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The Selection of Suitable Resistors for Power Supply Equipment

By the Engineering Department, Aerovox Wireless Corp.

THE selection of the proper resistor to use for any given condition in a circuit is a comparatively simple matter once a few fundamental relations are clearly understood.

The proper value of resistance to use depends on the voltage drop which is required in any particular part of a circuit and this value can very easily be calculated by using the simple formula known as Ohm's Law.

The proper type of resistor to use of any given resistance depends on the current which must be carried by the resistor. Resistors are therefore described in terms of their resistance value and the amount of current in amperes or milliamperes they will carry without undue heating. The rating of a resistor may also be given in the number of watts which the resistor is capable of dissipating under any given conditions of temperature rise.

The current carrying capacity or watt rating of a resistor is a very variable factor which depends on the temperature rise which can be permitted in the operation of the resistor.

The watt rating of a resistor is equal to the square of the current carrying capacity in amperes multiplied by the resistance of the unit. The formula used is shown in Fig. 1, in which "W" is watts, "I" is the current carrying capacity of the resister in amperes and "R" is the resistance of the unit. It is easy to see that if the resistance unit and its current carrying capacity are known the watt rating can easily be determined. Similarly if the watt rating of the resistor and its resistance are known, the current carrying capacity of the unit can be determined by substitution in the formula.

$$W = I^2 R$$

Fig. 1

The maximum current and watt ratings of a resistor are based on the current flow which will produce a temperature of 250 degrees Centigrade or 482 degrees Fahrenheit at the hottest point of the resistor when surrounded by at least one foot of free air space with the temperature of the room or enclosure not higher than 20 degrees C. or 68 degrees F.

To take a concrete instance let us assume that we have a resistor of 500 ohms and rated at 20 watts or .2 amperes (200 milliamperes) carrying capacity. These values of resistance, watt rating and current carrying capacity are all interrelated.

These ratings however are not practical for ordinary use because they are based on the operation of the resistor at an excessive temperature rise and under ideal conditions of ventilation. The operation of a resistor at such high temperatures will not damage the resistor but may seriously damage apparatus placed in its immediate vicinity.

For all practical conditions therefore, it is necessary to operate the resistor at much lower than its maximum rating. With fairly good ventilation, using the resistor near apparatus where a temperature of approximately 100 degrees Centigrade or 212 degrees Fahrenheit is not likely to do damage to such apparatus it is possible to operate a resistance at approximately 70% of its maximum current rating which is equivalent to approximately 50% of its watt rating. The reason for this difference in percentages is due to the characteristics of the components of the formula shown in Fig. 1.

Where the resistor is used in close proximity to condensers or other units which are likely to be damaged by the heat developed by the resistor at such temperatures, or where the resistor is used in very poorly ventilated places, it is recommended that a greater margin of safety be employed. In such cases the use of the resistor at 50% of its current rating (25% of its watt rating) is recommended. The use of the resistor at this conservative rating will result in cool operation of the resistor and will reduce to a minimum the possibility of damage to the resistor and to other parts.

To understand the procedure necessary to select the proper resistors for any given requirement, we will consider a concrete instance of the voltage divider network of a receiver and amplifier which employs two CX-350 tubes with a plate voltage of 400 volts, three C-324 tubes with a plate voltage of 180 volts, a C-327 tube with a plate voltage of 90 volts and a C-327 tube with a plate voltage of 45 volts.

The current drawn by the two CX-350 tubes will be 110 milliamperes; that drawn by the C-324 tubes will be 12 milliamperes; that drawn by the C-327 at 90 volts will be 3 milliamperes and that drawn by the C-327 tube at 45 volts as a detector will be 2 milliamperes, making a total load of 127 milliamperes. If we allow 10 milliamperes as a bleeder current, the total load will amount to 137 milliamperes. The filter and voltage divider system for such a receiver are shown in Fig. 2.

If the power transformer and filter sytem have been properly designed for this receiver, we should have a voltage output of 470 volts D.C. measured at the output of the filter (between points "A" and "B") at a current drain of 137 milliamperes. This will allow 400 volts for the plates of the CX-350 tubes and 70 volts grid bias for the CX-350 tubes.

If the transformer and filter circuit is not properly designed, the voltage across the output of the filter may be lower or higher than the required voltage at the desired load of 137 milliamperes.

If it is lower, the power supply unit will not be suitable. If the output voltage is higher than that required, it may be reduced at the output by introducing a suitable resistor either at point "X" or "Y".

Since any resistor introduced at point "X" or "Y" must carry the full output current, the current carrying capacity or watt rating of the resistor should be sufficient to meet the requirements imposed.

If we assume for the sake of illustration that the output voltage at a current drain of 137 milliamperes measures 550 volts instead of the required 470, the difference of 80 volts must be obtained by using a resistor of 80 (volts) divided by .137 (amperes) or approximately 584 ohms. The resistor necessary would have to be a 584 ohm resistor capable of carrying 137 milliamperes without undue heating. The required watt rating can be found either by multiplying the voltage drop across the resistor (80 volts) by the current in amperes passing through the resistor (.137 amperes) which equals 10.96 watts or by multiplying the square of the current in amperes (.137 x .137 or .018) by the resistance (584) which equals 10.96 watts.

If the output voltage at the required current were 600 volts or 130 volts more than required, the resistance required at "X" or "Y" would be 130 divided by .137 or 948 ohms. This resistor would have to pass 137 milliamperes. Its watt rating however would have to be higher because of the higher resistance of the unit. The value would be .137 x .137 x 948 or 17.06 watts. It is easy to see from this illustration how the watt rating is affected by difference in resistance even when the current through the unit remains the same and explains why any series of resistors of the same watt rating but of different resistance values will have different current carrying capacities, the lower resistance units having bigger current carrying capacities than the higher resistance units.

Since most manufacturers of resistors give maximum ratings on their resistors, it is important from the standpoint of safety that a resistor be selected whose watt rating is twice that of the calculated value if excessive heat in the unit is undesirable. As a matter of fact, a better plan is to select a resistor whose maximum watt rating is four times that of the calculated value. If this is done no trouble will be experienced with excessive heating and possible damage to nearby apparatus.

When stated in terms of current carrying capacity, the percentages for safety will not be the same as those given for watt ratings. The reason for this, as already mentioned is due to the characteristics of the equation for obtaining the watts dissipation when the current and resistance are known. A simple example will show this clearly. The watts dissipation in a 500 ohm resistor passing 100 milliamperes (.1 ampere) is 5 watts. To be on the safe side a resistor having a watt rating four times that which will be dissipated should be used. In this case then, a 20 watt resistor would be used.

The maximum current which such a resistor of 500 ohms would carry (as rated by resistor manufacturers) would be the square root of (20 divided by 500) or .2 amperes (200 milliamperes).

It is easy to see therefore that while the maximum watt rating of the resistor selected is four times or 400 percent of the calculated value, the maximum current carrying capacity of the resistor selected need be only twice or 200 percent of the calculated value.

In other words a resistor which is listed by the manufacturer at the maximum allowable current carrying capacity and watt ratings should never be used at more than 25 percent of the maximum watt rating or 50 percent of the maximum current carrying capacity rating when the resistor is to be used in a confined space such as a receiver, amplifier or power supply unit where ventilation is poor and excessive heat is likely to injure surrounding pieces of apparatus.

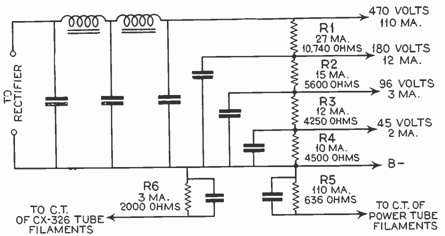

Fig. 2

The ratings of the resistors used in the voltage divider can easily be figured on the same basis. If we consult Fig. 2 we will find that 110 milliamperes is drawn at the 470 volt tap (470 minus 70 for grid bias leaves 400 volts for the plates of the amplifier tubes). The remainder of the 137 milliamperes or 27 milliamperes flows through resistor "R1". The value of this resistor to produce the required drop to 180 volts at a current of 27 milliamperes, is 10,740 ohms. The watts dissipated in this section will therefore be 7.83 watts. The resistor used in this section of the voltage divider should therefore be one whose maximum watt rating is 31.32 watts or which is capable of carrying a maximum current of 54 milliamperes.

At the 180-volt tap, 12 milliamperes are drawn off and the remainder or 15 milliamperes flows through section "R2". This resistor, being a 5600 ohm resistor to produce the required voltage drop from 180 to 96 volts, will dissipate 1.26 watts. A resistor rated at 5.04 watts or 30 milliamperes will be sufficient for this section.

In the same manner it will be found that a resistor with a maximum rating of 2.45 watts or 24 milliamperes will be suitable for section "R3" and one rated at 1.8 watts or 20 milliamperes will be suitable at "R4". Of course standard resistors of higher ratings can be used with perfect safety.

When we come to the grid bias resistors, it must be remembered that the grid bias resistor must carry all the plate current of the tubes for which it acts as the grid bias resistor. Resistor "R5" for instance, used as the grid bias resistor for the two CX-350 tubes will be called upon to carry the plate current of these two tubes or a total of 110 milliamperes. The watts dissipated in this resistor, 636 ohms, will be 7.7 watts. A resistor should therefore be used which has a maximum watt rating of 30.8 watts. A 30 watt resistor would of course be suitable.

The rating of the 2,000 ohm resistor "R6" which provides a grid bias of 6 volts for the first stage audio tube and carries .003 ampere can be determined in the same way. The current passing through this unit would be 3 milliamperes so that a unit having a current carrying capacity of 6 milliamperes would be sufficient. The energy dissipated in the resistor will be .018 watts so that a .072 watt resistor would be sufficient for this unit.

If these factors are taken into consideration in the design of voltage dividers and in the use of resistors generally it will often be found possible to use lower rating resistors where higher ratings are now being used. On the other hand it may be found that resistors of insufficient current carrying capacity are being used in places where higher current carrying capacities are required.

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Manufacturing limitations of course must be considered in specifying resistors for voltage dividers. While the maximum watt ratings required for section "R4" may only be 1.8 watts it is impractical to use an exceedingly fine wire to wind a resistance to fulfill those conditions. A larger wire is therefore used which may give a rating of 10 watts at the maximum current which the unit will carry and therefore result in a very high safety factor for the section.

The number of taps required on a resistor wound on a given size of tube will also affect the watt rating or current carrying capacity of the resistor. The space taken up by the taps reduce the available winding space on the resistor and thereby make it necessary to use a smaller wire to obtain the same total resistance. The use of the smaller wire naturally reduces current carrying capacity of the resistance for any given allowable temperature rise and of course the reduction in current carrying capacity reduces the watt rating of the resistor.

In ordering tapped resistors therefore it is necessary to specify the resistance of each section and the current carrying capacity required in the section. Where space limitations are to be imposed, such as the maximum length or maximum diameter of the resistor tube, some balance must be arrived at as regards length and diameter of winding to permit the use of the required size of wire to give the necessary resistance, current carrying capacity and dissipating characteristics. It is also advisable to state in what manner the resistor is to be used and give a layout of the assembly showing the location of other pieces of apparatus which might be affected by the temperature developed in the resistor at any given load. In connecting several resistors in series to get a higher resistance, the current carrying capacities of the resistors must be considered.

Current and Watt Ratings of Series Resistors

The first step in selecting a resistor is to determine whether it will carry the current which is to be passed through it, without heating up excessively.

If a high enough resistance of the required current carrying capacity cannot be obtained, it is possible to connect up two or more resistors of the required current carrying capacity to obtain the desired high resistance with the necessary current carrying capacity.

If for instance a 200 watt, 5,000 ohm resistance capable of carrying a current of 200 milliamperes is required and no single unit of that rating is available, two 100 watt, 2,500 ohm resistors connected in series can be used since the 100 watt, 2,500 ohm resistor is capable of carrying a current of 200 milliamperes.

The same object could be obtained by using a 2,000 ohm resistance capable of carrying 200 milliamperes in series with a 3,000 ohm resistance capable of carrying 200 milliamperes. In this case the 2,000 ohm resistance would be rated at 80 watts and the 3,000 ohm resistance would be rated at 120 watts. The total resistance would be 5,000 ohms and the watt rating of the 5,000 ohm resistor would be 200 watts.

In making up the total resistance, all that is necessary is to determine the current carrying capacity required and then connect together several resistors of the required current carrying capacity whose total resistance equals the required resistance.