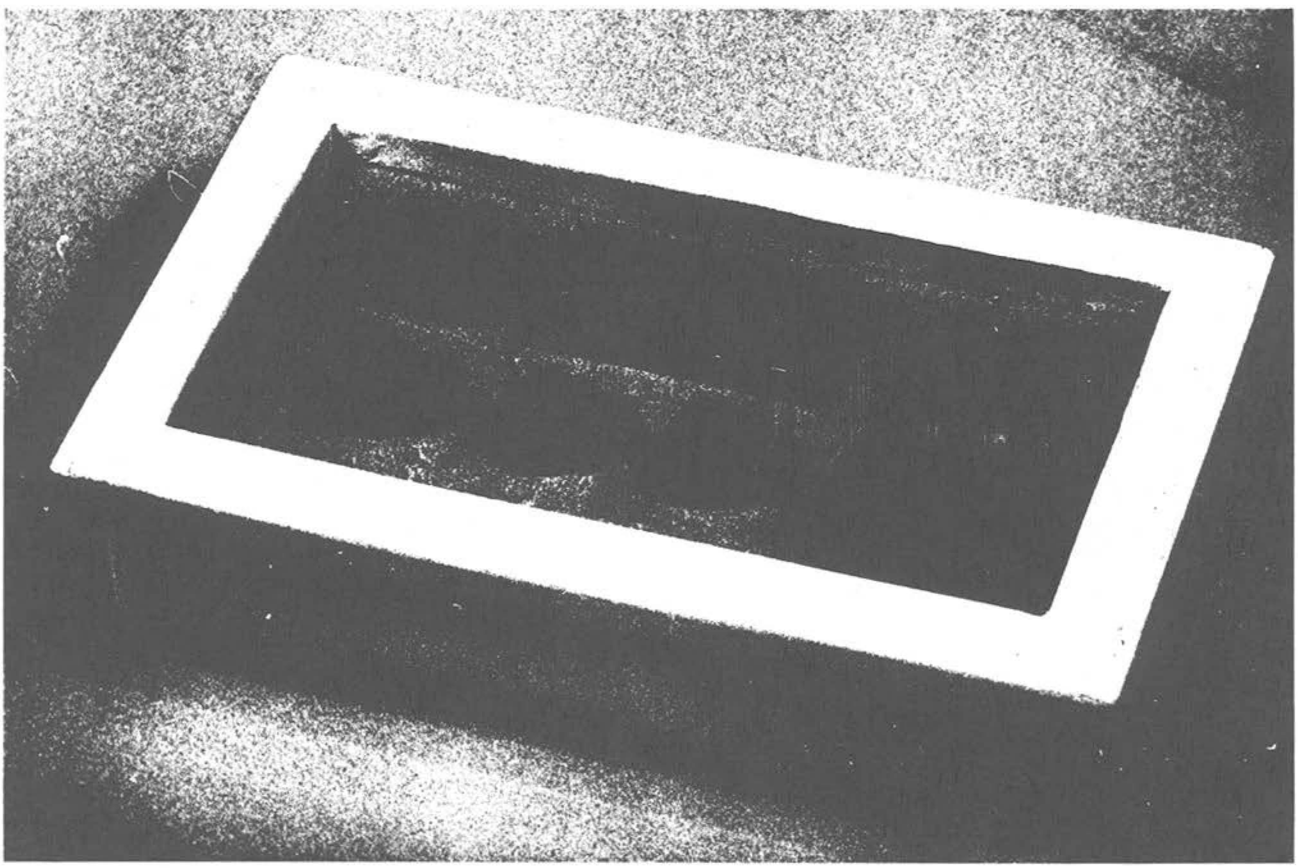

FIGURE 7. A Modular Distribution Amplifier.

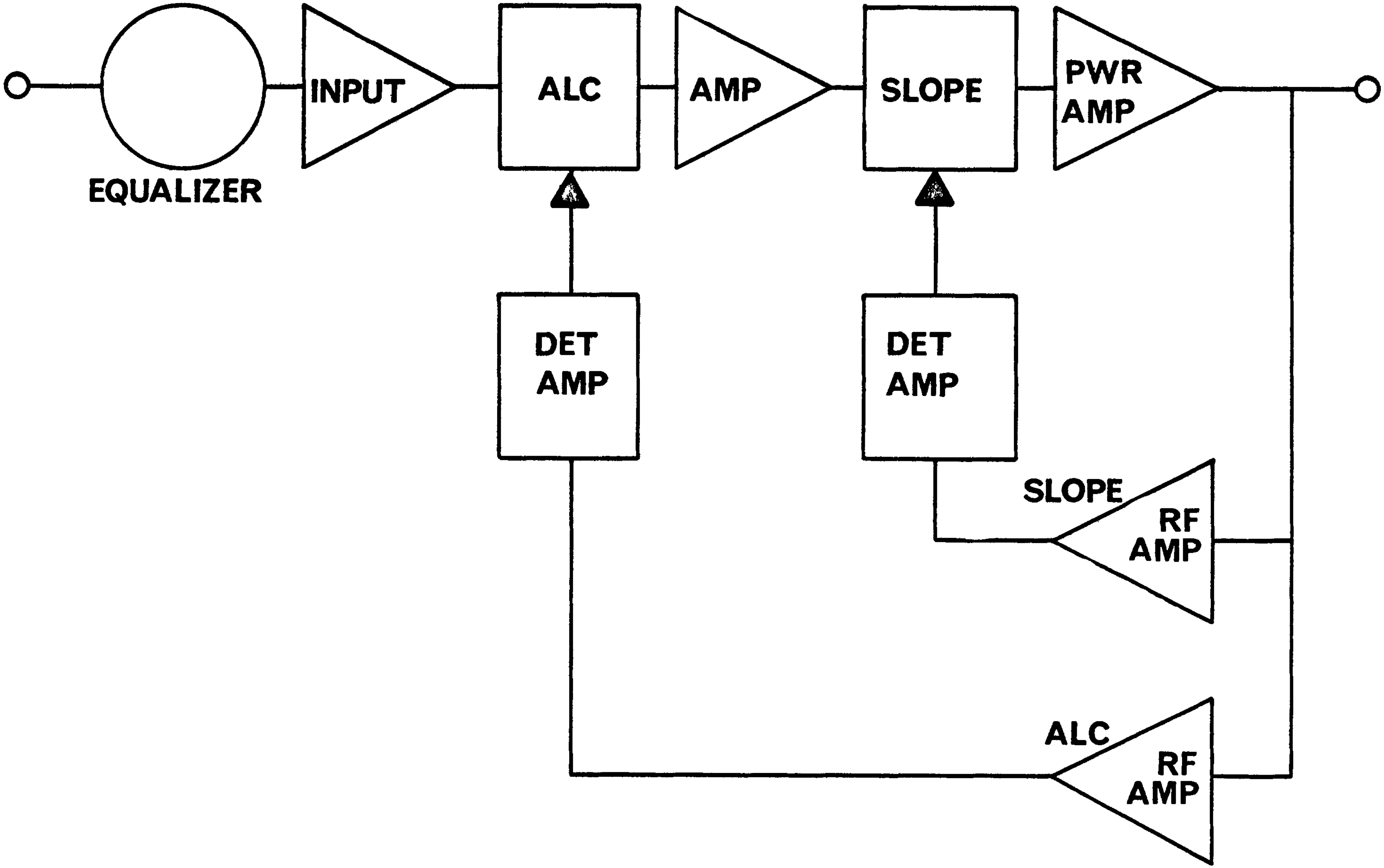

FIGURE 8. Functional Diagram of a Typical Trunk Amplifier.

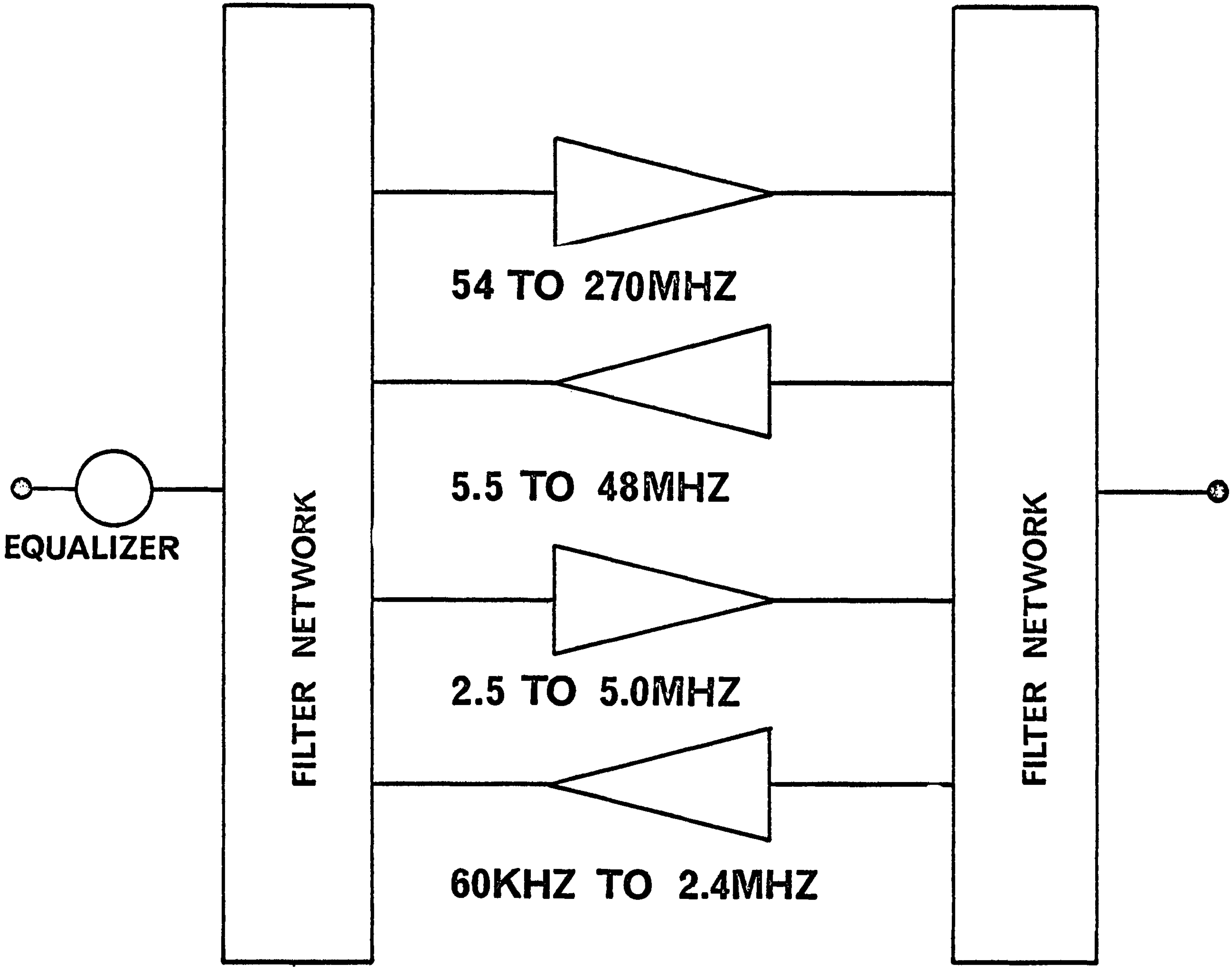

FIGURE 9. Amplifier Requirements for Proposed Frequency Plan.