RADIOTRONICS

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A simple amplifier with very low distortion and noise figures, intended to be used in conjunction with standard noise and distortion meters.

With the introduction of the transistor, battery applications have increased many-fold. The user and designer of equipment for battery operation should understand some battery theory in order to get the best performance.

A short survey of noise and related problems, both common and abstruse, with particular reference to the electron valve and its application.

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LABORATORY AMPLIFIER

by B. J. Simpson

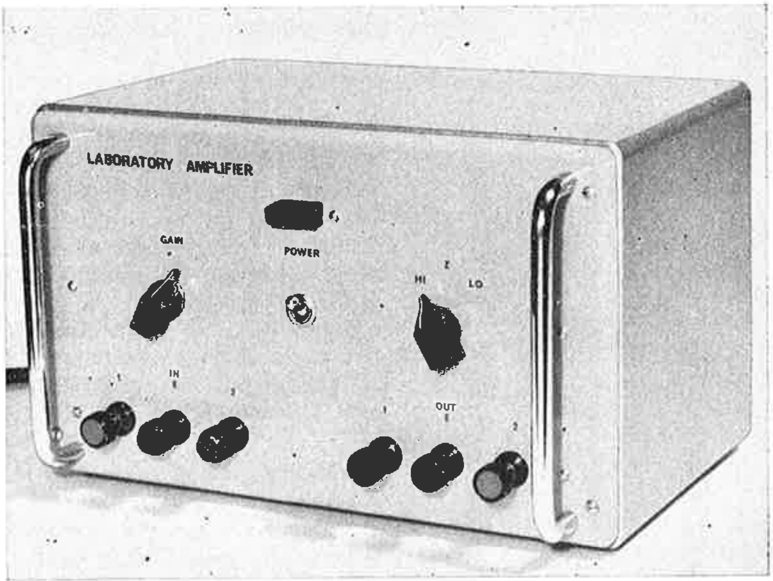
Introduction

One of the problems associated with working on preamplifiers and other low-level units is that of making satisfactory noise and distortion measurements. This arises out of the fact that most commercial noise and distortion meters require an input of the order of 1 volt or more, whereas individual stage levels in a preamplifier will often be much less than this.

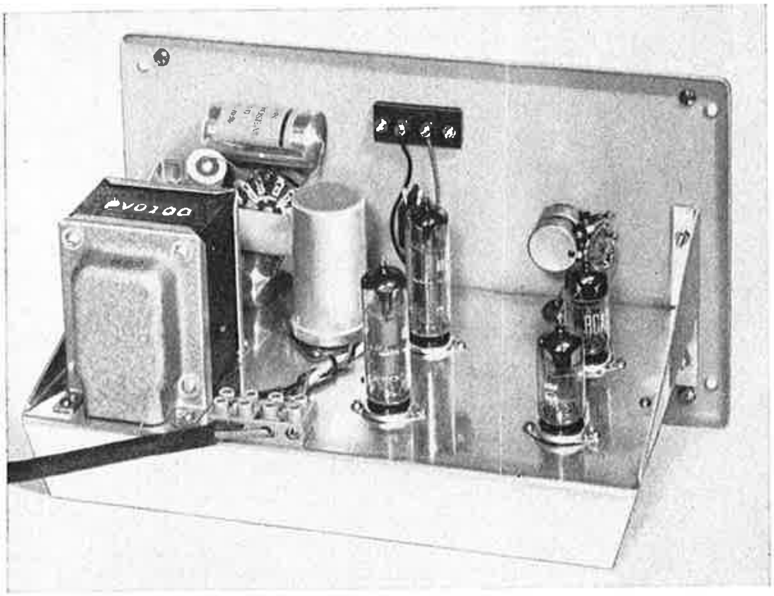
In some cases, the problem can be solved by setting up the meter for the measurements with the distortion range switch set to the position below the normal setting position, and mentally correcting the readings taken. This device is useless, however, when we are trying to measure very low noise and distortion levels, and need the whole available range of the meter.

The solution is to interpose an amplifier between the stage we are measuring and the measuring instrument. But this apparently simple solution requires an amplifier which itself has a very low noise level and a very low level of distortion, otherwise our readings will be in error. Any noise and distortion in the amplifier we are going to interpose in the chain will be added to the unwanted products of the unit on which we are trying to make measurements.

Further, it is desirable that the "laboratory" amplifier, as we have called it, should have a reasonably high input impedance so that it can be connected to a circuit under test with the minimum disturbance. A suitable amplifier was designed some years ago by Mr. F. Langford-Smith, and published in these pages. That



View of the front of the unit, showing the neat appearance and small size.



Top view of the chassis, showing the general layout. The four output capacitors are mounted above the chassis, around the OUTPUT IMPEDANCE selector switch.

amplifier was taken as the basis of this one, and in its essentials is almost identical.

General Description

In its original form, the laboratory amplifier was a single channel unit, and used a power supply that happened to be available. In the construction of this unit, it was decided that the amplifier would be complete with its own power supply. At a late stage it was also decided that twin channels would be incorporated in the unit, so that there are now two identical signal amplifiers, with separate input and output terminals, the only common features being the ganged gain control and the power supply.

This may seem a strange thing to do, especially as there is no provision for operating the two separate amplifiers in series for increased gain; in fact that is not possible. The idea behind the two channels was that these days we are often concerned with stereo, involving two identical channels in the amplifier under test. Very often, of course, the development of such an amplifier is carried out on one channel, and two channels are subsequently incorporated in the finished design.

It very often happens however, that it is convenient to have two channels actually in the development stage. The two channels in the laboratory amplifier then allow measurements to be made simultaneously on both channels if required. In addition, I have sometimes found it useful with a development unit to leave one channel untouched as a "control" whilst adjustments to the circuit of the second channel are being made.

These then were the considerations behind the unit. If only one channel is required, then only one channel need be built. A single-channel unit could be built into a smaller case if required.

The Circuit

The circuit diagram featured here shows one of the two identical channels of the amplifier, together with the common power supply. It should be noted when building the unit that this circuit also includes B+ line decoupling arrangements which are common to both channels. The second channel would pick up its HT voltages at the points marked A, B and C in the diagram.

Each channel of the amplifier uses a 12AT7 and a 6BQ5, forming three resistance-capacitance coupled stages. The two stages using the 12AT7 are conventional, except for the fact that negative feedback is applied in each stage by means of the unbypassed cathode resistors.

The 6BQ5 is used as a triode in a cathode-follower arrangement to reduce loading on the previous stages. DC feedback is provided between the cathode-follower output stage and the input stage of the amplifier, through the 22K resistor.

Because the amplifier may be required to work into a variety of impedances, two alternative outputs have been incorporated. The "low" output is intended for a nominal 600 ohms or thereabouts, and the "high" output for about 5K ohms and above. The value of the cathode resistor for the 6BQ5 has been chosen to be a reasonable compromise for these two alternative requirements.

The power supply is straight-forward. It uses a standard stock transformer, a PVD100, specially designed for use with silicon diodes in the type of voltage-doubling service adopted here. This transformer has a number of secondary taps, allowing the user to make small adjustments in the precise value of the HT voltage produced. Use that tap which produces the nearest value of HT to the nominal 250 volts, depending on whether the unit is built with one or two channels.

Although RC filtering of the rectifier output was used and found satisfactory, there is no reason why an inductance should not be used if desired.

Construction

The unit was constructed in an Imhof 1490B steel case fitted with 10C handles, resulting in a very neat-looking instrument. The front panel layout is very simple. Input and output terminals with a common earthy connection are used, and the three controls are GAIN, OUTPUT IMPEDANCE selector and the POWER switch. A neon is used as a positive indication when the amplifier is in operation.

The two views shown of the inside of the amplifier show the general layout used. The layout is not critical, due to the exceptional stability of the circuit, but care should be taken with the input stage to avoid unnecessary hum and noise pickup. The use of a steel case reduced the amount of screening that may otherwise have been required.

Performance

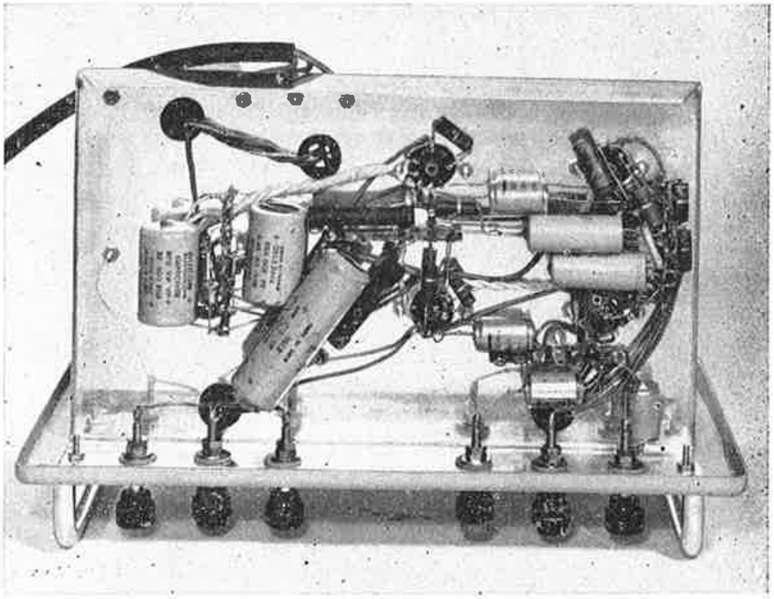
The input impedance of this amplifier fills the requirement already stated. The frequency response of the amplifier is within 0.5 db from 20 cps up through 100 Kc, and therefore will not "colour" any normal amplifier to which it is connected. Further response up through the supersonic region was felt to be undesirable, and was reduced by means of the 5 pf capacitor connected between the plate and grid of the second stage. This capacitor provides increasing feedback and loss of gain as the input frequency increases above 100 Kc.

The voltage gain of the amplifier is 25 db, or about 20 times. Assuming the normal noise and distortion meter input requirement of about 1 volt, this means that this amplifier extends the useable signal level down to 50 millivolts. Maximum undistorted output levels from this amplifier are 8 volts and 10 volts respectively for the low and high impedance outputs, working into 600 ohms and 5,000 ohms. These figures correspond to maximum input levels of 400 and 500 millivolts respectively, with the gain control in the maximum gain position.

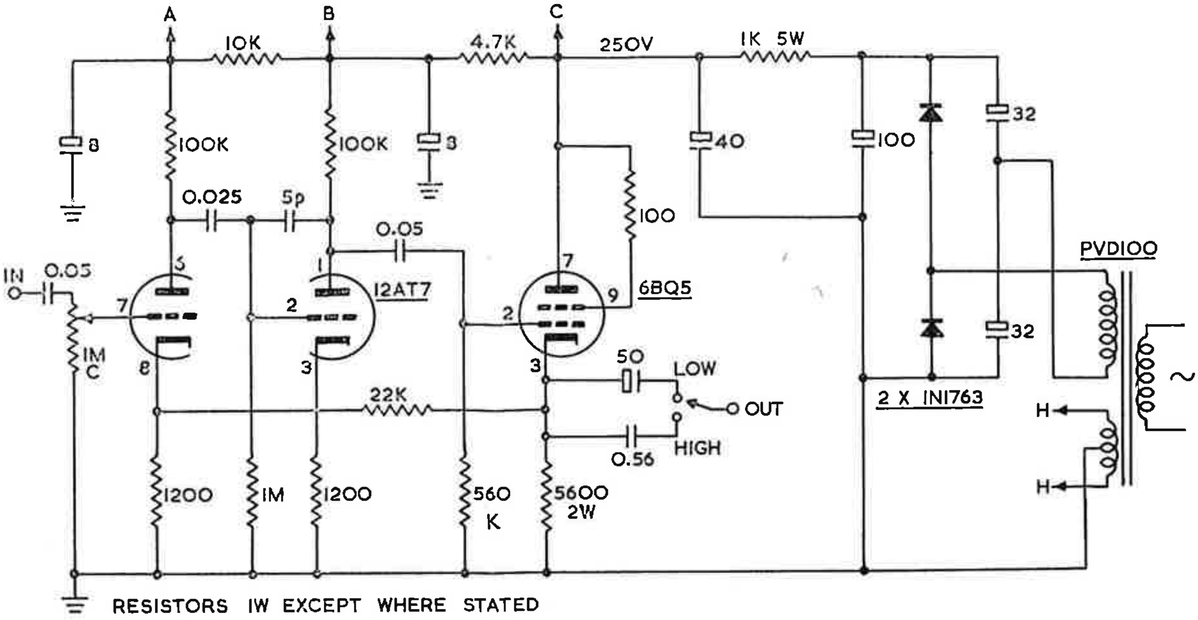
Total harmonic distortion is very low at 0.02% at 1 volt output. Noise and hum at the same output level is —75 db.

Using the Amplifier

The purpose of this amplifier has already been described, but there are a few hints on its application that may be useful. The input lead



View of the underside of the chassis, showing the simple construction and layout.



Circuit diagram of the laboratory amplifier. This diagram shows one of the two channels, the common HT decoupling arrangements and the common power supply.

to the amplifier must be adequately shielded, and a preliminary test on the laboratory amplifier and connecting leads is advisable before proceeding to take measurements on the unit under test. This will ensure that there is no undue noise pickup, earthing faults, or other circumstances which would nullify the tests or produce spurious results.

Care should be taken at all times, by observation of an oscilloscope, to make sure that the permissible input levels are not exceeded; severe distortion will result from overloading of the laboratory amplifier.

Where only one channel of the amplifier is in use, it is not usually necessary to short circuit the input or output of the other channel, due to the very low level of cross-talk. It may, however, be necessary to take such precautions in certain critical conditions.

This amplifier may be used with units undergoing square-wave testing. It must, however, be understood that the gain control is an ordinary carbon potentiometer, and is not corrected for frequency. It should therefore be in the maximum gain position at all times when square waves are applied to avoid the possibility of introducing distortion into the square wave. The only way to overcome this would be to use a frequency-corrected stepped potentiometer, such as is used at the inputs of oscilloscopes and similar units.

When used as specified, the square wave response is excellent, as one would expect from the frequency response. A 20 Kc square wave is passed with distortion barely detectable, a very severe test for an audio amplifier. The response at low frequencies is also very good.

Apart from the obvious utility in raising a signal level to that required by measuring equipment, one of the great features of this type of amplifier is the added flexibility it provides in the matter of checking individual stages for distortion, an exercise that can sometimes be very difficult. Particularly when chasing out small remaining distortion readings, the ability to determine precisely where the distortion is arising is invaluable.

Conclusion

This amplifier is a specialised unit for a specific application. It has been in use for several months, and has already more than repaid the cost of building it. Whilst not a general-interest type of building project, this information may be useful to those who have the type of problem this unit was built to solve.

BATTERIES

INTRODUCTION

The battery was the first practical source of electrical energy developed in man's search for portable power sources. Although many other techniques have been developed for supplying electrical power, the battery, which converts chemical energy directly into electrical energy, is still the most widely used source of electrical power when portability is the prime requisite.

The development of semiconductor devices such as transistors, diodes, etc., missiles, satellites, and a great variety of mobile equipment, has imposed rigorous demands for power sources which are compact, dimensionally adaptable, able to operate over a wide temperature range, and highly dependable. That the battery meets these demands is proved by the enormous increase in battery use and continuous demands for new battery types.

HISTORY

The compact, attractively packaged battery seen on store counters differs considerably from the original "voltaic pile" and "crown of cups" discovered and developed by Allessandro Volta in 1798.

Early experimenters had suspected that there was a relationship between chemical and electrical phenomena. It remained for Volta to confirm this relationship with his scientific disclosures. Volta's original "voltaic pile" consisted of a series of zinc and silver discs separated from each other by a porous non-metallic material and made electrically conductive by being impregnated with salt water. This arrangement produced a voltage across each silver and zinc disc. Volta arranged these discs as shown in Fig. 1.

Another arrangement demonstrated by Volta was the "crown of cups", a group of cups containing salt water, arranged in a circle, and connected to each other by conductors with terminating electrodes of zinc and silver. This arrangement is illustrated in Fig. 2. Both the voltaic pile and the crown of cups were not practical batteries because of their bulk and awkward arrangement of cells.

A major advance in the evolution of the battery was the Daniell cell named for its inventor J. F. Daniell. This cell improved on earlier cells by incorporating a depolarizing agent (a material used to reduce the accumulation of hydrogen on the electrode) which aided in extending the life of the cell. The Daniell cell utilized a zinc negative electrode immersed in a dilute acid electrolyte (zinc sulphate + sulphuric acid), and a copper positive electrode immersed in a copper sulphate solution.

In 1868 Georges Leclanche introduced a cell which was the forerunner of the present dry cell and which has essentially the same chemical

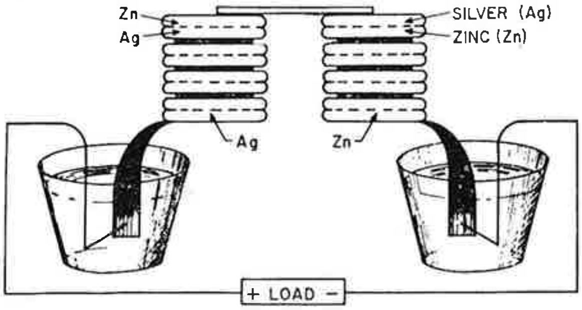


Fig. 1—Voltaic Pile.

constituents as the present cell. Because of these chemical similarities, the dry cell, also called the zinc-carbon cell, is still referred to as a Leclanche-type cell. The Leclanche cell had the desirable feature of employing only one liquid material, an ammonium-chloride (sal-ammoniac) solution which replaced the acid electrolyte used in earlier cells. In addition, the depolarizing solution was replaced by a dry mix composed of manganese dioxide and carbon. Imbedded in the centre of this mix was a carbon bar which served both as a current collector and as the positive electrode. Another advantage of the Leclanche cell over the Daniell cell was its higher electromotive force (voltage). Although superior to the Daniell cell the Leclanche cell was still restricted to laboratory and fixed installations because of its liquid content.

The first true dry cell was developed during the period 1886-1888 by Dr. Carl Gassner. This cell used a paste electrolyte composed of zinc oxide, sal ammoniac, and water. The zinc negative electrode was ingeniously modified so that it also served as the container for the cell contents. As in the Leclanche cell, the carbon rod was retained as the positive electrode and located in the centre of the battery. To prevent leakage and evaporation, the space between the carbon electrode and the zinc container was sealed at the top with plaster of Paris. The result of these innovations was a far more practical cell which was portable and was adaptable to varying space requirements. Furthermore, several of these cells could be conveniently connected to form batteries for higher voltage and/or current requirements.

Dr. Gassner's development made it practical to manufacture dry cells on a commercial scale. Commercial production of the Gassner cell began shortly after its announcement. Since then many improvements have been made to increase the life and the current capacity, prevent leakage, and extend the temperature range of this dry cell.

BASIC TYPES

The terms CELL and BATTERY are often used interchangeably but incorrectly. For example, the popular flashlight "battery" seen on most store counters is not a battery but actually a 1.5-volt cell. A cell may be used either singly or two or more cells may be connected together to form a battery. The manner in which cells may be arranged to form batteries is discussed in detail below.

This section describes three of the more popular dry-cell types: the Leclanche cell (also known as the zinc-carbon cell), the mercuric oxide or Ruben cell (also known as the mercury cell), and the alkaline cell. A brief description of the wide variety of cells and batteries in use today will give the reader a broader picture of this important source of electrical energy.

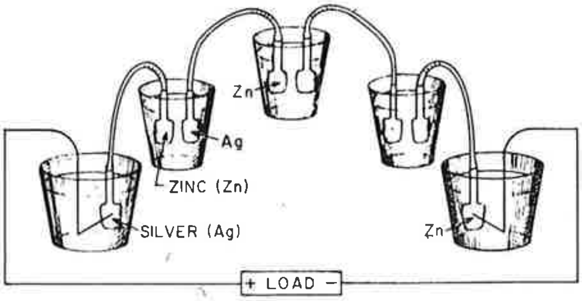


Fig. 2—Volta's "Crown of Cups."

Previously we were concerned with the historical development of the dry cell, specifically with zinc-carbon type cells (Leclanche type). To meet the requirements of special industrial and military applications, other types of cells which differ both chemically and structurally from the Leclanche cell have been developed. By varying the composition and quantity of the chemicals of a cell a manufacturer can produce a cell which can handle light current drains for long periods or heavy current drains for short periods. Research is constantly going on to further the development of cells which can handle heavier current drains for longer periods.

Cells are generally classified in two major groups: (i) Primary cells which are used until the voltage output is too low for useful work (as in flashlights) and are not rechargeable, and (ii) Secondary cells or rechargeable cells. The latter are probably best known for their application as automobile batteries. In a secondary cell, chemicals which provide the energy may be restored to their original condition by applying a direct current to the cell in a reverse direction to the flow of current during discharge. Both primary and secondary type cells contain the following essential elements.

Negative Electrode. The negative electrode is generally a metal such as lead, zinc, iron or cadmium. These metals are characterized by the ease with which they give up electrons into the external circuit, thereby becoming a source of positively charged ions.

Positive Electrode. The positive electrode is generally a chemical compound such as MnO_2, PbO_2, CuC1, or AgC1 (Manganese Dioxide, Lead Dioxide, Copper Chloride or Silver Chloride) which serves as both the positive electrode and depolarizer. Such compounds are characterized by the ease with which they accept electrons.

Electrolyte. The electrolyte is a solution functioning as an ion-transfer medium between the negative and positive electrodes. In dry cells this solution is in the form of a paste.

Separator. The separator is an inert insulating medium which physically separates the positive and negative electrodes, and at the same time permits the transfer of ions between the electrodes through the electrolyte.

A seal or covering is also employed to prevent the evaporation and spillage of the cell contents, while permitting the escape of gases which can accumulate as a result of the chemical reactions within the cell.

A representation of a cell incorporating these elements and indicating the relative flow of electrons and ions during discharge is shown in Fig. 3.

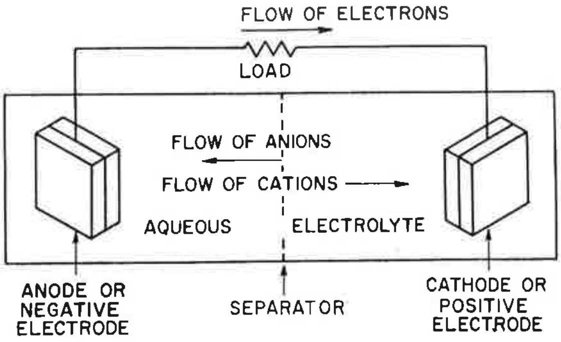


Fig. 3—Representation of a dry cell.

Primary Cells

Primary cells may be categorized into six significant subgroups as follows:

EMF Standard Cells. These cells use chemicals of very high purity and are designed for use as voltage-reference standards.

Solid-Electrolyte Cells. These cells use only solid materials. The principal advantage of such cells is their long shelf life. Their use, however, is restricted to low-current applications.

Wet Cells. These cells are used principally in signalling and in telephone and telegraph systems, because they can handle relatively large currents. Two of the more popular wet cells are the Lalande cell and the zinc "air" cell, which are activated by adding a caustic-soda electrolyte just prior to use.

Reserve Cells. These cells are designed for use in "one-shot" or "delayed-action" applications. A reserve cell remains essentially inactive in the standby state until required. It is then activated by the addition of a liquid or gas, or by the application of heat.

Dry Cells. This type of cell is the type most widely used and most familiar. In addition to the zinc-manganese dioxide (Leclanche) type, there is the zinc-mercuric oxide (Ruben or mercury) type, the zinc-manganese dioxide (alkaline) type, and several developmental types.

Fuel Cells. The familiar process of burning the fuel to obtain heat energy, which in turn is converted into mechanical energy and then electrical energy, may be replaced eventually by the development of so-called "fuel cells". By adding carbonaceous or hydrogen fuels to these cells, a reaction which converts chemical energy directly into electrical energy takes place. These cells are still in the experimental stage.

Secondary Cells

In secondary cells the chemical reactions which produce electrical energy are reversible. The materials used in most commercial secondary cells are lead, cadmium, iron, and zinc for the negative electrode, and lead dioxide, nickel oxide, and silver oxide for the positive electrode. This major group of cells may be classified into the following subgroups: Lead-Acid Cells, Nickel-Iron Cells, Nickel-Cadmium Cells, Zinc-Silver Oxide Cells and Cadmium-Silver Oxide Cells.

Lead-Acid Cells. These are the most widely used secondary cells because they can supply large currents in the order of several hundred amperes at relatively high voltages, approximately 2.1 volts per cell. In a lead-acid cell the negative electrode is a plate of lead; the positive electrode is a plate of lead dioxide. Both electrodes are immersed in an electrolyte consisting of dilute sulphuric acid.

Nickel-Iron Cells. These cells, popularly called Edison or alkaline cells, have useful applications where severe operating conditions are encountered such as in railway service and in other heavy industrial services. In addition, these cells can be discharged for long periods of time or subjected to freezing temperatures without damage. The nickel-iron cell consists of a positive electrode of nickel oxide and a negative electrode of iron, and delivers an open-circuit voltage per cell of approximately 1.5 volts.

Nickel-Cadmium Cells. This cell is similar in construction to the nickel-iron type except for its use of cadmium as the negative electrode and slightly lower open-circuit voltage of approximately 1.3 volts. The nickel-cadmium cell can operate satisfactorily under adverse conditions

Material	Composition in %
Typical Black Mix	
Manganese Dioxide	62
Acetylene black •	8
Zinc Chloride	14
Sal Ammoniac	1
Water	15
	100
Typical Electrolyte	
Ammonium Chloride	9
Zinc Chloride	26
Water	65
	100

• Some mixes use graphite instead of acetylene black.

Table I—Typical cathode mix and electrolyte composition of a zinc-carbon dry cell.

and produces a negligible quantity of gas during inactive periods. Because of the latter feature, these cells may be hermetically sealed to permit greater portability in certain applications.

Zinc-Silver Oxide Cells. These cells employ silver-oxide as the positive electrode and have greater current-handling capacity and higher watt-hour capacity than most secondary cells. Because of their relatively high cost and shorter operating life, zinc-silver oxide cells are not used as extensively as the lead-acid and alkaline cells.

Cadmium-Silver Oxide Cells. These cells employ silver-oxide as the positive electrode for a high watt-hour capacity and cadmium negative electrodes for long operating life. Although cadmium-silver oxide cells do not have as high a watt-hour capacity as zinc-silver oxide cells they have longer operating life and are more useful for low-current applications.

In recent years considerable research has been conducted to develop compact cells having greater capacities and longer life. However, it is not always possible to obtain all desirable features in one cell. Therefore, some degree of compromise in design is necessary to combine the most desirable features in one cell for a particular application.

CONSTRUCTION

The preceding sections presented an over-all picture of the development of cell and battery types. This section will cover in greater detail the chemical composition of three types of dry cells having very extensive use in commercial applications. These are the zinc-carbon (Leclanche) cell, the zinc-mercuric oxide (Ruben or mercury) cell, and the zinc-manganese dioxide (alkaline) cell.

The Zinc-Carbon Cell

In the zinc-carbon (Leclanche) cell the zinc case serves as the negative electrode and the container for the cell contents. The material for the positive electrode of this cell is the cathode mix, and because it is a powder, it is not a mechanically suitable termination for the positive electrode. To overcome this problem a carbon rod with a large surface area is inserted in the cathode mix. The carbon rod is a good electrical conductor, is chemically inert, and in addition, has a large surface area to provide a low-resistance conducting path. The carbon rod is also porous enough to permit the escape of gases accumulating in the cell but does not permit leakage of the electrolyte material.

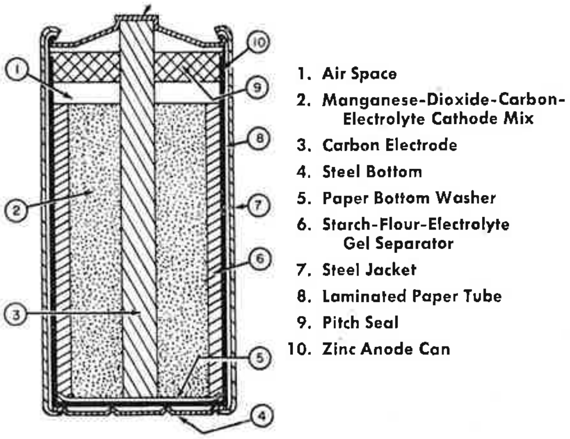


Fig. 4—Cross-section of a typical cylindrical zinc-carbon dry cell.

The cathode mix which serves as both the positive electrode and depolarizer, and to some degree as the cell electrolyte, occupies most of the cell interior. Most cathode mixes use graphite or acetylene black to improve electrical conductivity. However, this material plays no part in the chemical reaction. A gelatinous paste composed of corn starch and flour, and containing the electrolyte material separates the cathode mix from the zinc can and functions as the ion-transfer medium between the electrodes. Typical examples of the composition of the cathode mix and the electrolyte are shown in Table I.

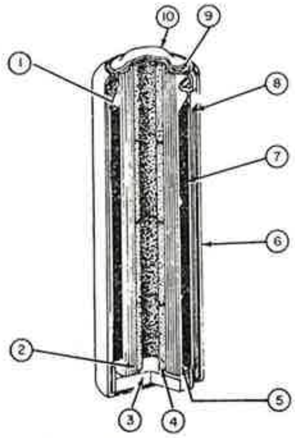
Finally, to make the dry cell "dry" an insulating material is employed to seal off the cell contents. The seal forms bonds with the cap on the carbon rod and the top rim of the zinc container. This arrangement prevents the solution from spilling and permits the cell to be operated in any position.

An example of a typical zinc-carbon cell showing the construction and chemical composition is shown in Fig. 4.

The Zinc-Mercuric Oxide Cell

The zinc-mercuric oxide cell, popularly known as the mercury cell, uses red mercuric oxide (HgO) for the positive electrode and depolarizer.

Graphite is mixed with this material to make it electrically conductive. The negative electrode is a zinc-mercury amalgam, and is separated from the positive electrode by an absorbent pad containing an electrolyte solution of potassium hydroxide (KOH) and zinc oxide (ZnO). In the mercury cell shown in Fig. 5 the powdered-zinc negative electrode makes contact with a plated steel cap which is insulated from the outer steel case. This arrangement makes the cap, or top terminal, negative with respect to the steel casing. Consequently, the polarity of the mercury cell is the reverse of that of the zinc-carbon cell.



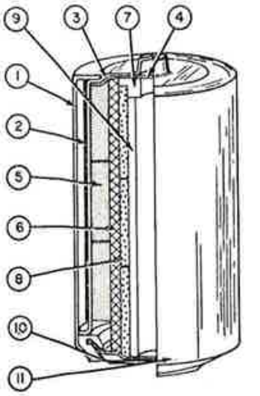
1. Sealing and Insulating Gasket
2. Electrolyte Absorbent Separator Material
3. Insulator Spacer
4. Powdered Zinc Anode
5. Microporous Plastic
6. Outer Steel Case
7. Mercuric Oxide-Graphite Cathode Cylinders
8. Absorbent Sleeve
9. Tin-plated Steel Inner Top
10. Nickel-Plated Steel Outer Top

Fig. 5—Cross-section of a typical cylindrical zinc-mercuric oxide dry cell.

Although mercury cells have a lower open-circuit voltage (1.4 volts) than zinc-carbon cells, they have a flatter voltage-time discharge curve. Mercury cells also have a greater watt-hour capacity per unit of volume and weight, and a better shelf-life than zinc-carbon cells.

The Zinc-Manganese Dioxide Cell

Zinc-manganese dioxide cells, commonly known as alkaline cells, are rapidly assuming an important place in the commercial dry-cell industry. Alkaline cells differ from conventional zinc-carbon cells in their electrode structure and in their electrolyte material which is a solution of potassium hydroxide (KOH). Both alkaline cells and zinc-carbon cells have zinc negative electrodes and manganese-dioxide positive electrodes. A typical alkaline cell is shown in Fig. 6.



1. Outer Nickel-Plated Can
2. Tube Adapter
3. Inner Gold-Plated Can
4. Insulator Disk
5. Manganese-Dioxide Cathode Cylinders
6. Electrolyte Absorbent with Barrier
7. Insulating Ring
8. Zinc Anode Cylinders
9. Inner Absorbent
10. Molded Double Top
11. Insulating Plastic Jacket

Fig. 6—Cross-section of a typical cylindrical zinc-manganese dioxide dry cell.

The alkaline cell has an open-circuit voltage of 1.5 volts, with a relatively constant ampere-hour capacity over a wide range of current drains. Although alkaline cells do not have any particular advantage at low current drains, when compared to zinc-carbon cells, they do have higher efficiency at high current drains.

CHARACTERISTICS

The preceding section discussed different types of cells and batteries, their construction and chemical composition. This section will discuss the electrical characteristics of dry cells, such as open-circuit voltages, current capacities, working voltages, and internal resistance. These cell characteristics are determined by the cell contents, the size of the cell, and environmental factors.

A knowledge of the characteristics and limitations of dry cells will permit the user to select a battery or cell for a specific job.

Voltage

As stated earlier, the terminal or open-circuit voltage of a cell is determined by its chemical composition. For example, the open-circuit voltage of a typical zinc-carbon cell may vary from about 1.5 to 1.6 volts. A desired open-circuit

Cell Type	Average Flash Current	Internal Resistance
ASA No.	Amperes	Ohms
AA	4.6	0.311
C	5.4	0.284
D	6.6	0.227
F	8.8	0.173
No. 6	32.0	0.038

Table II—Approximate internal resistance of zinc-carbon dry cells.

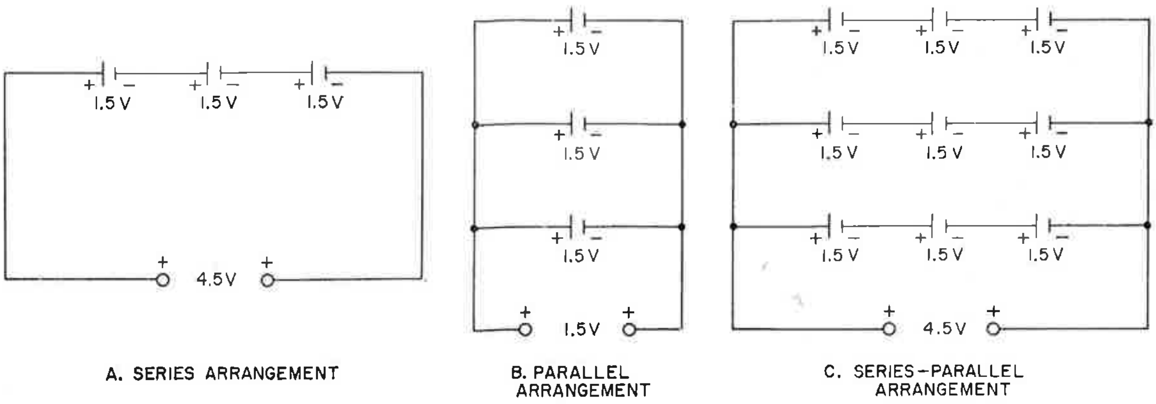


Fig. 7—Three examples of battery arrangements using 1.5-volt dry cells.

voltage can be obtained simply by connecting two or more cells in a parallel or in a series parallel arrangement. In the parallel arrangement the total open-circuit voltage is the same as for a single cell. However, the current capacity of a battery using a parallel cell arrangement is multiplied by a factor equal to the number of cells. In the series-parallel arrangement both the voltage and current capabilities are increased. The series arrangement increases the open-circuit voltage; the parallel arrangement increases the current handling capability. Fig. 7 shows the three possible battery arrangements.

Internal Resistance

More significant than the open-circuit voltage of a cell is the working voltage or the actual voltage developed when the cell is connected to a load. The working voltage is lower than the open-circuit voltage by an amount equal to the voltage drop in the battery. The difference between the open-circuit voltage and the working voltage of a cell is due to internal resistance. This resistance is always present because conventional cell materials are not perfect electrical conductors. The internal resistance increases with use, storage time and with decreasing temperature. Larger cells have lower internal resistance than smaller ones. Table II shows the approximate internal resistance of several sizes of dry cells.

From a practical point of view, the internal resistance may be neglected when the cell is new and operating at a temperature of about 70°F. As the cell ages, if it is operated continuously, or if the temperature drops sharply, the internal resistance rises producing a marked effect on the working voltage.

Connecting the cell to the load produces a current through the load and the cell. Because of the increased internal resistance within the cell, the internal voltage drop across this resistance also increases. When the voltage drop becomes excessive the cell becomes useless. Table III shows the ratio of the operating voltage to the open-circuit voltage at different current drains and temperature conditions for a size C cell.

Capacity

The capacity of a cell is the ability of the cell to maintain its open-circuit voltage under full-load conditions. The capacity of a cell depends on the load, the cutoff or endpoint voltage, the size of the cell, the shelf-life period, discharge cycle, and on the operating and storage temperatures.

Load. The load is the device or equipment to which the cell or battery must deliver power. A cell will deteriorate rapidly if the load requires more power than the cell is designed to supply. On the other hand, a battery used with a load drawing almost negligible current may have a service life almost equal to the battery shelf life.

Cutoff or Endpoint Voltage. Endpoint voltage is the closed-circuit voltage below which the equipment will not operate. For a zinc-carbon cell having an open-circuit voltage of approximately 1.5 volts per cell, the endpoint voltage is usually from about 1.1 volts to 0.75 volts.

Cell Size. The size or volume of a cell determines the current capacity of the battery in which the cell is used. For cells having the same chemical composition, the larger the cell the greater the capacity. Most zinc-carbon and mercury cells have been standardized, with respect to volume, by the American Standards Association (ASA) under the sponsorship of the National Bureau of Standards.

Shelf Life. Shelf life is the length of time that the battery can be stored at room temperature and still retain approximately 90 per cent of its original capacity. All dry cells will deteriorate with time, resulting in a loss in cell capacity even though they are not being used. This loss of capacity is due to the loss of moisture in the cell, and an interaction of some of the material within the cell (local action). As a result, less material is available for useful work and, therefore, the service capacity is reduced. The temperatures at which dry cells and batteries are stored also have a marked effect on shelf life; the lower the temperature, the longer the shelf life. For example, A-size zinc-carbon cells stored for 24 months at 21.1°C retained only 50 per cent of their rated capacity, while cells stored at 7.2°C and 17.8°C retained 70 per cent and 90 per cent, respectively of their rated capacity.

Temperature °F	Cell Type ASA No. C				
	Terminal Volts at Ampere Drains of:				
	Open Circuit	0.03	0.05	0.075	0.15
113	1.57	1.56	1.55	1.54	1.50
70	1.57	1.55	1.53	1.51	1.48
32	1.57	1.51	1.49	1.48	1.43
0	1.57	1.49	1.48	1.46	1.40
—40	0.02	0	0	0	0

Table III—Initial voltages of a "C" type cell, under varying conditions of temperature and current drain.

Discharge Cycle. The discharge cycle is the number of hours the battery is in use during a 24 hour period. In high-drain applications, the service capacity of most cells used two hours a day will be considerably different than that of the same cells used 12 hours a day. This difference occurs because continuous operation does not permit sufficient recovery time for depolarization. The average service hours may be used as a guide in estimating life expectancy. However, these values are average values for large numbers of batteries, and individual batteries may have somewhat different service life. Any change in the discharge cycle will alter the operating life of the battery.

Operating and Storage Temperature. One of the most important factors determining the capacity of a cell or battery is the environmental temperature to which it is subjected during discharge and idle periods. Generally, zinc-carbon cells provide optimum performance at normal room temperature 21°C (70°F) with a decrease in open-circuit voltage of about 0.0004 volt per °C over the temperature range of 25°C (77°F) to —20°C (—4°F). These cells become inoperative at about —30°C (—22°F). Table III shows the results of measurements on a C-size zinc-carbon cell under various temperature conditions.

Mercury cells are less efficient than zinc-carbon cells at low temperatures because of a reduction in the chemical activity of the materials used in the cell. Mercury cells are also better adapted for use at moderately high temperatures than at low ones. Table IV shows the percentage of service capacity available at temperatures from 0°F, where the cell is completely inoperative, to 140°F. The 100 per cent point, in this table, is the capacity of the cell at 70°F.

Table III and Table IV show that dry cells and batteries are most efficient when operated at elevated temperatures. However, the shelf life of cells and batteries is extended when they are stored at lower temperatures, because the chemical reactions which cause deterioration occur at a faster rate at higher temperatures. A test made on zinc-carbon cells, revealed that those stored at 9°C were in better condition at the end of five years than those stored at 40°C after one year.

Tests made at extremely low temperatures indicate that dry cells can be stored at freezing temperatures provided care is taken to avoid moisture condensation on the cells, and provided sufficient time is allowed for the cells to reach room temperature before being placed in service. Excessive moisture will generally destroy the jackets on the cells and increase electrical leakage.

TESTING

The American Standards Association, with the co-operation of dry-cell manufacturers, has established standard methods for testing dry cells and batteries. A proper test should reflect the kind of service in which the cell will be used. Applying the same test to all cells may not give a valid indication of the capacities of the cells. In certain applications, cells which show high-current readings during flash-current tests may not perform as well as other cells which show low-current readings on the same tests.

There are, however, several tests which a user can make to determine the condition of a cell or battery. The simplest of these utilizes a high impedance voltmeter to measure the working voltage in the equipment in which the battery is used. The user must determine the endpoint voltage of the battery in the equipment. A comparison of the endpoint voltage and the working voltage permits an evaluation of the condition of the battery. When large numbers of batteries are to be tested, an external resistor which presents the same load as the equipment may be used.

Zinc Carbon		Mercury	
Temperature °F	(%) of Cell Capacity	Temperature °F	(%) of Cell Capacity
—20	6	0	0
0	27	10	4.5
20	48	20	10
40	69	30	27
60	90	40	58
70	100	50	80
80	115	60	93
100	140	70	100
		80	103
		90	105
		100	106
22.5-volt batteries, F cells discharged through 1250-ohm load.		110	106
		120	105
		130	104
Endpoint = 15 volts		140	103

Table IV—Effect of temperature on the capacity of zinc-carbon and mercury dry cells.

Another method may be used when the load presented by the equipment is not known. This method utilizes a resistor which presents a load drawing one-half of the maximum current recommended by the battery manufacturer.

These tests cannot be used as a measurement of the remaining useful life of a cell or battery because the remaining useful life is affected by additional factors such as storage time and temperature, and previous operating history. However, a comparison of the measured voltage at a specific current drain—with the manufacturer's data for the same current drain—can provide an approximation of the average number of hours of service life at a specific endpoint voltage.

RECHARGING

It is possible to recharge a primary battery, but only for a limited number of cycles and under controlled conditions. To be economically practical, battery recharging should be done on a large scale basis. A zinc-carbon battery, before recharging, must have a working voltage not less than 1 volt. The battery should be charged very soon after removal from service. The ampere-hours of recharge should be 120% to 180% of the ampere-hour discharge and the recharge should take place over a period of 12 to 16 hours. In addition, the battery should be put into service as soon as it has been recharged, since such cells have a very poor shelf life.

SELECTION

The following procedure is a step-by-step method for selecting a battery:

1. Determine the voltage and current requirements of the equipment under load conditions.
2. Determine the endpoint voltage (the lowest closed-circuit voltage which will permit the equipment to operate).
3. Check for the batteries which will meet the voltage and current requirements.
4. Data on battery types includes average service hours for each battery. Average service hours are based on specified current drains and endpoint voltages. In most cases both continuous and intermittent duty data are given.

Because a dry battery is a sealed chemical system, it contains a fixed amount of available energy. Generally, the larger the basic cell, the greater the available energy. Therefore, an increase in cell size can provide higher current capability, longer service life, or both. There are, however, differences between chemical systems. For example, an alkaline cell has a larger current capacity than the same size carbon-zinc or mercury cell, and can provide longer service life at high current drains. Conversely, a mercury cell has longer service life at low current drains than either an alkaline or carbon-zinc cell of the same size.

Several factors in addition to voltage, current, and service requirements must be considered in the selection of a battery type. These factors include size, weight, cost and availability.

The designer should determine the battery type to be used before the "packaging" of the equipment is made final, and should provide adequate space for the batteries. When possible, it is advisable to use commercially available batteries rather than "custom made" batteries. The use of commercially available batteries results in lower initial costs, reduces storage problems, and simplifies replacements.

(With acknowledgements to RCA)

NOISE

By B. J. Simpson

Introduction

In an every-day context, noise generally denotes unpleasant or unwanted sounds. It comes in all sizes, from a dripping tap in the small of the morning to jack-hammers tearing up the road outside. But to the electronic world, the word means something a little different, although still something we would like to be without.

Noise can perhaps be described simply as any disturbance which causes an output from an amplifier or receiver when no signal is applied. The disturbance is generally electrical, but is mechanical in the case of microphonism. With regard to the simple definition just quoted, it is important to remember that the noise will still be present when the signal is actually applied.

It is also important to remember that noise is always present in any electronic circuit, and that we are always amplifying both the wanted signals and the noise which is present. This means that we cannot get rid of the noise by further amplification of the wanted signals, because the noise will be amplified in the same proportion. To the designer of receiving and amplifying equipment, therefore, noise poses a problem and a limitation.

Sources of Noise

Before going further, it will be necessary to examine briefly the sources of this unwanted disturbance in our equipment, and so to draw a picture of the problem. We can start off by dividing the noise into two categories, that which arises in the equipment itself, and that which gets into the equipment from outside sources.

Both of these categories can be further subdivided into two. Internal noise, generated in the equipment itself, may be subdivided into that which is generated in the active devices of the circuit (valves or transistors), and that which is generated in the passive elements of the circuit, such as resistors or inductors. External noise, which is generated outside our equipment, gets into the apparatus through the aerial, mains lead, pickup leads or any similar path, or is directly induced into the circuit. External noise can be subdivided into that which arises out of natural phenomena, and that which is man-made.

Because it is in the area of external noise that the designer is in general able to take only defensive measures against noise, these sources will be discussed first and disposed of before passing on to the internally generated noise.

Natural Noise

Noise arising out of natural phenomena is usually of significance only where receivers are concerned, and is of no consequence to the amplifier designer. This type of noise appears in the main to consist of a series of random impulses, uniformly distributed through the frequency spectrum. It arises from such causes as electrical storms, radio stars, and the activation of portions of the atmosphere by radiation from the sun and other very active bodies in the universe.

Because this type of noise is distributed in an essentially uniform way through any frequency band, the amount of noise energy absorbed by a receiver will be proportional to the frequency range to which the receiver responds. In other words, the noise energy is essentially wide-band, and the energy allowed to enter the receiver will depend on the bandwidth of the receiver. This is a very important fact, which is reiterated in various forms throughout the literature of the electronic art.

Because the designer has no control over the sources of this type of noise, he has to take action to minimise the amount of noise allowed to enter the receiver. His chief weapon has already been hinted at in the preceding remarks, and consists of reducing the bandwidth of the receiver as much as possible, consistent with operational requirements. He can also, in some applications, use electronic noise limiting circuits; it must be remembered, however, that these circuits do not remove the noise, but only mitigate its effect on the intelligibility of the wanted signal. The effectiveness of noise limiters depends on conditions obtaining at the time, the strength of the wanted signal, the nature of the noise present, and other considerations. They do not therefore provide anything like a complete answer.

When the measures mentioned above have been taken, there remains only the remedy of increasing the signal strength by increasing the power output of the transmitter or the efficiency of the aerial systems. For example, directional aerials have commonly been used for point-to-point communication on fixed frequency allocations. As the nature of this type of noise indicates, it usually enters the receiver at the aerial, along with the signal.

Man-made Noise

To the natural phenomena which surround him, man has added countless numbers of noise generators in the shape of rotating electrical machines, radio-frequency processing equipment, welding apparatus, discharge lamps and devices, and a long list of other equipment. Every electrical spark or discharge, every starting and stopping of a current flow, is a source of electrical noise.

Many of these sources are very familiar to us. A radio may click when an adjacent lamp is switched on, or a streak may appear across the TV screen when the refrigerator starts up. Many of the sources have only little energy and their importance is very localised. Many of the sources are suppressed to avoid the emission of large noise signals, but there still remains a large number to be taken into account.

This type of noise generally enters equipment through the power cord, although it can happen that the noise source is sufficiently strong for the noise to be induced directly into the circuitry of the equipment. Measures which are taken are the filtering of the power input lead, and efficient screening of the circuit. In some cases of course, there is also available suppression of the offending motor or other source of noise.

Man-made noise varies considerably in its characteristics, but where it occupies a substantial part of the frequency spectrum, it can enter a receiver through the aerial lead. Hence we see special anti-interference aerial systems to reduce the effect of man-made noise. These aerials usually consist of an active element supported as high and as far from the source of noise as possible. The active element is transformer-coupled to a very low impedance line which is then brought down to the receiver. A further transformer then matches the line to the receiver input circuit. The low impedance line has negligible pickup as it travels through the noisy environment to the receiver.

Very often it happens that man-made noise from a particular source is concentrated largely into one or more discrete bands of frequencies. This is the case that most readily lends itself to noise rejection by filters, either at the offending source, or at the receiver, or both.

Circuit Noise

All resistors possess an inherent noise voltage, sometimes known as "Johnson Noise", which is due to thermal agitation within the component. This is nothing to do with such matters as over-heating or over-running the resistor, and is present at all temperatures down to Absolute Zero. This noise does, however, increase with increasing temperature. There is a small increase in the noise voltage when the resistor is carrying a current.

A further noise component is also introduced as soon as a current is passed through a carbon or metallized resistor; this is known as current noise, or resistance fluctuation noise. It is important to note that this noise component is not uniformly distributed through the frequency spectrum, but rises with increasing frequency. Lower current noise is generated by high stability cracked-carbon resistors, which explains why they are used in critical points in low-level stages of audio amplifiers and similar locations.

Thermal agitation noise increases with increasing resistance values; the increase of noise is very roughly proportional to the square root of the resistance value. When two or more resistors are connected in parallel, the thermal agitation noise is that corresponding to the resultant values of the combination of components. The noise voltage is less when the resistor is shunted by a capacitor, due to the lower impedance of the parallel combination of R and C.

So far in this section we have discussed a resistor as having an inherent noise voltage, but this may be extended to include the resistive components of reactances. In general, and for most practical applications, this may be read as the resistance of any inductors used in the circuit.

This type of noise is held to a minimum where required by the use of high-grade components, operation of components well within ratings to avoid temperature rises, and by the use of circuits having lower impedances.

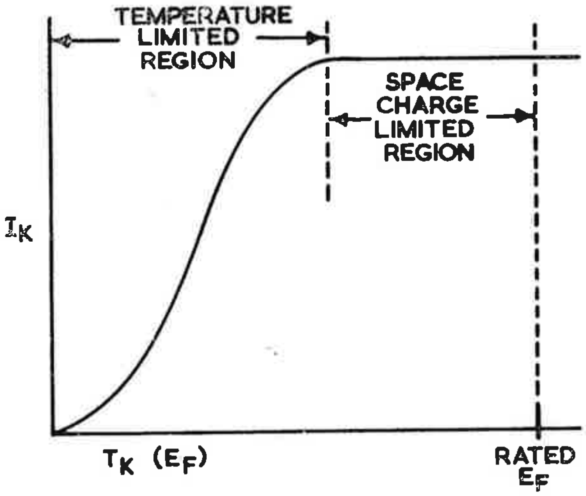


Fig. 1—Cathode current plotted against cathode temperature, with plate voltage constant. The two limiting modes can be seen here, with a sharp rise of current with temperature in the temperature-limited region, and a flattening out in the space-charge limited region.

Device Noise

Every amplifying device we use, whether it be a thermionic valve, transistor or other component, introduces noise as well as gain into the circuit. This is inescapable, and is inherent in the nature of the devices, as will be seen. Not all the sources of noise attributable to thermionic valves are present in semiconductors, whilst the weight given to those noise features which are common to both types of device will vary in each case. The accent here will therefore be on the thermionic valve. Noise sources inherent in the valve will be dealt with in arbitrary order.

Shot Noise

Most readers of electronic publications will be familiar with this term. It is defined as that noise component which is generated by random emission of electrons and their arrival at the anode. When the dc current through a valve is measured, the resultant reading represents an averaging of electron flow over a period of time which is long in relation to the electron transit time in the valve. The meter would have no chance of indicating small fast random changes in the current which are believed to occur in all valves.

The generation of shot noise is closely related to the filament or cathode operating temperature. Other conditions remaining the same, there are two areas in which control of electron flow in a valve is controlled by the cathode temperature. The two areas are shown in Fig. 1. As the temperature of the cathode is raised, cathode current rises as the emission of electrons is increased. This is the temperature-limited region, where the electron flow is related to cathode temperature, that is, to the ability of the cathode to emit electrons. In this region, all electrons which leave the cathode are immediately drawn to the plate.

As the temperature of the plate is increased, a point is reached where the cathode is capable of emitting more electrons than can reach the plate for a given plate voltage. This condition is due to a space charge or "cloud" of electrons which forms in the cathode-to-plate space. This comparatively dense body with a negative charge will then prevent any increase in electron flow to the plate, and the valve is then said to be in the second condition, the space-charge limited region.

As far as shot noise is concerned, this is highest, as one might expect, in the temperature-limited region. This fact is used in special temperature-limited diodes which are used in noise generators. In the space-charge limited region, shot noise is considerably reduced, but is not eliminated. This raises the importance of operating valves within the specified cathode ratings; manufacturers of valves design them so that when used in the recommended way, the valves are always space-charge limited.

Operation of a valve at heater voltages lower than the specified minimum runs the risk of placing the valve in the temperature-limited region, with a consequent increase in noise. Further, as the valve ages, the "knee" between the two regions tends to rise, and the minimum heater voltage needed to put the valve into the space-charge limited region will also tend to rise.

Partition Noise

When the operation of a multi-element valve such as a pentode is considered, one tends to think that the cathode current divides between the screen and the anode in an immutable ratio depending on the operating conditions of the valve. This however is not so. Even under quiescent conditions, the ratio of the currents is subject to small fast random fluctuations, and this gives rise to noise in much the same way as shot noise is generated.

Partition noise is the reason why pentodes and other multi-element valves generally produce higher noise levels than triodes. Partition noise can be minimised by selecting a valve which offers the best ratio of plate current to screen current under the required operating conditions, and/or by using the valve with potentials which offer the most favourable ratio in current division.

Ionization Noise

Ionization occurs in a gas when one or more electrons are removed from atoms of the gas, thus leaving the atoms deficient in electrons. Because electrons are negatively charged particles, this leaves the gas atom with a positive charge. Ions are comparatively heavy particles, and are capable of damaging the valve or cathode ray tube in which they appear.

In the case of valves, ionization is caused by collisions between electrons (forming the cathode current) and any gas atoms that remain in the valve after evacuation. Stringent precautions are taken by valve makers to remove all possible gas from a valve, both by heating and pumping, and by the firing of a getter after sealing off. During the life of a valve, it is possible for gas to appear in various ways, such as the liberation of occluded gases from electrodes due to excessive overloads and heating.

Noise is generated when electrons collide with gas atoms. The liberated electrons join the cathode current flow to the anode, whilst the ions, being positively charged, are attracted to the cathode. In this way the ions with their large mass can bombard the cathode and damage it. Sometimes the grid, with its negative potential, exerts the strongest attraction for the ions, and they travel to the grid instead of the cathode. A similar process can occur in a cathode ray tube, where negative ions can damage the screen.

There are cases where ionization is deliberately encouraged and used, as in the case of "soft" valves like thyratrons, and the obsolescent so-called "cold" rectifiers. In these valves, a current path is formed by deliberate ionization of the gas filling of the valve.

In most cases, ionization noise is of no practical importance. It can become a significant factor in certain applications involving the processing of very low level signals. These applications are usually met by selection of a premium valve type specifically suited to the purpose, and by keeping the dissipation and temperature rise in the valve as low as possible.

Microphonism

To most experimenters, this is a much more familiar source of noise. Unlike other noise sources, it is not due directly to the valve itself, but to mechanical shock or vibration applied to the valve during operation. The mechanical excitation causes relative displacement of the valve electrodes with respect to one another, and so changes the operating conditions. This is particularly easy to detect when an applied vibration has a component corresponding to the natural frequency of some part of the electrode structure; this results in a characteristic "ringing" sound.

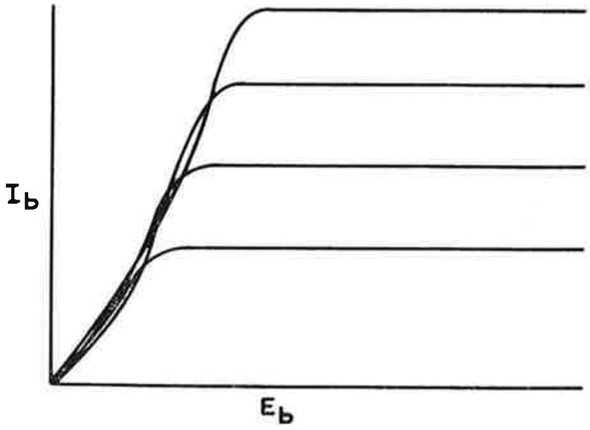


Fig. 2—Family of plate curves showing the crossover points where separate bias curves intersect. Note that these crossover points are all below the "knee" in the characteristics.

Microphony can be considered as of two types, sustained and damped. In the former case, the excitation and the noise output are present all the time. In the latter case, noise results only during and for a short time after the mechanical excitation has been applied.

Sustained microphonism implies mechanical feedback somewhere in the system. Such a case could arise from placing a valve too close to the loudspeaker in a radio, so that the mechanical movement of the cone could be coupled back to the valve. Cases such as this are almost inevitably due to faulty design and layout, and the problem should be susceptible to an easy solution. By its very nature, this type of thing is almost entirely restricted to audio systems.

Damped microphonism is random in nature. The excitation is not continuous, and the noise output ceases almost immediately the excitation is removed. Typical causes can include just about any type of mechanical shock or vibration delivered to the apparatus, such as records falling on an auto-changer, heavy closing of a radiogram lid, severe traffic vibration, and so on.

The reduction of microphonism by correct design has already been mentioned. Other measures are the provision of flexibly-mounted valve sockets, isolation of the speaker from the chassis, anti-vibration mounting of the complete equipment, and similar measures. It must be pointed out that microphonism is not common today, and many of the cases that are seen are due to old or damaged valves. For example, dropping a valve may not break the envelope or stop it operating; it may however loosen the electrode assembly inside. Where operation under severe conditions of shock, vibration and acceleration is required, special valves are available.

HF Noise

Induced high frequency noise only becomes a potential problem at very high and ultra high frequencies, and is therefore of limited interest to the average reader. At the frequencies mentioned, there arises a conductive component of noise, caused by the transit time of the electrons from cathode to anode, and by the introduction of cathode lead inductance into our operating considerations.

The journey of an electron from cathode to anode occupies a finite time. This time is so small in relation to low operating frequencies as to be of no concern. Consider however the condition that arises when, as we increase the operating frequency, the period of oscillation of our signal becomes shorter and shorter. In imagination, we can extend this thought until the transit time and the periodic time become equal, and then as the frequency is increased still further, the transit time gets larger and larger in relation to the periodic time. In practice of course, the valve would long since have ceased to operate in the intended way.

We think of the cathode lead as a short length of wire which merely serves to make a necessary connection. But in elementary text books, we were told that even a very short length of straight wire possesses inductance. That inductance can be large at very high and ultra high frequencies, large enough unless precautions are taken to prevent successful operation of a valve. These are some of the reasons why valves for operation at ultra high frequencies have close electrode spacings and are so constructed that the connections to the electrodes can be made part of a resonant circuit. In more extreme cases, such as the magnetron and the reflex klystron, special measures are taken to reduce the disability of transit time, and the tuned circuit is placed right inside the valve.

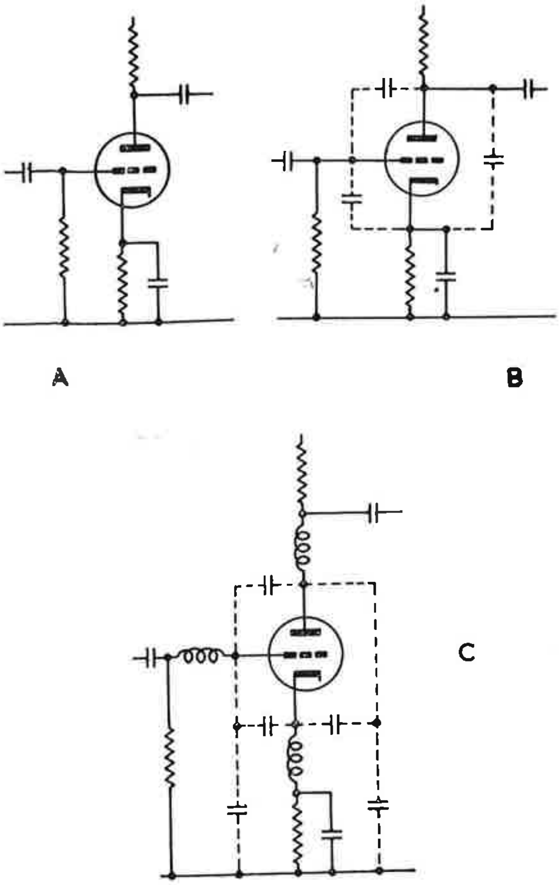


Fig. 3—A simple RC coupled amplifier appears in the circuit in the form seen in (A). In actual fact, it is electrically more like part (B) of the diagram, where the inter-electrode capacitances are drawn in. At very high frequencies, the circuit could in fact be as shown in part (C), where the lead inductances also are shown. Whilst such a simple circuit would in fact hardly be used at very high frequencies, this simple illustration portrays some of the problems that do not appear on the circuit diagram.

The foregoing digression was necessary to complete the picture for those who have not had the opportunity of using valves at very high frequencies. The fact remains that the transit time and the cathode lead inductance cause a high frequency noise component to be induced into the grid, and so to modulate the electron stream. These high frequency components vary as the square of the frequency.

Crossover Noise

Radiated noise may result from rf noise generated inside a valve that is operated in a region of the plate family curves that shows crossover, as shown in Fig. 2. Two or more bias traces intersect at the crossover points, which are bistable, as they indicate one value of plate current for two or more values of bias. These crossover points will of course always be restricted to those areas below the "knee" in the plate current characteristic.

As the path of operation of a valve passes through one of these points, abrupt changes in plate current will occur. These abrupt changes may result in the generation of noise and parasitic oscillations. This rf disturbance may be radiated into the earlier parts of the equipment, amplified and processed, and finally appear at the output. In very severe cases, the discontinuities in the plate current will cause noise sufficient to be heard in the output without the necessity for radiation and further amplification. The obvious means of overcoming or avoiding this type of noise is to make sure that the operating conditions are so set up that the dynamic load line does not pass through any crossover areas.

Envelope Bombardment

In power output valves, where high values of plate current flow, it is not always possible to ensure that all the electrons remain within the area of the electrodes and complete a substantially direct journey from one to the other. Some electrons travel past the electrodes and strike the glass envelope. This produces varying charges on the walls of the envelope, resulting in the radiation of a noise signal.

Precautions are taken by valve manufacturers to ensure that this type of thing is minimised, because apart from the question of noise, this feature is undesirable from an efficiency point of view. Even where this type of radiation occurs, it is often of no practical concern unless the layout or design of the equipment allows the radiated signal to be picked up and amplified in the way described above for radiated types of noise. From the practical point of view therefore, this is a very rare type of trouble.

Barkhausen Oscillations

To those who had not met them before, Barkhausen oscillations came to mean something during the early days of television. In that case, radiation was caused from the horizontal output valve. During a portion of the operating cycle, the plate goes negative with respect to the screen grid. Any electrons in transit at that time between the screen grid and the plate would find the electrostatic field in which they were moving suddenly reversed, and would tend to turn back towards the screen. Very shortly the plate runs positive again and the condition is reversed once more. This sets up an oscillatory condition in the vicinity of the beam-forming plates of the valve.

This oscillation could be picked up at the input of the set, or at some other point in the circuitry. Advancing techniques and designs of valves have sent this particular trouble into the limbo of forgotten things, at least as far as TV is concerned. From a practical point of view, this source of noise would be very rare in any type of application.

Hum

One of the most potent and common sources of noise in electronic equipment is hum, particularly in high-gain low-level stages handling audio frequencies. So much has been written on the subject that it seems almost superfluous to say more. One thing that can perhaps be said with some degree of justification is that in spite of the weight of opinion brought to bear on it, the problem is still with us.

Most people are familiar with the many ways in which hum can intrude into a circuit, and with the classic measures taken against it. Further, the whole subject of hum could well merit a complete article to itself. Suffice it to say here that careful attention to the basic rules will eliminate hum as a trouble from most units. In cases where requirements are severe, special or premium valves are available, with double-helical heaters, and specifically tested for low hum and

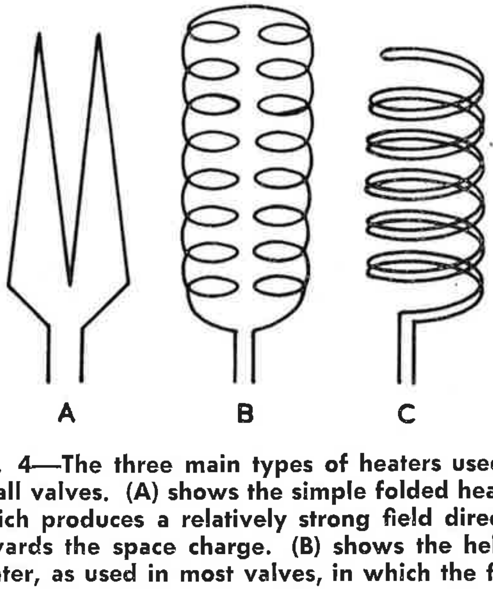


Fig. 4—The three main types of heaters used in small valves. (A) shows the simple folded heater, which produces a relatively strong field directed towards the space charge. (B) shows the helical heater, as used in most valves, in which the field is concentrated largely within the toroid. (C) shows the double-helical heater, as used in hifi and other premium valves, in which adjacent strands carry currents in opposite directions, thus cancelling field effects.

noise. Typical of these is the 7025, a high fidelity version of the 12AX7. The 7025 has an equivalent hum and noise voltage, referred to the grid, of an average value of 1.8 microvolts rms.

Parasitics

Parasitics, or parasitic oscillations, to use what is perhaps a better term, are due to the unintentional formation in the circuit of a resonant circuit. This circuit then becomes excited, possibly by the varying signal currents which are flowing, possibly by transients in the signal train, by switching pulses, and so on.

Frequently it is found that parasitic oscillations are the result of using valves beyond their ratings, overdriving them or otherwise overloading them. This is not the sort of pitfall into which the experienced builder would fall, and the use of modern valves has helped considerably in the reduction of the incidence of this type of trouble.

It is sometimes difficult to see how quite high frequency oscillations can be generated in an audio circuit. Every laboratory has had experience with audio amplifiers displaying either damped or continuous oscillation at frequencies sometimes of the order of hundreds of kilocycles. Typical of the way in which resonant circuits can be formed are avoidable loops in wiring, a choke resonating with its own self capacity and strays, a circuit outside a valve resonating with the inter-electrode capacitances, and many more.

This shows that even in audio work, care must be taken and checks made that parasitic oscillations are not present. The examination of any audio power amplifier should always include a check on this point right up through the supersonic region to 100 kilocycles, or further if necessary.

Summary

From the foregoing it may appear that the problem of noise is very great. In the more common applications, this would hardly be true, but it becomes a major problem in the more specialised fields. It must however be remembered always that whether the equipment be simple or complex, noise is always the limitation in the minimum usable signal that the apparatus can handle. Reflection will show that unless the signal level at the input of an amplifier is greater than the equivalent noise voltage referred to the input grid, then the signal cannot be successfully processed. The lower the signal level that has to be handled, the greater the problem.

It is also important to note that, at least in cases where the input signal voltage is not very large with respect to the equivalent noise voltage at the input grid, then the signal-to-noise figure which will be obtained will vary with the input signal level, the noise remaining substantially constant. The signal-to-noise ratio quoted for a preamplifier therefore needs qualification by the input signal voltage, which is usually the normal input level quoted for the unit.

One more point to remember is that in general, there is only one stage to worry about as far as noise is concerned, and that is the first stage. Here the noise level, having been reduced as far as possible by circuit techniques, becomes fixed, and at the rated signal input level, the ratio of signal to noise is now fixed. Both signal and noise will now by amplified right through the amplifier. Stages subsequent to the first will in general make little or no contribution to the noise level, as by the time the signal reaches them, it has already been amplified so far beyond the level of later-stage noise as to be of no consequence.

Editor .... **Bernard J. Simpson**

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