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RADIO DESIGN AND MANUFACTURING CONSIDERATIONS FOR DEVELOPING COUNTRIES 1/

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Contents

Introduction

Should a developing country enter the highly competitive radio manufacturing business?

What degree of automation should be considered for a young electronics company?

Should the company make its own components or buy on the world market?

These are just some of the questions facing anyone, private industry or governmental, when contemplating the manufacture of radios. No, this paper will not provide a cookbook recipe to answer the above questions. However, it is hoped that the discussion of the alternatives and decisions that should be contemplated before starting such a venture will aid in determining the best answers that suit the local environment.

Please note that all costs are in US dollars. Also, any labor and transportation costs are in terms of the USA. Adjustments for local conditions must be made by using the official monetary exchange rates and other productivity guidelines.

Low Cost Concept

One of the reasons for promoting a radio industry in a developing country would certainly be to further the education and especially to increase the literacy percentage. Thus, the radio should have a low manufacturing cost to make it readily attainable by most of the population. If the local government plans to supply radios to the population, it is also desirable to keep the cost low.

In this presentation a low cost design does not imply an unreliable design. The term is used to indicate that maximum value should be obtained from the cost of the system, thus over-designing must be avoided. Since the entire system is in question, the transmitting system must also be considered.

The area to be covered, type of terrain and interference problems will determine the type of transmission to be used. The advantages and disadvantages of various radio transmission systems will be discussed.

Long Wave - Amplitude Modulated transmission with radio frequencies from 150 kHz to 350 kHz. Long Wave is used for public broadcasting in Europe and several countries outside of Europe. In the USA Long Wave is used for weather information, marine communication and aeronautical navigation. At those relatively low radio frequencies the ground wave attenuation is small so reception over lossy terrain is good. For instance, the British Broadcasting System completely covers England with its Long Wave transmission system.

Since the electrical wavelength is on the order of one to two kilometers, the transmitters and antenna arrays are large and expensive.

Medium Wave - Amplitude Modulated transmission with radio frequencies from 540 to 1600 kHz. This band of frequencies is commonly called the Broadcast Band in the USA. Most of the commercial entertainment radio stations in the world use this band. Since this is a relatively low radio frequency band the coverage is mainly ground wave for reliable reception, although there is some sky wave reception at night. Under good atmospheric conditions night time reception up to 1600 kilometers is common with 50 kilowatts of transmitter power. About 300 kilometers is an average daytime limit for reception.

One of the main problems with using Medium Wave is its popularity. The frequencies to be used must be carefully chosen with regard to local interference stations. With the common superheterodyne radio receiver interference can be troublesome even from frequencies well out of the Medium Wave band. This is caused by heterodyning effects of harmonics of the receiver's local oscillator frequency and by image frequencies.

Both the Long Wave and Medium Wave bands are highly susceptible to electrical interference caused by either atmospheric or man made conditions.

Short Wave - Amplitude modulated frequencies generally from 5 MHz to 30 MHz in specific bands such as 60 meter, 49 meter, 41 meter, 31 meter, 25 meter, 19 meter, 16 meter, etc. These frequencies are most useful where long distance communication is desired, since the sky wave is reflected from the ionization layers covering the earth thereby enabling long range transmission with relatively small power.

These sky waves are very susceptible to atmospheric conditions, time of day, solar disturbances and electrical interference. Antenna beaming is generally employed at these frequencies to improve the reception. Of course, at the higher frequencies the antenna arrays become less expensive since the dimensions decrease linearly as the frequency is increased. However, as the frequency is increased the preciseness of the radio receiver becomes more critical. This includes the design, manufacture and operation of the radio.

Frequency Modulation - This band of frequencies, commonly called the FM band in the USA and the VHF band in Europe, is situated at about 100 MHz. In the USA, the band is 88 to 108 MHz while in Europe it is restricted from 88 to 104 MHz.

With frequency modulation, amplitude limiters can be employed in the radio receiver which can greatly reduce electrical interference. It is possible to listen to noise free reception even during severe electrical storms which render the amplitude modulated bands useless. Since the wavelength is only about 3 meters, high gain antenna arrays can be built economically.

No reflection from the ionosphere occurs at these frequencies so the reception distance from the transmitter antenna is limited to line of sight distance or about 80 kilometers. Thus, an area of approximately 20,600 square kilometers can be covered with one transmitter-antenna system. Since these frequencies behave somewhat like light, mountains and hills can block the signal transmission. Reflections from buildings or mountains can also cause a phenomenom known as multipath reception. This is caused by the reception of the desired radio signal plus an out-of-phase signal that has been reflected or refracted.

Due to the high frequencies involved, the receivers are more complex and more expensive than the common medium wave receivers. Also, a whip antenna or dipole is required for good reception.

Power Requirements

The power required to operate a modern transistorized one watt audio output table model radio consists of about three watts. This would be for the common four transistor model employing a Class A, high voltage transistor output stage. This compares with about 30 watts required for the common four tube plus rectifier table model.

The problem of power input is negligible in most developed countries, but it can certainly be of prime importance in a developing country without a good electric power system. Battery power would have to be considered in this case. If battery power is required, then the common Class "A" audio circuit should be abandoned in favor of a Class "B" audio output circuit even though the Class "B" system requires an extra transistor and additional circuitry.

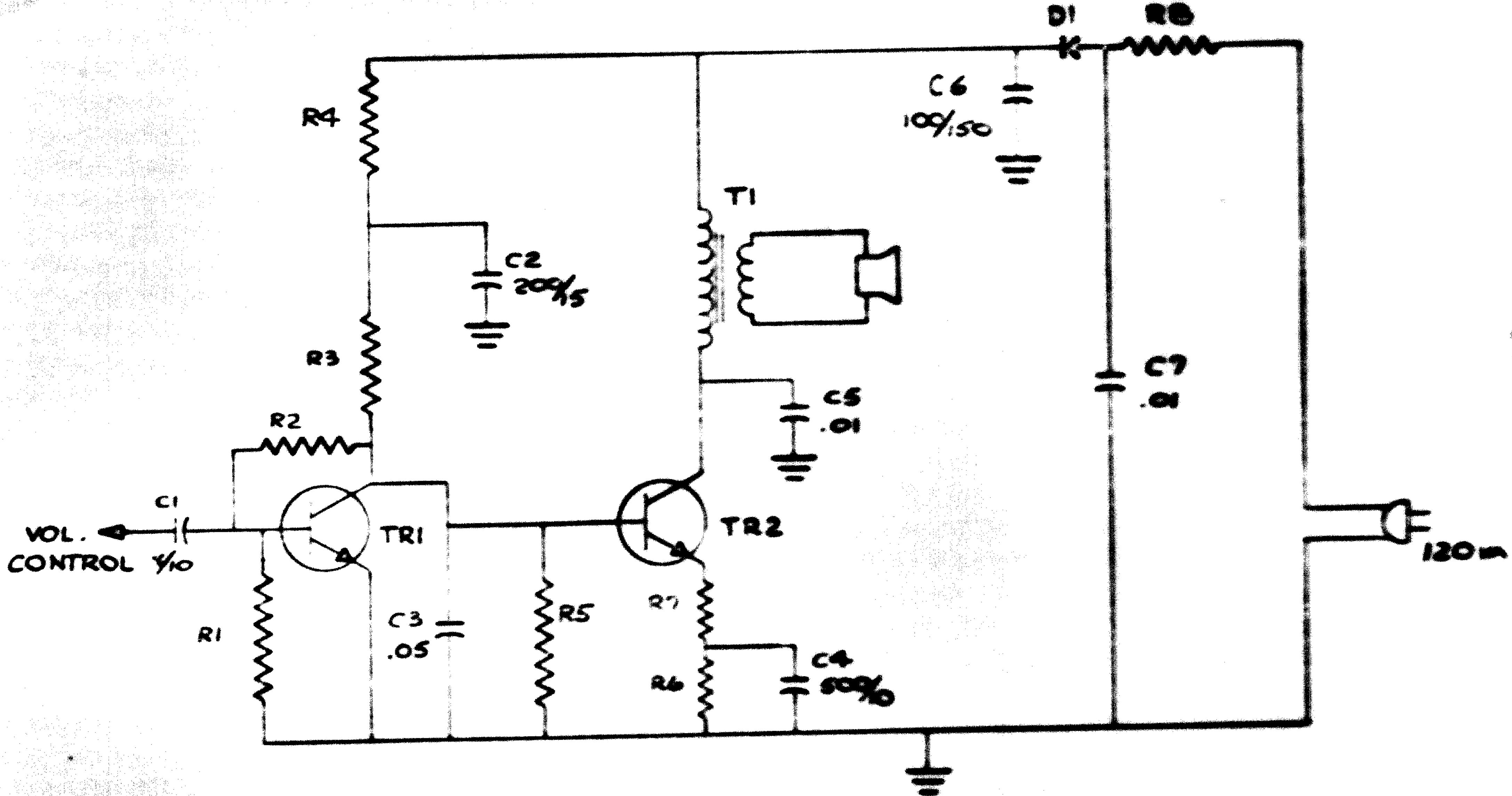
If line power is available at least part of the time, a rechargeable battery supply should be considered. Even though the initial cost of the rechargeable battery system is relatively high, the long term expense of the system can be cheaper. This system also allows greater portability than a line connected power supply.

A typical Class "A" audio system is shown in Figure 1 and a Class "B" system is shown in Figure 2. The Class "B" system with variations is used almost exclusively throughout the world in battery operated portable radios.

CLASS "A" AUDIO SYSTEM

AC MAINS POWERED

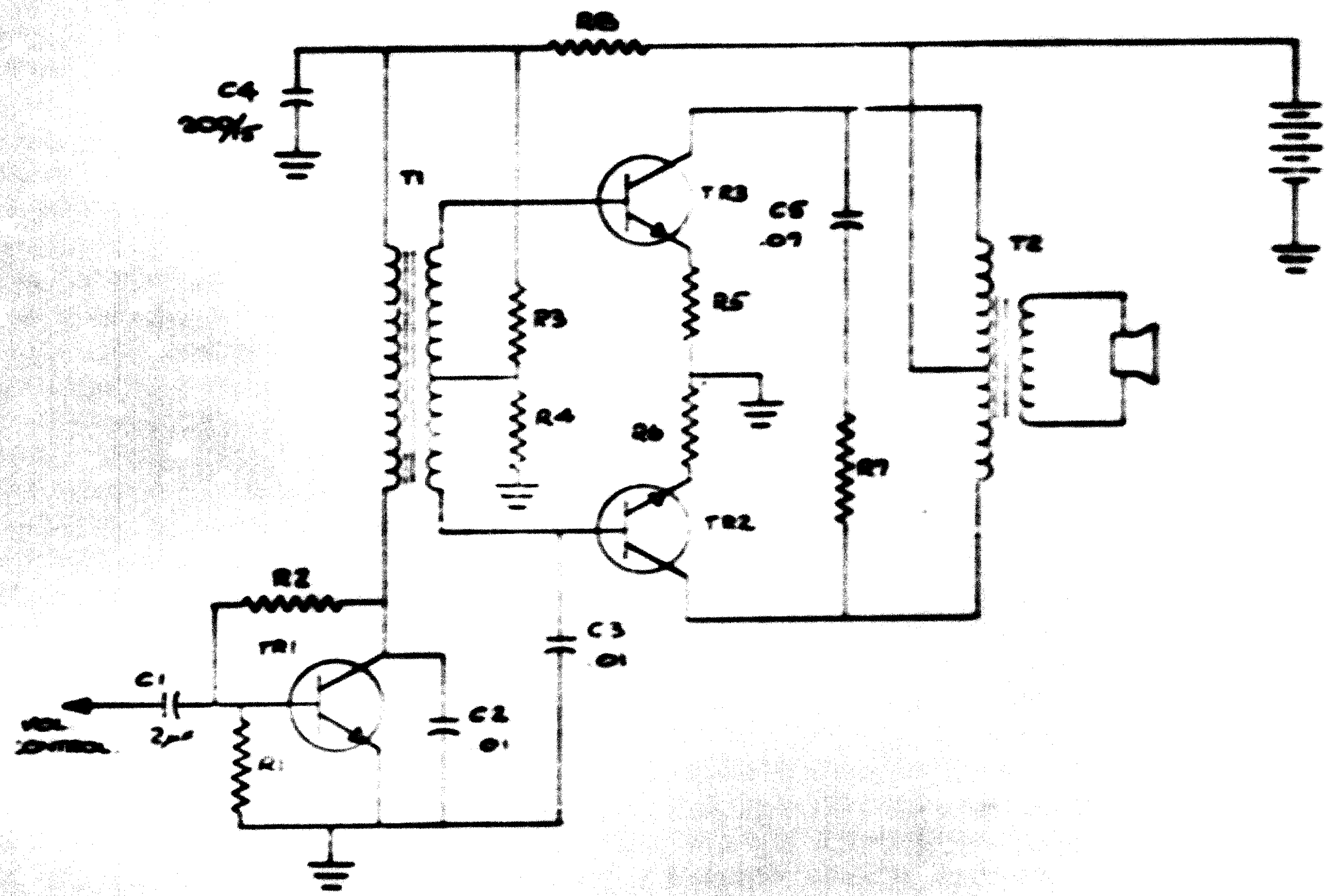
FIGURE 1



CLASS "B" AUDIO SYSTEM

BATTERY POWERED

FIGURE 2



For best results the output transistors should be of the same type and matched as well as possible. Larger mismatches can be tolerated if negative feedback is employed to reduce distortion. Semi-conductor vendors will furnish output transistors in matched pairs.

Radio Specifications

After the type of transmission has been chosen, the radio's electrical, mechanical and environmental specifications must be formulated. During the design, some of the specifications might have to be altered, but at least the original specifications will provide direction and cost estimates.

Some basic considerations that must be known before the specifications can be written are:

1. Is the radio to be used inside or outside of a dwelling?
2. What are the climate factors, namely temperature, humidity?
3. The terrain of the country.
4. Electrical interference problems, either from local or neighboring countries.
5. Acoustical power and type of broadcasting; namely, voice or music.
6. Size requirements.
7. Radio power source, batteries or mains?

Manufacturing Requirements

The age old problem of balancing initial investment with producibility is one of the most basic and critical problems to be solved before a design can be considered. Of course, a large initial investment in manufacturing facilities, tooling, and design is required in areas where the cost of labor is expensive. For instance, in the USA it is not uncommon to have an initial investment of up to $200,000 in salaries, tools and manufacturing equipment before the start of the production of a new AM broadcast radio design. This is exclusive of the initial investment of the manufacturing and engineering facilities.

This investment can be drastically reduced in low labor rate areas. This is done by utilizing more applied direct labor in exchange for automation. This approach, however, does not lead to long term technological improvement of the population. Thus, the factor of gaining education and experience must be considered in deciding what degree of design sophistication should be used. Since this problem is generally handled at governmental level rather than at a technical level, this paper will not pursue it further.

The quantity of radios to be produced will have a large bearing on the type of production techniques and the radio design. The quantity of radios will also have a bearing on the degree of vertical integration. Examples of all levels of vertical integration are available throughout the world. Some of the very large corporations, especially those building television and phonographs along with radios, find it profitable to manufacture most of the components used in their products. At the other extreme are found companies that utilize sub-contractors to fabricate the chassis while the final assembly at the main plant consists of merely inserting the chassis into the cabinet.

Vertical integration can be profitable if there is a large production base to justify the investment. However, if a radio manufacturer decides to build commonly available items such as capacitors or resistors, they find themselves competing with companies that specialize in these components. Thus, the advantage of competitive bidding is lost. There is also a natural tendency to use one's own product even during times when the quality level is low. There is also a danger in not assigning actual costs and in underestimating the problems to be encountered in component manufacturing. In this age of relatively easy trade and transportation throughout the world, the electronic component business is extremely competitive and must be constantly scrutinized for optimum cost, quality, and availability. It is not uncommon in modern radios to find components from several countries incorporated in one model. Even decorative parts and cabinets are frequently purchased from several countries for the same model.

It is even possible to purchase complete chassis from another country and simply install it in a cabinet for final assembly. From the above statements concerning vertical integration and component purchasing it is obvious that there are many different avenues of approach available to radio design and manufacture.

Figure 3 is a graphic presentation of basic design considerations verses quantity of radios per year. Note that the abscissa is in units of identical models per year. Even if the total quantity of all models is high, the economic advantages of common tooling, design expenditures, special manufacturing fixtures and other variable costs will not be realized if there is a high variation of model types.

Figure 4 depicts some of the typical vertical integration decisions that must be made as a function of identical components per year. Here again, the word identical must be emphasized. Many good plans have gone astray because the advance

Fig. 3

Basic Design Considerations vs. Annual Production Quantities

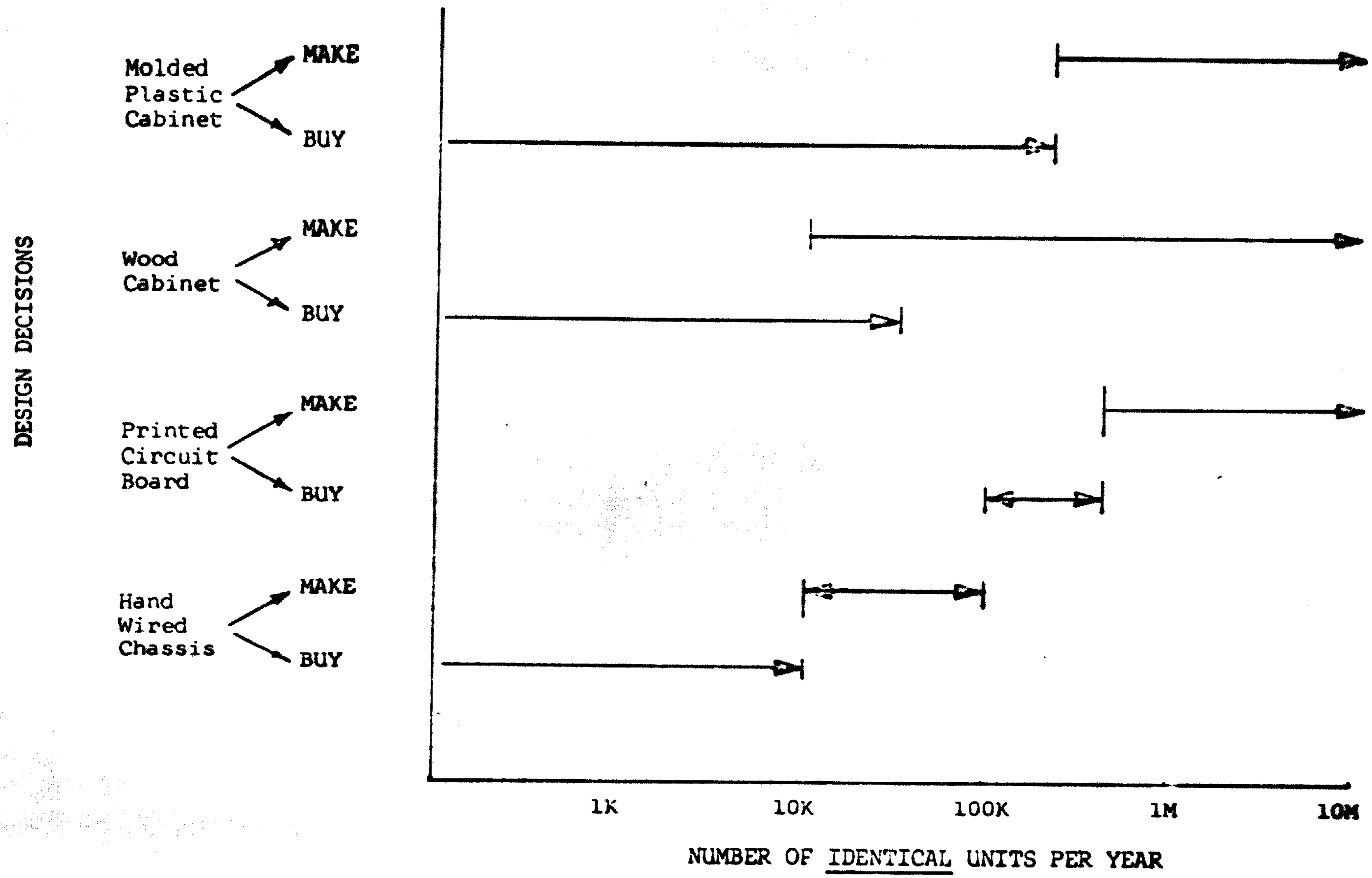
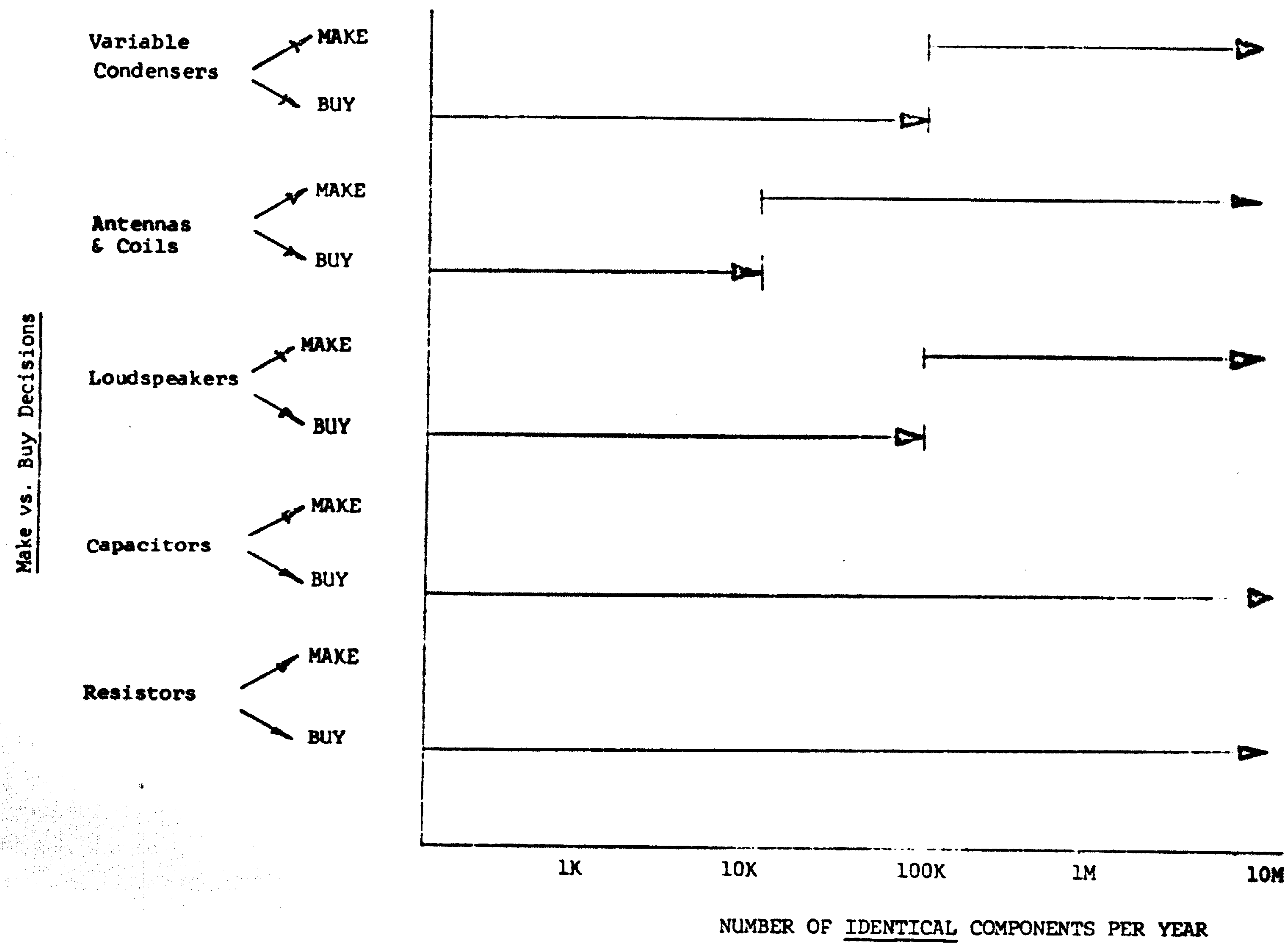


FIG. 4

Vertical Integration Considerations vs. Annual Production Quantities



planning did not foresee the proliferation of component variations that occur as the business grows and the design concepts evolve. It takes very strict design disciplines to make extensive vertical integration economical. A radio manufacturer who decides to make loudspeakers, for instance, places himself in direct competition with component vendors that have a volume base of millions of units per annum.

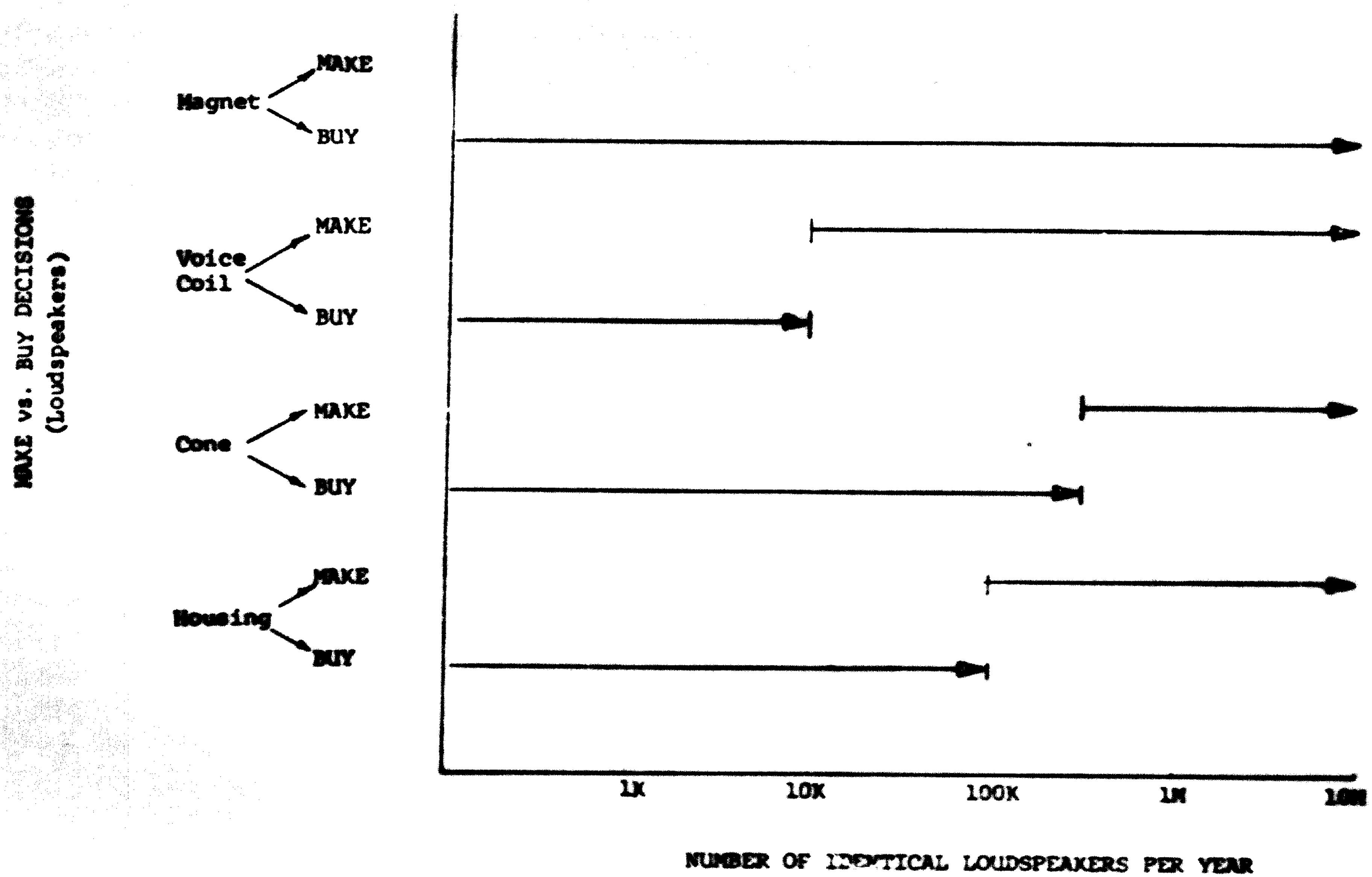
Figure 5 shows that there are further decisions to be made even after it is decided to manufacture a component. For this example, a loudspeaker is examined per what parts should be purchased and what parts should be manufactured.

Without belaboring the point too much it is now obvious that even each part shown in Figure 5 can be broken down into raw materials where make versus buy decisions can be made. The radio manufacturer would have to be in a very healthy financial and technical situation if he was considering extensive vertical integration. However, these points should not be completely ignored, even by a new manufacturer, since his particular geographic location or labor situation might make it advantageous for him to make some of the components competitively.

FIG. 5

<u>Design Consideration for Partial Vertical Integration</u>

(Loudspeakers)



Radio Design

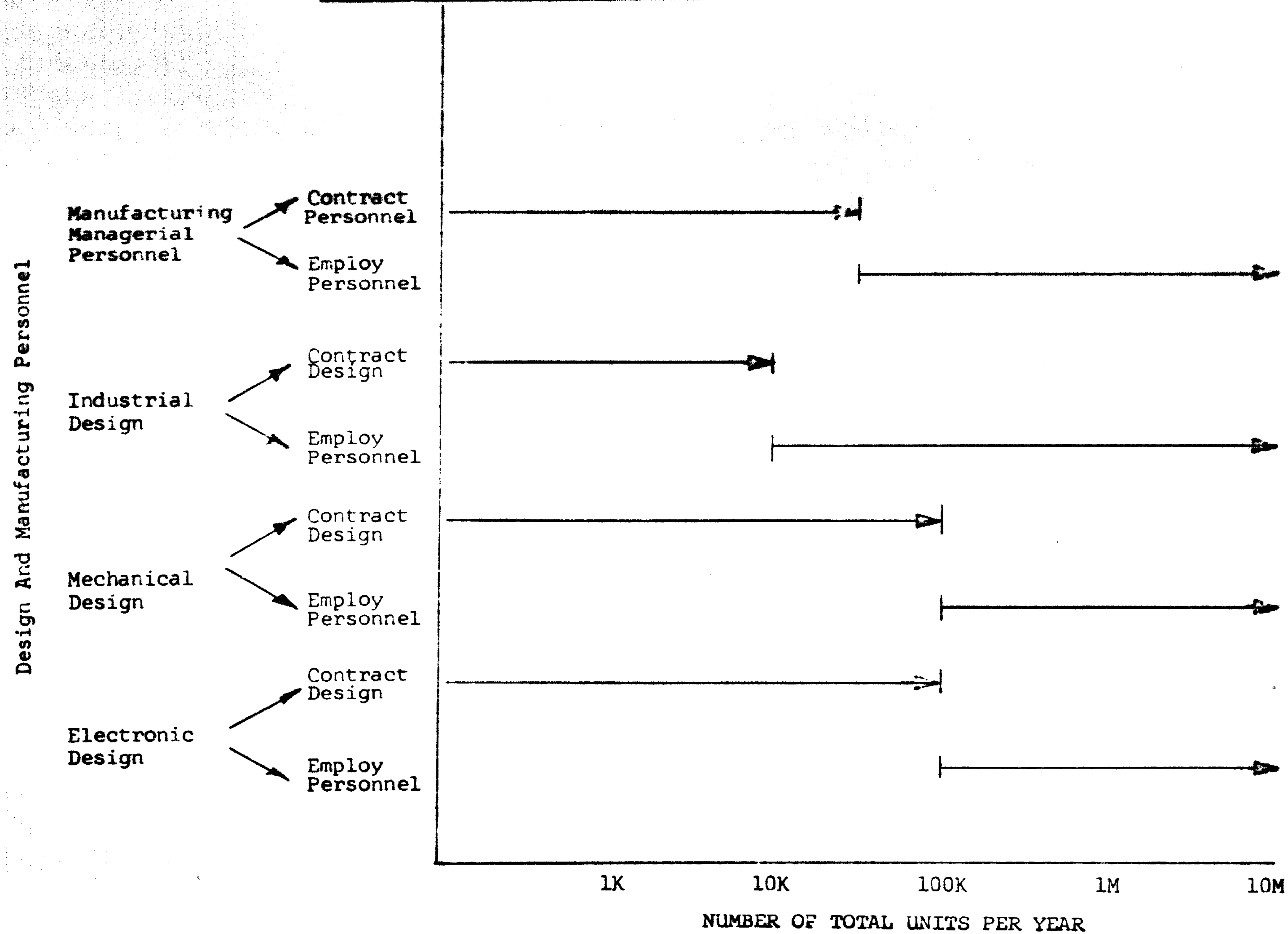
From the standpoint of electronic circuitry there is much literature available on the common broadcast radio. Since the cost of transistors has decreased, vacuum tube entertainment radios have become obsolete. Most of the radio design literature is written for vacuum tube application, but the theory is usable for transistor application by making allowances for the impedance and feedback characteristics of solid state devices. If design personnel are not available, transistor manufacturers can usually supply application engineers to assist in the design.

Of course, a radio can be designed by simply employing basic electronic theory and developing the necessary mathematical equations. Without a doubt this is the best way to obtain a complete understanding of the design theory. However, no manufacturer would be willing to pay a design engineer to develop design theory that has already been developed. Thus, a compromise is generally reached between the amount of original design and a copy of existing designs. In fact, to obtain the maximum usage of design personnel, existing designs should always be examined carefully to avoid costly "re-invention of the wheel" projects. The "not invented here" attitude must be overcome in order to optimize any design group.

Figure 6 gives an approximation of break-even points for design personnel. Just as in the cost of equipment the utilization of design personnel and other overhead personnel must be carefully considered as a function of annual production. It is very easy to overstaff the design groups in good times but it can be quite embarrassing and disrupting if the need arises to reduce the number of personnel

FIG. 6

Design and Manufacturing Personnel Consideration vs. Annual Quantities



when the production pace slackens.

However, the judicious use of contract design personnel will allow for fast changes in the quantity of designs without jeopardizing regular core personnel. The disadvantages of a large amount of contract work are that continuity of design is difficult to maintain, direct design costs will be higher, and there is little training of permanent personnel. Most large companies find it necessary to utilize some contract design personnel to keep the expense budget somewhat flexible.

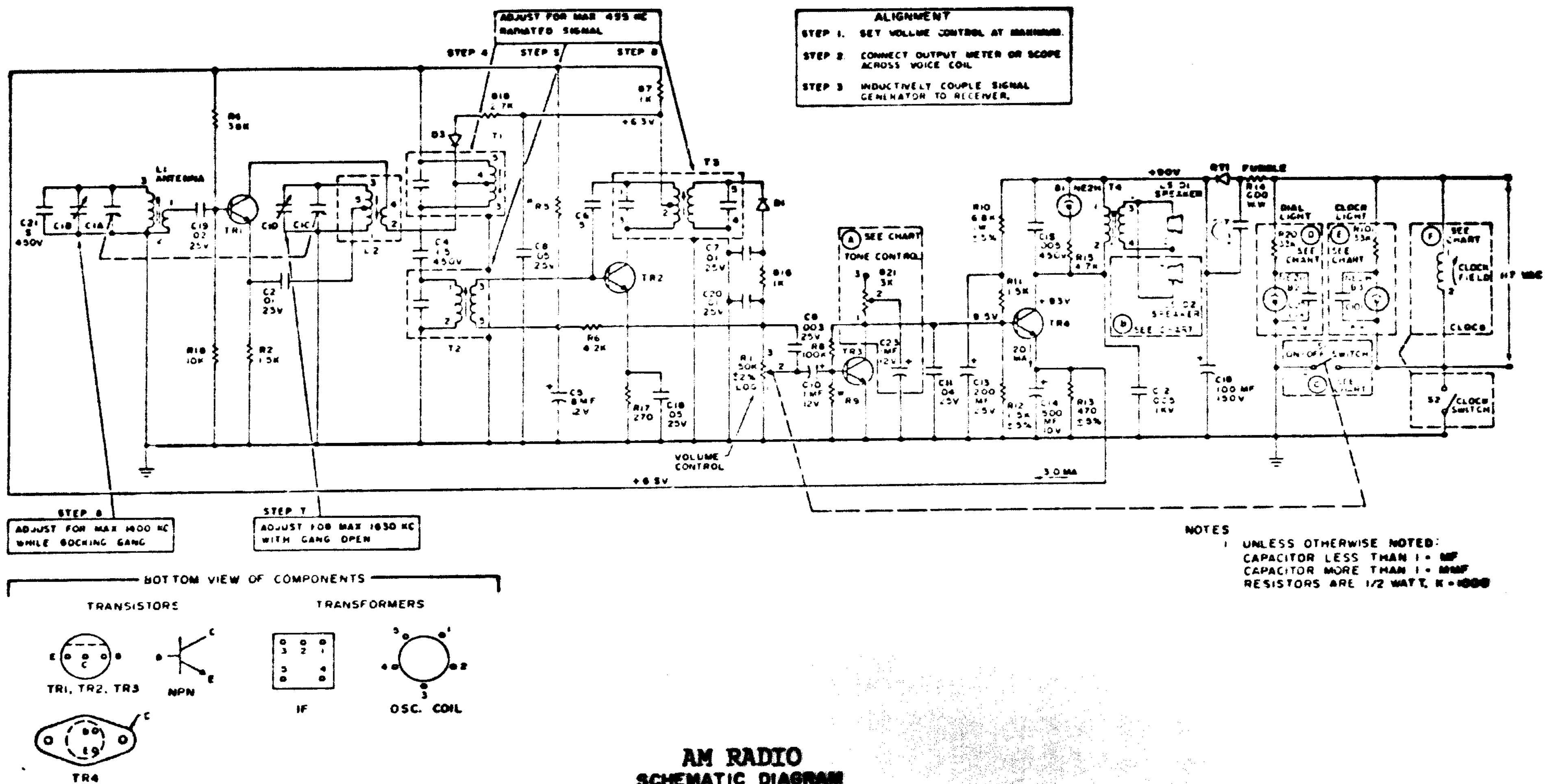
The complexity of the radio system will also have a large bearing on the number and type of personnel needed. The medium wave and long wave circuits require much less design talent than the FM and shortwave circuits. These designs are also much simpler to operate from a user standpoint.

Transistors and associated components are most readily available for the lower frequency bands. For instance, a difference of two or three picofarads in the transistor at 100 MHz is very important while at 1 MHz it is not as troublesome. Thus, the medium wave circuits can better tolerate component variations caused by manufacturing tolerances, aging, temperature, humidity and voltage fluctuations.

Radio Circuits

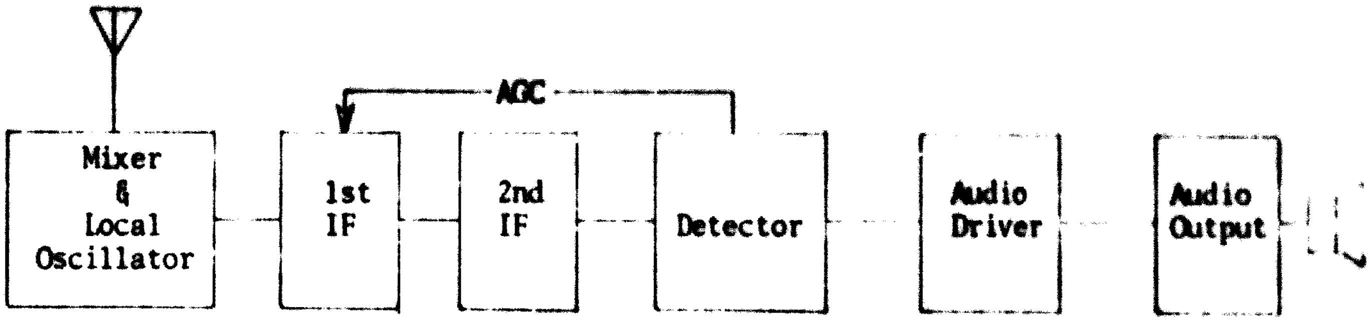
To indicate the complexities involved in the most common types of radio circuits examples will be shown for an AM and an AM/FM radio.

Figure 7 shows an AM, class A audio output, mains powered Medium Wave superheterodyne circuit. The below block diagram pertains to Figure 7.



AM RADIO
SCHEMATIC DIAGRAM

FIG. 7



The superheterodyne circuit is employed in all entertainment and commercial radio and t levision receivers regardless of the frequency band. A superheterodnye circuit is one in which most of the amplification takes place at an Intermediate Frequency (IF). The IF is obtained by adding the incoming RF signal to a Local Oscillator signal generated in the receiver. The IF is the resulting difference frequency that occurs when these two signals are impressed across a non-linear mixer circuit. Highly selective fixed tune filters and amplifiers can then be used to amplify the IF signal while rejecting interferring signals. Note that any spurious RF signal that adds with the Local Oscillator signal or any of its harmonic frequencies in such a combination as to result in the Intermediate Frequency will be amplified by the IF amplifiers, and thus cause an interference to the desired RF signal. These types of interference signals can only be rejected by filtering the incoming RF signals ahead of the mixer circuit. These circuits are called tuned RF (TRF) amplifiers and are used in high quality receivers. The major difficulty in using TRF stages are that they must be variably selective in order to cover the desired frequency spectrum. Note that in the Medium Wave band, the frequency ratio is about three to one.

Another problem that occurs in superheterodyne designs is the tracking of the Local Oscillator to the RF signal across the band to maintain a constant difference frequency. Since the IF stages are very selective, the tuning of the radio by the operator is determined by the Local Oscillator and the IF tuning. Thus, any mistracking will result in a signal loss and a selectivity loss in the RF tuned circuits preceeding the mixer.

The Detector circuit is used to extract the audio intelligence from the IF carrier and then is sent on to the audio amplifier circuits and thence to the loudspeaker where it becomes audible.

The AGC (Automatic Gain Control) feedback loop indicated in the block diagram is used to keep the audio level constant under varying RF signal strength conditions. This is generally accomplished by feeding the DC component of the detected signal back to the IF amplifier to reduce the gain as the RF level is increased. The amount of control must be carefully adjusted so that weak signals are not attenuated and strong signals do not distort.

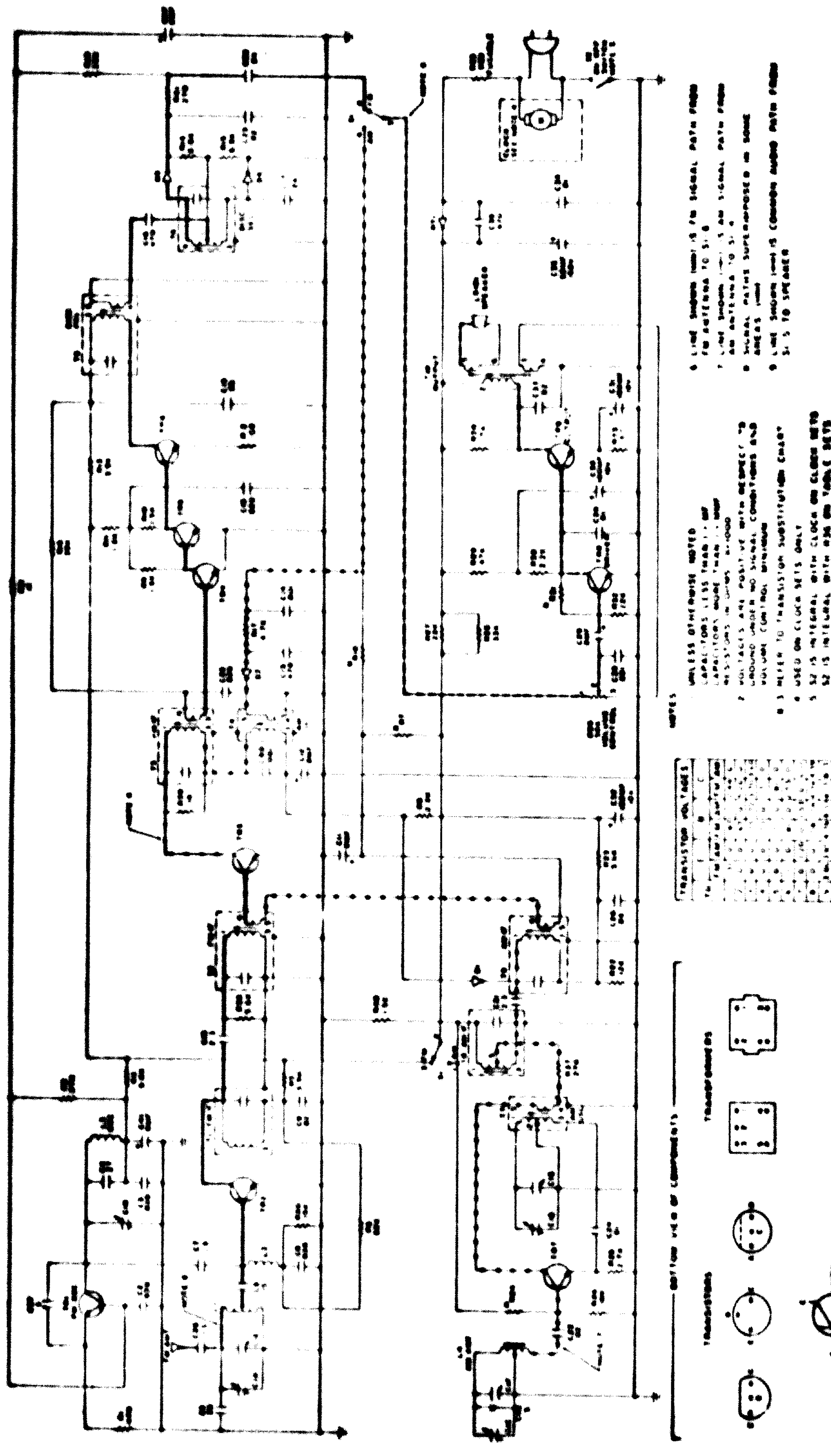
An FM receiver would have the same block diagram but the detector is much more complicated than an AM detector. In an AM receiver a simple diode is commonly used as the non-linear element to detect the audio intelligence. However, in FM the audio intelligence must be extracted by a frequency sensitive detector. These are commonly called discriminator circuits. A good discriminator circuit must be accurately aligned to the IF signal and must be linear over a large frequency range.

The value of the Intermediate Frequency is largely a function of local interference signals. For instance, in the Medium Wave band, 455 kHz is the common IF used in the USA. However, in Europe it is common to use 465 kHz to avoid interference from the very powerful BBC station at 908 kHz in England. The second harmonic of the IF, which is generated in the non-linear detector circuit feeds back to the RF circuits when they are tuned to that frequency. Thus, in the USA, radio stations avoid operating at 910 kHz, whereas the European radios have a potential interference problem at 930 kHz. The third harmonic of the IF is usually not troublesome but it can be, particularly in AM/FM receivers using common AM IF and FM IF amplifier transistors.

The common IF for FM radios is 10.7 MHz. This frequency seems to be universally accepted even though two interference points occur within the USA FM band, at 96.3 MHz and at 107 MHz, the ninth and tenth harmonics respectively. Both in AM and FM, unwanted coupling from the detector circuits to the RF circuits must be minimized to reduce interference problems.

Figure 8 shows a combination AM/FM, class A audio output, mains powered circuit. Note the increase in complexity compared with Figure 7 just by the number of parts. Also keep in mind that the electrical alignment of an AM/FM circuit is more than double that of an AM circuit.

An FM only circuit diagram is not shown but the complexity would fall between an AM only and an AM/FM radio.



AM/FM RADIO
SCHEMATIC DIAGRAM

FIG.8

Mechanical Considerations

Some mechanical considerations were discussed and shown briefly in Figures 3 and 4. Let us take a more thorough look at what is expected of the mechanical functions:

1. To protect the electrical components from the environment.
2. To enhance the appearance of the radio.
3. To provide operator controls such as a station selector and an audio level adjustment.
4. To tie together both electrically and mechanically all of the radio components.
5. To provide for a visual tuning indication.
6. To provide a suitable pack to transport the radio to the user.
7. To protect the user from dangerous voltages present in mains powered radios.

Cabinet Material

Wood is the oldest material that has been used as the main cabinet material. Even at this date the most expensive and prestigious radio cabinets are made from wood. Wood has disadvantages that make it difficult to handle, especially on a high production basis. Good woodwork also requires skillful workmen and clever craftsmen. These are some of the reasons why radio manufacturers usually purchase their cabinets from furniture and wood cabinet specialists.

One structural problem with wood is that dimensional tolerances are much harder to maintain as compared with fabricated materials such as plastic and metal. Thus, the designs must be made to accommodate the wood tolerances where interfaces occur between dissimilar materials. Part of the problem in maintaining dimensions in wooden parts is caused by moisture and wood curing. By properly sealing the wood against moisture these problems can be minimized. Note that moisture in wood can make it electrically conductive enough to be hazardous to the user. Therefore any dangerous potentials should be isolated from the wood cabinet.

Since a radio generates internal heat, the cabinet is further subjected to temperature variations as the receiver is turned on and off. In some very moist localities it is common practice to leave the radio turned on at all times to maintain a supply of heat to help keep the receiver dry. Some commercial and military communications equipment have thermostatically controlled heaters to maintain a constant temperature environment.

Plastic material, mainly polystyrene, is used extensively in the radio industry throughout the world. Without a doubt its main attraction is ease of fabrication and low material cost. The use of plastics has become quite sophisticated and is improving daily. Plastic does not enjoy the prestige factor of wood but it has made tremendous inroads since the end of World War II.

One drawback for the use of plastics in a developing country is the large initial investment required for injection molding equipment. There is also a large amount of know-how and engineering required to obtain the maximum structural benefits from a plastic cabinet design. A good knowledge of tooling is also required since the designer working with plastic must have a good knowledge of molding problems when he is formulating the design. Good liaison between the designer and the mold maker is also required. Cabinet molds for a table model radio can cost up to $75,000. Injection molding machines cost $50,000 for a 24 oz. molding machine, the size needed to mold table model size radio cabinets. However, once the initial investment is overcome, the raw plastic cost is only $0.20 per pound and cabinets can be molded at a rate of about one per minute.

As an interim means of using plastic materials, entire cabinets can be purchased from vendors. Of course, unless catalogue items are purchased, any unique tooling costs will have to be paid for by the purchaser. It is also possible to purchase perfectly good tools from radio manufacturers when they are discontinuing a model. Since tools have a finite life, the condition of used tools should be carefully examined by an expert.

Printed Circuit Chassis

Another major consideration as shown in Figure 3 is the phenolic printed circuit board versus a hand wired chassis. Here again one of the main problems is the large initial investment required to design and produce circuit boards. Circuit board punching tools must be purchased and chemical processes must be set up to either etch off or plate copper onto the phenolic board material. Both etched circuit boards and plated circuit boards are in use in the industry. In the case of etched boards, fully copper clad raw material is purchased and the copper is selectively etched away to obtain the desired circuit pattern. In the plated board process, copper is selectively deposited on the phenolic board to obtain the desired circuit pattern.

Completed circuit boards can be purchased from vendors, but any unique tools must be paid for by the purchaser.

After components are inserted in the circuit board, electrical solder connections can be made to the copper pattern by either automatic means or by hand soldering. If hand soldering is used, very close component spacing can be held to maintain compact designs. Here again, automatic soldering techniques will only be economical for a large volume base.

Hand Wired Chassis

The use of a hand wired chassis involves very little tooling and other initial investment, since the only major component is a metal stamping with a few mounting holes. A hand wired chassis obviously requires more direct labor than a printed circuit board chassis, since each wire must be hand crimped around a mounting terminal. The solder terminals, in turn, must be connected to the main metal chassis. Wire dress can vary from set to set as opposed to a circuit board which has its circuitry permanently fixed in place. This can be a very important factor especially when using unskilled labor since product uniformity will suffer. Thus, a new radio manufacturer with limited resources would probably be well advised to purchase printed circuit boards whether or not he plans to use automatic soldering techniques.

Purchased Designs

As opposed to designing a complete radio, a completed design can be purchased from an existing radio manufacturer. Licensee arrangements can be obtained for as little as 3% of the net sales billed. Under these agreements, complete kits of parts can be purchased for assembly in a developing country. This is an inexpensive way to start in the business with little initial investment and few skilled personnel.

Product Service

Another consideration in the radio business is what to do about field failures and routine maintenance. Several arrangements are popular in the industry, such as:

1. A central repair facility is maintained by the manufacturer and all defective radios are returned for repair. There is usually a modest

fee for this service.

2. Service personnel are trained and located in major population areas or strategic geographic centers. Of course, spare parts must be available at these service centers.

3. An exchange system is also used whereby the customer merely brings his defective radio to a service center and a good unit is given to him. The defective radio is then sent to a central repair facility.

Needless to say, in a competitive, commercial business the field repair system and the resulting customer satisfaction is sometimes as important as the product itself.

Kits

Another approach to the overall radio system would be to furnish the population with unassembled radio kits. Radio kits are sold by several corporations in the USA. There are several benefits to be derived from kits, especially in the developing countries.

First, the use of kits obviates the need of having an extensive assembly plant, since the individual radio parts are merely packaged by the processor.

Second, the use of kits would help to educate the population. Pictorial diagrams can be used so that even an illiterate could assemble the radio.

Third, there is a psychological benefit to be derived from having built one's own radio receiver. It is possible that a radio would get used more often if a person constructed it himself rather than if it was just given to him as a complete unit.

Fourth, a self-constructed radio could be more readily serviced by the individual owner since he would be very familiar with its construction.

If kits are used, care must be taken to have all the electrical alignment performed either by the component manufacturer or at the final packaging plant. To further simplify construction a sample assembled radio could be included with each lot of kits. If kits were sent to small villages, it would even be possible to bulk-pack the components to reduce packing and shipping expenses.

Appendix

1. "Performance Specifications for Low-Cost Sound Broadcasting Receivers" - CCIR Recommendation 415, Volume V, Oslo, 1966

2. "Performance Specifications for Low-Cost Sound Broadcasting Receivers for Community Listening" CCIR Recommendation 416, Volume V, Oslo, 1966

3. "Choice of Intermediate-Frequency and Protection Against Unwanted Responses of Superheterodyne Receivers" CCIR Report 184 Volume I, Oslo, 1966

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