SECTION 2

ADVANCED
PRACTICAL
RADIO ENGINEERING

TECHNICAL ASSIGNMENT

LINE TERMINAL AND INPUT EQUIPMENT

Capitol Radio Engineering Institute
Washington, D. C.

244E

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LINE TERMINAL AND INPUT EQUIPMENT

LINE TERMINAL INPUT EQUIPMENT

RCA Supervisory Console

Gates SA Line Equalizer

INTRODUCTION.—Among the most important elements in a broadcasting system in the chain of apparatus between the microphone and the receiver are the speech control units and the telephone line terminal equipment. This is true whether it is a chain program involving hundreds or thousands of miles of telephone circuits or a local program in which only very short lines are involved.

In the process of transmitting the average program signal from the microphone, where the sound waves are converted into electrical impulses, to the radio transmitter where these signal voltages modulate a radio frequency carrier, the signal is ordinarily amplified and attenuated a number of times. In each of these steps there is a tendency for some frequencies to be amplified or attenuated out of proportion to other frequencies. For example, when a program signal is transmitted over a long telephone circuit two major effects occur: first, the signal is attenuated due to the losses in the line; second, the high frequencies are attenuated to a greater extent than are the lower frequencies because of the short-circuiting effect of the line capacity which increases with frequency. Both of these effects must be compensated for. To compensate for the undue loss of the higher frequencies a 'line equalizer' is employed to introduce low frequency attenuation which in turn will flatten the general attenuation curve. To compensate for the attenuation due to line loss a sufficient amount of amplification is employed to bring the signal up to the desired level.

Very often, particularly where a temporary line is used for a remote pickup, considerable line noise will be encountered. Where such a line must be used it is customary to place the signal on the sending end of the line at a higher than normal level. If the signal level is sufficiently high it will over-ride the line noise. At the receiving end an 'attenuation pad' is inserted ahead of the speech input equipment. The pad attenuates the signal to the desired level, at the same time attenuating the noise in the same proportion, and since the signal was placed on the line at a level sufficient to over-ride the line noise, when both are attenuated sufficiently the noise level should not be objectable. In this connection, the telephone company usually specifies a limit of 2 db on the signal level that can be delivered to the line in order that cross-talk and amplifier overloading do not occur.

Each amplifier unit in the program chain must contain a volume control, usually variable in steps of 1 or 2 db each and ordinarily allowing a variation in gain of about 20 db. This is necessary to accommodate the variations in signal level which may be encountered in practice.

In the control of a broadcast program a mixing panel is essential in order that several microphones may be used to provide proper pickup of musical instruments, singer, speaker, etc. The mixing panel must allow the variation of gain or attenuation of the output of each microphone and proper mixing in any desired combination without disturbing the impedance relations of the circuit.

The following discussion will consider attenuation pads, volume controls, line equalizers and mixers, as well as the use of calculations involving the decibel as a unit of power and program signal level.

THE TRANSMISSION UNIT.—In all broadcast or telephone work volume is considered as it affects the human ear, thus it is logical to use a measuring unit that bears a relation to the sensitivity of the human ear. Telephone engineers have worked out such a unit known as the transmission unit, originally abbreviated TU. This unit is now known as the Decibel, abbreviated 'DB'. The prefix Deci signified tenth; Bel was selected in honor of Alexander Graham Bell. The name decibel has been selected as the international designation of the transmission unit.

It is just possible for the ear to distinguish the difference between the sounds produced by two power levels that differ in intensity by one DB. *The transmission unit is defined as ten times the common logarithm of the RATIO between any two powers, or twenty times the logarithm of the ratios of the two voltages or currents in equal impedances.* It is expressed mathmatically as follows:

$$db = 10Log_{10} \frac{P_1}{P_2}$$

$$db = 20Log_{10} \frac{E_1}{E_2}$$

$$db = 20Log_{10} \frac{I_1}{I_2}$$

TABE I

POWER RATIO	TRANSMISSION UNIT IN db
1 = (10^0)	0 = $(10Log_{10} 1)$
1.259 = $(10^{.1}$	1 = $(10Log_{10} 1.259)$
10. = (10^1)	10 = $(10Log_{10} 10)$
100. = (10^2)	20 = $(10Log_{10} 100)$
1000. = (10^3)	30 = $(10Log_{10} 1000)$

VOLTAGE OR CURRENT RATIO	TRANSMISSION UNIT IN db
0.001	-60.00
0.005	-46.02
0.01	-40.00
0.05	-26.02
0.1	-20.00
0.2	-13.98
0.5	- 6.02
1.0	0.00
1.5	3.52
2.	6.02
5.	13.98
10.	20.00
20.	26.02
50.	33.98
100.	40.00
500.	53.98
1000.	60.00

Consider two audio frequency amplifiers whose power outputs are 800 and 1,000 milliwatts, respectively. It would appear that the output of 1,000 milliwatts would give a considerable increase in sound volume over that of 800 milliwatts. However, this difference could hardly be detected by the ear.

From the above equation expressing db, the ratio of the two powers is:

$$\frac{1{,}000 \text{ milliwatts}}{800} = 1.25$$

A table of logarithms shows that the log of 1.25 is .097. Using this value in the equation for the transmission unit:

$$db = 10 \times .097$$

$$db = .97$$

Since this is slightly less than one db the difference in signal level will be practically unnoticeable.

Table I gives the numerical values of power, voltage and current ratios corresponding to particular values of the transmission unit.

Energy level, expressed in db, refers to signal intensity or volume at a given point and time and is based upon an adopted standard of zero level in db as being a power of 6 mw. A zero db power level will be represented by 1.73 volts across a standard 500 ohm telephone line or across any 500 ohm impedance.

In order that there may be no confusion it should be noted at this point that while .006 watt is used as the standard zero db power level by the telephone company, in broadcasting for a number of years a zero db level of .0125 watt has been taken as standard. This represents 2.5 volts across a 500 ohm impedance. The .006 watt zero level is based upon the average value of human speech, while the .0125 watt zero level is based upon 'peak' value. The peak value is particularly important in broadcasting because it is excessive peak values which overmodulate transmitters with accompanying distortion.

NEW VOLUME INDICATOR AND REFERENCE LEVEL.—It will be observed from the above that two different zero reference levels have been in common use by the telephone and broadcasting companies. In addition to this there have been in general use a number of different types of volume indicators differing in characteristics as : r.m.s. or peak reading; slow, medium or high speed; half or full-wave rectifying; critically or lightly damped; several reference power levels in different values of resistance. These differences have led to confusion and misunderstanding throughout the communication industry, particularly when it became necessary to correlate measurements and data from the various communication groups. This situation resulted in an agreement by the Bell Telephone Laboratories, the Columbia Broadcasting System and the National Broadcasting Company, after many conferences and tests, on a distinctly new volume indicator and a new zero reference level. The new indicator and reference level were discussed at a number of conferences with other broadcasting organizations; the agreement between the three companies was announced in December, 1938; the new instrument and reference level were adopted May 1, 1939. Since then there has been widespread adoption of the new standards throughout the broadcasting industry.

The new standard reference level was announced as follows:

Zero or reference volume level shall be defined by specifying (A) the characteristics and method of use of the volume indicator instrument, and (B) a steady state reference of 1 milliwatt. The impedance of the circuit across which the instrument is calibrated shall be 600 ohms. The characteristics of the instrument as well as the value of the calibrating power are important features of the definition.

In order to avoid the more cumbersome term "db above zero volume level" and confusion with several existing standards it is proposed to designate the readings of the new instrument as so many "VU", numerically equal to the number of db above the reference volume level.

In considering the above, it first should be realized that this new term 'VU' does not violate the established system of db calculations and measurements, but rather, adds to that system. The decibel has always been used in two different manners: first, as a relative indication of difference between two power or voltage levels; second, as an absolute level of power *with respect to an accepted zero reference level.*

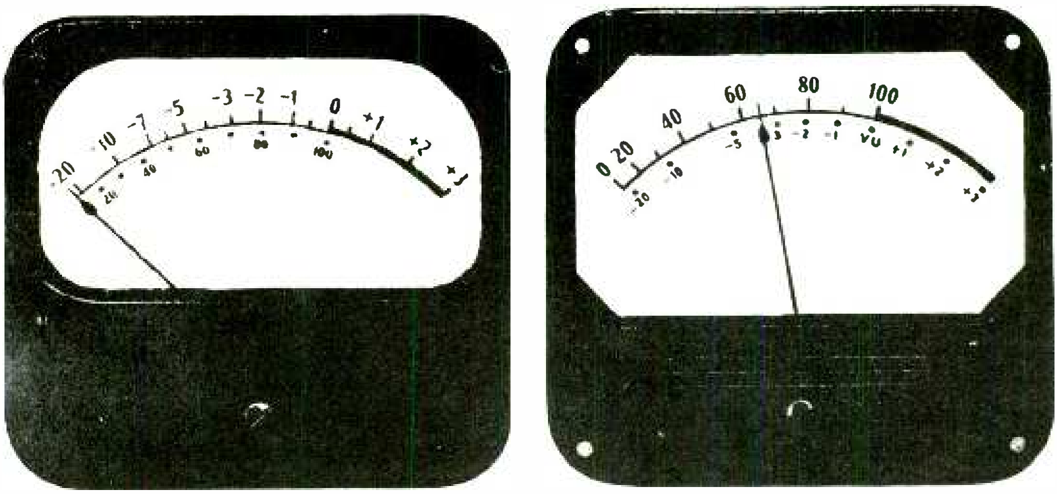
It is in the second use that the new standard introduces a change, but this change refers only to the reference level used. For example, if an absolute level of power is expressed as 4 db, it is understood that this represents power amplitude of 4 db above a reference level of 6 milliwatts. If an absolute level of signal volume is expressed as 4 VU, it is understood that *this represents a volume level 4 db above the reference level of 1 milliwatt. The only factor that has been changed in going from one term to the other is the reference level.* Of course an absolute signal level of 4 VU is different than an absolute signal level of 4 db because the two are computed from different zero reference levels. However in each case the actual signal level will be 4 db above the respective reference level.

As stated above, 'The characteristics of the instrument as well as the value of the calibrating power are important features of the definition.' These characteristics are as follows:

1. The instrument employs a full-wave, copper-oxide rectifier contained within the meter case.
2. The ballistic characteristic is such that the sudden application of a single frequency voltage of such value as to give a steady reading at 0 VU or 100 mark will cause the pointer to overswing by 1 to 1-1/2 per cent (0.1 to 0.15 VU). The pointer speed is such that under the same conditions, a deflection of 99 per cent of the steady state value is reached 0.3 second after the sudden application of the single frequency voltage.
3. The scale card is a cream yellow and has markings in black and red. Two scale types are available.
4. The meter sensitivity is uniform to within 0.2 db of the 100 c.p.s. value over the frequency range from 35 to 10,000 c.p.s. and within 0.5 db over the range from 25 to 16,000 c.p.s.
5. The instrument is capable of withstanding, for at least 0.5

second without injury or effect on calibration, voltage peaks of ten times the value equivalent to a reading of 100 per cent or zero VU. It is capable of withstanding a continuous overload of five times the 100 per cent or zero VU voltage.

Fig. 1 illustrates the new volume indicator and the two types of scales that are available, one being preferred by the Bell System, the other by the two broadcasting companies.



Type A scale, preferred by the Bell System, is intended for use in program transmission. The illustration is approximately three-fourths full size. Scales are from Weston type 30 volume indicator

Type B scale, preferred by NBC and CBS is intended for program production and transmission applications. Meter case is 4¼ in. wide and 4 in. high

Fig. 1.—Showing two types of volume indicators.

The instrument itself has an impedance of 3,900 ohms and *must* be used in series with an external resistance of 3,600 ohms in order to have the required ballistic characteristics. *The instrument with the series resistance has a sensitivity such that the pointer is deflected to the 0 VU or 100 mark on either program material or single frequency power having a volume level of +4 VU.* For reading high signal levels a variable 3,900 ohm attenuator may be iserted between the meter and the external resistance to decrease the meter sensitivity. This is shown in Fig. 2. The meter is of the r.m.s. type.

It particularly should be emphasized that an expression of signal level in VU implies a measurement of absolute level and indicates that the measurement was made with the new type of meter. This is considered important because it permits a comparison of volume levels at different points along a long telephone circuit with the assurance that the measurements are made under identical conditions. Most earlier types of volume indicators will not give corresponding readings on program material, even though recalibrated to a reference level of 1 milliwatt.

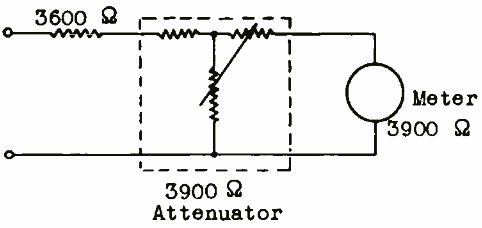


Fig. 2.—Attenuator to control sensitivity of meter.

IMPEDANCE MATCHING.—In the study of energy transfer it is constantly emphasized that the maximum power transfer is accomplished when the impedances of the output and input equipment are equal; in telephone circuits this relation must exist between the line itself and the terminal equipment. A 500 ohm telephone line should operate into a terminal impedance of 500 ohms; this same telephone line should be fed from an input impedance of 500 ohms.

In the study of high frequency antennas it is shown that energy can be reflected back along a circuit under certain conditions. Similar conditions exist in a long telephone line. If the terminal impedance does not equal the characteristic or surge impedance of the line, signal energy will be reflected back along the line. Proper termination eliminates the reflection. Since the engineer is vitally interested in transmission fidelity, he will appreciate the seriousness of the distortion that would be produced by a signal reflection component imposed on the following signal voltages.

To minimize energy reflection it is necessary to terminate the telephone line with the proper impedance. At the same time it is often desirable to use equipment the input impedance of which does not equal the line impedance; for example, the input impedance of the terminal equipment may be 200 ohms and the telephone line impedance 500 ohms. The solution is to couple the line to the apparatus by means of a transformer. The primary of the transformer connected to the line should have an effective impedance of 500 ohms and the turns ratio between the primary and secondary should equal.

$$\sqrt{Z_p/Z_s} = \sqrt{500/200} = 1.58$$

in order to properly couple the two impedances.

It is well at this point to see under what conditions the surge impedance of the line itself must be considered. The surge impedance, reflection and standing waves along a line are important only when the line is quite long, that is, approaching one-quarter wavelength at the highest frequencies to be considered. Ordinary good telephone lines used in broadcasting are equalized to 5,000 cycles, although there are some that will handle 8,000 cycles. The wavelength is equal to velocity/frequency. Assuming a propagation velocity equal to that in space (which of course is considerably too high) and upper frequency limit of 10,000 cycles (which is higher than will be transmitted), $\lambda = 300{,}000{,}000/10{,}000 = 30{,}000$

meters and one-quarter wavelength is 7,500 meters, or a little more than four miles. At the lower frequencies a quarter wavelength is still longer, even though the velocity of propagation along a wire is considerably slower than in space.

It is evident from this that at audio frequencies the surge impedance of a line a few hundred feet long—or even a mile or two—connecting two pieces of apparatus, ordinarily need not be considered. However an impedance consideration is still present. A short line will simply connect two pieces of apparatus together and it is essential that the two ends of the line be terminated by equal impedances. That is, the output impedance of one piece of apparatus must be matched by the input impedance of the following apparatus which may be a few inches, a few feet, or a few hundred yards distant.

Similar problems exist in studio equipment. The ordinary mixing control may be designed to operate across a 50 ohm transformer winding; the microphone used in broadcast work usually has an output impedance of 200 ohms. To feed the signal voltage from the microphone into the mixing panel a transformer having a 200 ohm primary and a primary to secondary turns ratio of

$$\sqrt{200/50}$$

should be used. In this connection it should be observed that a turns ratio of

$$\sqrt{200/50} = 2.$$

Thus the secondary will have 1/2 as many turns as the primary and its inductance will be reduced to 1/4 as will its reactance, so that if Z_p = 200 ohms, Z_s will equal 50 ohms. In case it is desired to feed a 500 ohm telephone line into this same mixing panel the transformer should have a 500 ohm primary and the proper turns ratio,

$$\sqrt{500/50} = 3.16$$

Very often it is desired to attenuate the signal voltage from the line before transferring it to the input amplifier. Assume it is necessary to decrease the signal by 20 db. Assume that the line impedance is 500 ohms and the amplifier input impedance is 200 ohms. The proper method of handling such a problem is shown in Fig. 3.

Transformer primaries and secondaries are commonly spoken of as having certain impedances. Of course the impedance of any such winding will vary with frequency. It is customary to measure audio transformer impedances at 1,000 cycles, so that a 200 ohm winding will have an impedance of 200 ohms at 1,000 cycles, a higher impedance at a higher frequency, etc.

In Fig. 3, the signal is shown as received from a 500 ohm telephone line which is terminated by a 500 ohm transformer winding; passed by mutual inductance into a 200 ohm secondary winding; delivered to the input terminals of a 20 db attenuation pad which is designed to connect between two 200 ohm circuits; decreased in level 20 db and then delivered to the input terminals of the amplifier, the input impedance of which is 200 ohms. Impedance matching transformers with tapped primaries and secondaries may be obtained. With such a combination the impedance characteristics of two pieces of equipment or of two lines can be quickly matched.

THE ATTENUATION PAD.—An Attenuation pad is sometimes called an 'artificial line', a 'network', a 'line pad', or simply an 'attenuator.' It consists of a combination of resistors so arranged that the desired ratio of the signal level leaving the pad to the signal level entering the pad can be predetermined and the necessary losses calculated. An important factor in pad design is the impedance which the pad represents to the line. It is important that the impedance of the pad, looking into each end equal the impedance of the line into which it is facing. The pad consists of resistances in series with the line and in parallel across the line. If a large signal loss in the pad is desired the series resistance should be high and the parallel resistance low, and vice versa.

Attenuation pads are used extensively in transmission measurements; in laboratories, to approximate the conditions existing in a long transmission line; in input equipment at the end of a line as previously explained, where a greater than desired signal is placed on the line to over-ride the normal line noise and then attenuated at the receiving end to obtain the desired level. *Attenuation networks are designed to operate between specific impedances and the calibration of a pad is only correct when used between the specified impedances.*

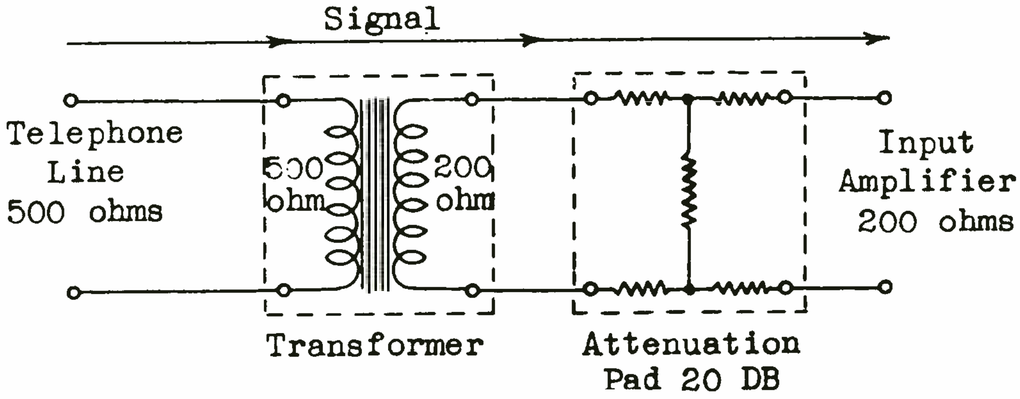
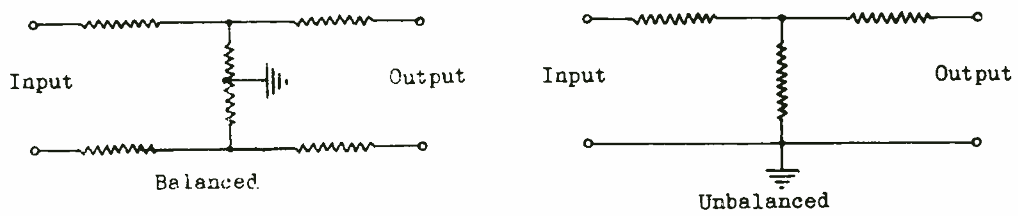


Fig. 3.—Use of impedance-matching transformer and attenuation pad.

Such pads may be designed to operate between unlike values of impedance, and are sometimes used in that manner. However, with unlike impedances it is difficult to properly design the pad for low values of attenuation. It is much more desirable to use the method as shown in Fig. 3 where an impedance matching transformer is used to equalize the impedances on both ends of the artificial line. Both types of pads will be discussed.

There are two principal types of attenuation pads, balanced and unbalanced. If all of the impedances, on both sides of the line, are symmetrical with respect to ground the network is said to be 'balanced.' Such a pad is shown in Fig. 4(A). An 'unbalanced' network is shown in Fig. 4(B). It will be seen that in the balanced pad the impedance between each of the input terminals to ground is the same; the same condition exists between the output terminals and ground. In the unbalanced network one side of the line is grounded, the other terminals, input and output, being at high potential above ground. A balanced and an unbalanced network could not be connected into the same circuit unless isolated from each other by means of a transformer, because otherwise a portion of the balanced network would be shorted out to ground.



(A)
Fig. 4.—Balanced H Pad.

(B)
Unbalanced T Pad

It is always desirable to ground an artificial line to eliminate the capacity to ground effect which, at the higher frequencies, may cause a considerable change in the reactance of the entire circuit. In planning the design of an attenuation circuit the condition of the line must be known. A balanced network could not be used with a line of which one is grounded without the use of a transformer between the pad and the line. If a simple pad is to be used with a grounded line the unbalanced type should be selected, making sure of course that the ground on the pad is on the same side as the ground on the line.

ATTENUATION BETWEEN LIKE IMPEDANCES.—Table II gives data to use in calculating all the values of resistance for both H (balanced) and T (unbalanced) types of attenuation pads. In these data it is assumed that the input and output impedances, that is, the impedances between which the pad is connected, are equal.

The most practical way to explain the use of this table is to work a problem showing the design of each type of pad. Suppose it is desired to design an H type pad having an attenuation factor of 16 db to connect between two 200 ohm impedances.

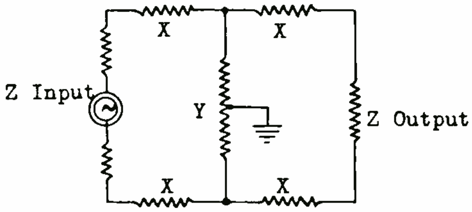
Referring to the design of the H pad, there are four resistors designated.

TABLE II

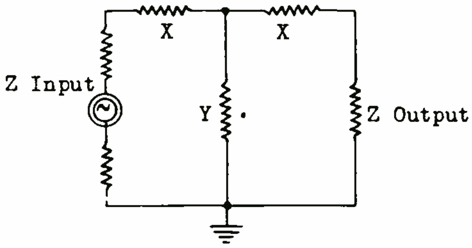
CHART AND FORMULA FOR COMPUTING VALUES OF RESISTANCES IN H AND T TYPE ATTENUATION PADS.

db	K=I'/I	Y^K	X^K	DB	K=I'/I	Y^K	X^K
1	1.122	4.48	.0566	24	15.85	.0636	.881
2	1.259	2.17	.15	25	17.75	.0565	.894
3	1.413	1.43	.17	26	19.95	.0505	.906
4	1.585	1.055	.225	27	22.40	.0448	.914
5	1.778	.829	.28	28	25.10	.04	.923
6	1.995	.667	.333	29	28.20	.0356	.93
7	2.24	.563	.382	30	31.60	.0316	.939
8	2.51	.473	.43	31	35.50	.0282	.945
9	2.82	.409	.476	32	39.90	.0251	.951
10	3.16	.352	.52	33	44.60	.0225	.955
11	3.55	.308	.56	34	50.00	.0201	.96
12	3.98	.269	.598	35	56.20	.01785	.965
13	4.47	.235	.635	36	63.00	.0159	.968
14	5.01	.208	.667	37	70.80	.01415	.972
15	5.62	.184	.699	38	79.30	.0126	.975
16	6.31	.162	.726	39	89.10	.0125	.978
17	7.08	.1445	.753	40	100.00	.01	.98
18	7.95	.1282	.776	41	112.00	.00892	.982
19	8.91	.1144	.798	42	126.00	.00792	.984
20	10.00	.1011	.818	43	141.00	.00708	.9855
21	11.21	.09	.836	44	158.00	.00631	.9875
22	12.58	.08	.853	45	178.00	.00562	.989
23	14.12	.0711	.868	46	211.35	.005	.99

Note: It is assumed that the impedance into which the pad feeds is equal to the impedance of the device from which the pad is fed.



H Pad



T Pad

$$X = \frac{Z}{2}\,\frac{(K-1)}{(K+1)} = \frac{Z}{2}\,(X^K)$$

$$K = \frac{I'}{I}$$

$$Y = 2Z\,\frac{K}{K^2-1} = 2Z(Y^K)$$

$$K = \text{Antilog}\,\frac{db}{20}$$

$$Y^K = \frac{K}{K^2-1}$$

$$X = Z\,\frac{K-1}{K+1} = Z(X^K)$$

$$Y = 2Z\,\frac{K}{K^2-1} = 2Z(Y^K)$$

$$X = \frac{K-1}{K+1}$$

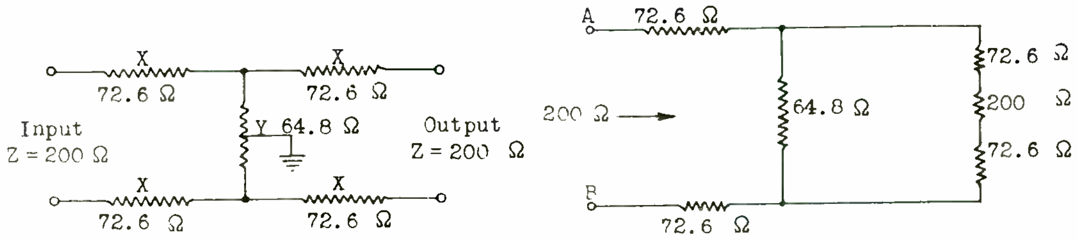
X and one resistor Y. It will be seen from the equation beside the circuit sketch that the value of each resistor is equal to $X = \frac{Z}{2}(X^K)$. X^K from the table for 16 db equals .726. Therefore

$$X = \frac{200}{2} \times .726 = 72.6.$$

The value of the Y resistor is given by $Y = 2Z\,(Y^K)$. Therefore

$$Y = 2Z\,(Y^K) = 2 \times 200 \times .162 = 64.8$$

ohms. In Fig. 5(A) the complete pad is shown.



(A)
Fig. 5.—H Pad designed for 16 db loss on a 200 ohm line.

(B)
Equivalence circuit of & pad and load.

Suppose it is necessary to design a T pad to use between two 300 ohm impedances. An attenuation of 24 db is required. From the sketch it will be seen that there are two X members and one Y member. From the equations, $X = Z\,(X^K)$. $Z = 300$ ohms; $X^K = .881$ (from the table for 24 db). Thus $X = 300 \times .881 = 264.3$ ohms. By the equation $Y = 2Z\,(Y^K)$; $Z = 300$ ohms. $Y^K = .0636$ (from the table). Therefore $Y = 2Z\,(Y^K) = 2 \times 300 \times .0636 = 38.16$ ohms. The pad with all values is shown in Fig. 6.

An inspection of the equations and values of the members of the H and T type pads will cause some interesting facts. The value of Y for both pads with given values of attenuation and impedance, is the same. $Y = 2Z\,(Y^K)$ in both cases.

In the T pad $X = Z\,(X^K)$; in the H pad $X = \frac{Z}{2}(X^K)$. In other words, in the H pad each value of X as determined for the T pad is simply divided into two parts and one-half placed in each side of the line.

The total value of resistance across the line between the two input terminals, in the case of the H pad, consists of two X members and the case of the H pad, consists of two X members and the Y member. In the 200 ohm impedance pad as calculated the total resistance is 72.6 + 72.6 + 64.8 or 210 ohms, *slightly* higher than the line impedance. The same relation exists with respect to the output terminals. An approximately similar condition will exist with *any* H or T pad used between *like* impedances. The total resistance facing the input terminals must approximately equal the input impedance; the total resistance facing the output terminals must approximately equal the output impedance. This allows the approximate accuracy of the pad design to be quickly checked.

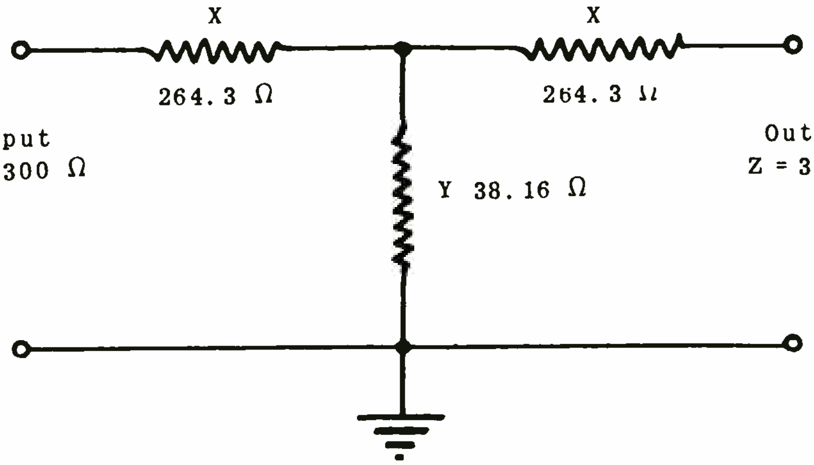


Fig. 6.—T Pad for 24 db loss and a 300 ohm line.

For a more reliable check on the accuracy of the pad calculations the pad should be resolved into its equivalent circuit and solved by ohm's law to check the impedance match. Fig. 5(B) shows the equivalent circuit of the pad in Fig. 5 (A). Looking into points A and B the impedance should be 200 ohms. This is a simple series parallel combination of resistances. The total resistance between points A and B is

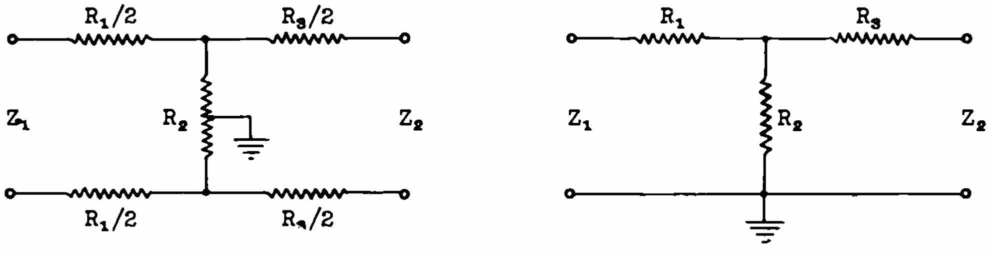
$$\frac{64.8\ (72.6 + 200 + 72.6)}{64.8 + 72.6 + 200 + 72.6} + 2\ (72.6)$$

$$= 199.8 \text{ ohms}$$

Thus the pad presents an impedance of 200 ohms to the line. Since the terminating impedances are identical, solving from the opposite end of the pad would also give an impedance match. If the pad were designed for operation between unlike impedances it could be solved from the opposite ends in a manner similar to the above to check the work. Thus a pad between 600 and 700 ohms should solve to 600 ohms from one end and 200 ohms from the opposite end.

It should be observed that as the attenuation factor is increased the resistance of the X members is increased and that of the Y member decreased, and vice versa.

ATTENUATION BETWEEN UNLIKE IMPEDANCES.—It may be desired to use an attenuation pad, either H or T type, between unlike impedances without the use of an impedance matching transformer. The calculations in this case are somewhat more involved because it is more difficult to prepare tables of constants that are applicable with all the various combinations of impedances and attenuation. For such pads tables may be dispensed with and the calculations made entirely from formula. In Fig. 7, (A) and (B), are shown H and T pads respectively with the designations of their resistance members.



(A) (B)

Fig. 7.—Circuits of H and T pads used in calculating resistance values to match unequal impedances.

Z_1 = Larger Z

Z_2 = Smaller Z

X = 'Equivalent Attenuation'

R_1 = Series R toward Z_1

R_3 = Series R toward Z_2

R_2 = Shunt Resistance

$$db = 20 \log \frac{1}{X}$$

Therefore, $\frac{1}{X}$ = Antilog db/20

And $X = \frac{1}{\text{Antilog db/20}}$

$$R_2 = \frac{2X}{1 - X^2} \sqrt{Z_1 Z_2}$$

$$R_1 = Z_1 - R_2 \quad [1 - X \sqrt{Z_1/Z_2}]$$

$$R_3 = Z_2 - R_2 \quad [1 - X \sqrt{Z_2/Z_1}]$$

It will be seen that the resistances for the T pad may be calculated directly from the known values of Z_1 and Z_2, and the desired attenuation in decibels. In the case of the H pad the calculations are the same except that the values of R_1 and R_3 are divided by 2, and one-half of each placed in each side of the line. R_2 is the same for both pads.

Suppose it is desired to use a T pad as shown in Fig. 7(A) between impedances of 500 and 200 ohms with attenuation of 30 db. First calculate the value of X.

$$db = 20 \log \frac{1}{X}$$

$$\log \frac{1}{X} = \frac{db}{20}$$

$$\frac{1}{X} = \text{Antilog } \frac{db}{20} = \text{Antilog } \frac{30}{20}$$

$$\frac{1}{X} = \text{Antilog } 1.5 = 31.6$$

$$X = \frac{1}{31.6} = .0316$$

$$R_2 = \frac{2 \times .0316}{1 - .0316^2} \cdot \sqrt{500 \times 200}$$

(From Formula)

$$R_2 = \frac{.0632}{.999} \cdot \sqrt{100,000}$$

$$R_2 = \frac{.0632 \times 316}{.999} = 20 \text{ ohms}$$

$$R_1 = 500 - 20\ [1 - .0316 \sqrt{500/200}] \qquad \text{(From Formula)}$$

$$R_1 = 500 - 20\ [1 - (.0316 \times 1.58)] = 500 - (20 \times .95)$$

$$R_1 = 500 - 19 = 481 \text{ ohms}$$

$$R_3 = 200 - 20\ [1 - .0316 \sqrt{200/500}] \qquad \text{(From Formula)}$$

$$R_3 = 200 - 20\ [1 - (.316 \times .632)] = 200 - 20(1 - .02)$$

$$R_3 = 200 - 19.6 = 180.4 \text{ ohms}$$

If it is desired to use an H pad as in Fig. 7(A) between the same 500 ohm and 200 ohm impedances with the same 30 db attenuation, then it is only necessary to divide R_1, 481 ohms, by 2, placing 240.5 ohms in each side of the line; do the same for R_3, placing 90.2 ohms in each side of the line; and use R_2, 20 ohms, unchanged but center-tapped for connection to ground.

By means of such comparatively simple calculations, attenuation pads for any desired attenuation, and for use between practically any values of impedance, can be designed.

It will be seen that the approximate check for accuracy as previously discussed, is still correct. Across Z_1 (500 ohms), the sum of the resistors $R_1 + R_2 = 481 + 20 = 501$ ohms. Across Z_2 (200 ohms), $R_3 + R_2 = 180.4 + 20 = 200.4$ ohms.

LINE EQUALIZER.—When it is desired to transmit a broadcast program over a long telephone line the frequency characteristics of the line must be taken into consideration and compensated for. A telephone line possesses distributed capacity between the wires. If the telephone line is short and is carried on poles the capacity may be practically negligible; if the telephone line consists of an underground cable the distributed capacity may be high even though the line is short; if the telephone line is many miles long the distributed capacity will be large even though the line is overhead and the wires are well spaced. The distributed capacity acts as a capacitor connected directly across the line. Under such conditions a certain amount of signal energy will be by-passed by the distributed capacity, and the higher the frequency the greater the attenuation due to the lower value of capacitive reactance and the correspondingly greater by-passing effect; also the longer the line the greater the attenuation of the higher frequencies due to the increased capacity of the line.

The lost high frequency energy cannot be replaced back into the circuit at the receiving end but it is possible to cause a corresponding loss of the *low* frequencies so that *all* frequencies are attenuated equally, and then amplify the program signal sufficiently to make up for the total attenuation.

A circuit as shown in Fig. 8 will accomplish the desired results. The values of L and C are such that the parallel LC circuit is inductive up to the highest frequency that must be passed. In other words, if it is desired to have the line pass equally well all frequencies up to 8,000 cycles the resonant frequency of the LC circuit must not be lower than 8,000 cycles. A parallel LC circuit, operated below its resonant frequency, will act as an inductance; an inductive circuit will offer less opposition to low frequencies than to higher frequencies, and the lower the frequency the less the opposition. This is exactly opposite to the line characteristics where the higher the frequency the greater the attenuation.

With the circuit of Fig. 8 the shape of the attenuation-frequency curve will be a function of the relative values of L and C; the degree of attenuation at any frequency along the curve will be a function of R; the lower the value of R the greater the by-passing effect and the attenuation of any frequency. Since individual lines have different lengths and different characteristics the actual equalization of any line will be an individual problem. However, with given values of L and C in the equalizing circuit, as the line length and capacity are increased the value of R must be decreased in order to increase the attenuation of the lower frequencies to compensate for the added attenuation of the higher frequencies by the line itself. On some long lines several equalizing circuits may be required to flatten out the line frequency characteristics, but each case will be an individual problem. So that the engineer may have some idea of the values required for practical equalizing circuits the values used at one installation will be given. For an 8,000 cycle high fidelity line, L = .0022 h, C = .171 μf, and R = 1,000 ohms. For a 5,000 cycle line, L = .005 h, C = .171 μf, and R = 1,000 ohms. Similar values will undoubtedly prove satisfactory in many cases. Calculations for the resonant frequencies of the two equalizers mentioned above will show

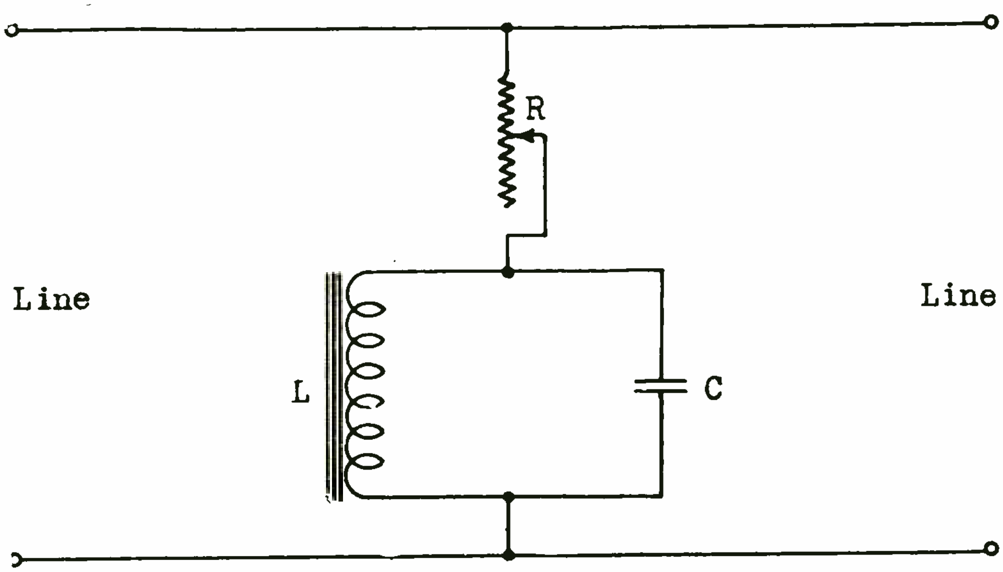


Fig. 8.—Circuit of a line equalizer.

that in each case the resonant frequency of the equalizing circuit is just slightly higher than the frequency to which the line is to be equalized.

The LC circuit of the equalizer should be so designed that the impedance of this circuit decreases with a decrease of frequency at exactly the same rate that the effective capacitive reactance of the line decreases with a frequency increase. If this condition is approximated the amount of the attenuation can be controlled within the desired limits by means of R.

EQUALIZING PROCEDURE.—Before commencing the equalizing run a volume indicator should be connected across both ends of the line. The signal generator at the transmitting end of the line should be tuned to 1,000 cycles and the output adjusted to about 2 db below normal peak program level. The equalizer at the receiving end of the line is then adjusted for approximately the same volume reading as is obtained at the transmitting end. Starting with the lowest frequency to be transmitted the frequency is increased in 100 cycle steps up to the maximum frequency to be passed by the line. During the run the input to the line must remain constant. The output of the line should remain within ±2 db over the entire range. If the output varies over these limits the equalizer must be readjusted until uniform response is obtained. More than one equalizer may be required if the frequency range is high and the line quite long.

Where time is short the usual procedure is to transmit a 5,000 cycle signal over the line and note the reading of the volume indicator at the receiving end. The signal generator is then shifted to 100 cycles keeping the input to the line constant. The equalizer is adjusted until the reading at the receiving end is the same as that obtained for the 5,000 cycle note.

After an equalization run is completed a turnover check showing that the line is balanced to ground should be made at the highest frequency at which the line is equalized. This is done by reversing the line at one end.

THE MIXING PANEL.—The mixing panel is used where several microphones are employed to pick up a program from different locations, or where it is desired to blend or 'fade' from one program to another. The same apparatus is also called 'Fader'. In picking up any program, say an orchestral program, from several different points and mixing the signal energy from the various microphones together for transmission into a common amplifier, the greatest care must be exercised in getting the proper signal voltage level from each source. Everyone has heard cases of poor mixing where a singer was accompanied by an orchestra or piano and the voice almost nullified by over-accentuation of the accompaniment. In such a case, if two microphones are used it will be a simple matter to correct the condition by increasing the signal level from the singer's microphone and decreasing the level from the accompaniment. This is one of the most important duties of the control engineer.

The mixing circuit should be designed to have the following characteristics:

(A) Each control independent of the other; that is, when the signal level from one microphone is varied from maximum to minimum it should have no effect on the input level to the amplifier from any of the other microphones.

(B) The impedance facing the input terminals of the amplifier following the mixing circuit should be constant regardless of the adjustment of any or all of the individual control units. That is, varying the controls of the mixing panel should not affect the total impedance across the output terminals of the circuit.

(C) Regardless of the adjustment of an individual control arm the impedance connected across that individual microphone transformer should remain unchanged. That is, varying the signal level into the amplifier from a certain microphone circuit should not change the impedance characteristics of the microphone transformer and load circuit.

The characteristics are satisfactorily approximated in the series type of mixing circuit shown in Fig. 9. This type of mixing panel is extensively used in broadcasting and, if the proper values are used, will give excellent results. The variation of the resistance across the secondary of any one microphone transformer will not vary more than 25 per cent with any range in the adjustments of any or all of the individual controls. The value of R_1 must be at least three times as great as the impedance of the transformer secondary in order that the total resistance facing the secondary

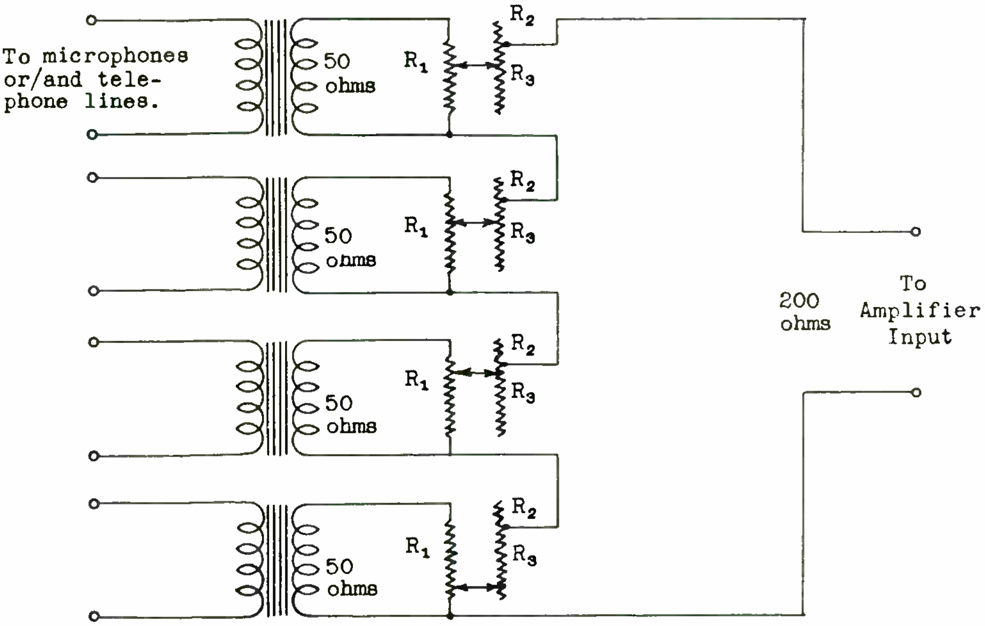


Fig. 9.—Series mixing circuit for program sources to be fed into an amplifier.

is not lower than the impedance of the secondary winding. This is due to the shunt resistance of the other portions of the circuit that are connected across this resistance by the variable arm.

The series resistance of R_3 increases in value as the control arm is moved down across R_1. By examining the circuit from the two output terminals and tracing the circuit from the upper terminal, it will be seen that the first connection is at the fixed tap between R_2 and R_3; through a portion of R_3; through the control contact to R_1; from R_1 to the junction of R_2R_3 on the next input circuit; etc. At the lower end of the last input circuit R_1 connects to the lower output terminal. If the resistance of R_3 increases in the proper proportion with a decrease of R_1 the total resistance across the output and across each transformer will vary very little with various adjustments.

R_2 is a compensating resistance having a suitable value and so arranged that it compensates for the shunting effect of R_1 and keeps the output impedance of the circuit up to the value of the amplifier input transformer impedance at the position of maximum and near maximum signal level from the microphone, in other words, at the upper limits of R_1.

The actual calculations of the values of resistance, R_1, R_2 and R_3, are somewhat involved and will not be entered into here. A commercial control unit that is extensively used in broadcasting is made up of the following values of resistance: R_1 = 160 ohms; R_2 = 35 ohms; R_3 = 50 ohms. This unit is designed for use with a microphone transformer having a 50 ohm secondary as shown, to feed an amplifier input circuit of 200 ohms.

It is essential that the control units be well designed and quiet in operation. The unit may afford continuous variation or it may be variable in steps. In the latter case the variations are usually in 2 db steps because this is about the minimum variation that the average ear can notice. For most purposes continuous variation is preferable to variation in steps because with such controls one program can be faded out and another in without noticeable abrupt changes in volume. Such a circuit is used in motion picture theatres. At the end of a reel or record, where the sound is on record, the sound from the completed record or reel must be faded out and the sound from the succeeding one brought in, this being accomplished in such a manner that the sound level from the reproducer is normal during the entire operation. There are many uses for the mixing panel in sound reproduction and the proper use of this circuit can make up for many deficiencies elsewhere along the path of the program from the source of sound to the antenna.

THE VOLUME CONTROL.—One of the quite simple but most important pieces of apparatus in the transmission of a program is the volume control. Volume controls are inserted in various portions of the circuit, in the studio control room, on the main control panel if one is used in addition to the studio control, and at the speech input amplifier at the transmitter. It is of the greatest importance, for maximum undistorted output from the transmitter, that means be provided for accurate adjustment of the program signal voltage entering the transmitter. If the level is too high on the peaks over-modulation will result, and the output will be distorted; if insufficient signal voltage is provided the modulation level will be too low and the output from the transmitter will consist mostly of carrier.

Since all amplitudes in broadcasting are based on the characteristics of the human ear and since this is a logarithmic characteristic, the volume control is calibrated in transmission units, db, usually in steps of 2 db. The volume control often consists simply of a tapped resistance connected directly across the circuit, all of the resistance being used across the input with an arrangement of taps along this resistance for taking off the desired voltage for the output. Such a volume control of the ladder type is shown in Fig. 10.

In the design of the volume control it is first necessary to determine the total resistance to use across the line. In order to keep the current and losses low the total resistance is usually made quite high. In Fig. 10 a total of 50,000 ohms is used. Very often the total resistance will be as high as 500,000 ohms.

In calculating the values of the individual resistances between steps it must be remembered that the Transmission Unit, db, is a logarithmic unit. It also must be remembered that the voltage across a series circuit varies directly as the resistance. Since the signal voltage is a direct function of the voltage across the output terminals, and since this voltage is to be varied at a logarithmic rate, it is apparent that the values of resistance must also vary at a logarithmic rate; the resistance cannot be divided up in steps of equal resistance.

Inspection of Fig. 10 shows that at zero level the output voltage is taken across resistance R_0. The total resistance, R_t, is specified as 50,000 ohms. It is first

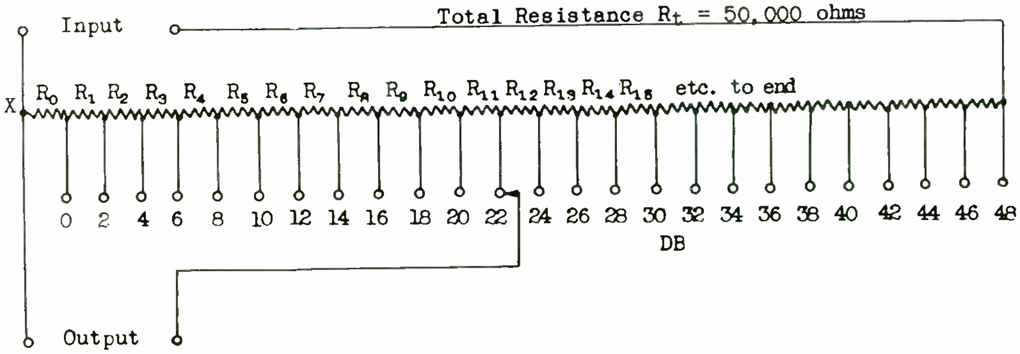


Fig. 10 —Ladder type volume control.

necessary to calculate the value of R_o. From the fundamental equation of the transmission unit,

$db = 20 \text{Log } E_1/E_2$ (where E_1 = Input voltage, E_2 = Output Voltage.)

$db = 20 \text{Log } R_t/R_o$ (because, since E varies directly as R, the ratios are interchangeable.)

$\text{Log } R_t/R_o = db/20$ (Rearranging.)

$db = 48;\ R_t = 50{,}000$

$\text{Log } R_t/R_o = 48/20 = 2.4$

2.4 is the Log of 251.2 (from tables.)

Therefore $R_t/R_o = 251.2$

$R_o = R_t/251.2 = 50{,}000/251.3$

= 199 ohms, the value of resistance in the output circuit at minimum signal level.

The value of resistance to add in the next step to give a signal voltage increase in the output circuit of 2 db must next be determined. Referring to the original equation and using R_x to represent the *total* resistance in the output circuit at the 2 db step,

$\text{Log } R_x/R_o = db/20$ (Since a db gain is desired, db is replaced in the equation with its equivalent, 2.)

$\text{Log } R_x/R_o = 2/20 = .1$

.1 is Log of 1.26

Then $R_x : R_o :: 1.26 : 1$

and $R_x = 1.26\ R_o$ (R_o from the previous calculation = 199 ohms.)

$R_x = 1.26 \times 199 = 250.7$ This is the total resistance between point X and the 2 db tap. The resistance added to R_o to permit the 2 db gain over the minimum signal level will be,

$250.7 - 199 = 51.7$ ohms.

The value of the next resistor is computed in a smaller manner, using 4 db in the original equation above instead of 2 db, and then subtracting from the total calculated resistance the resistance between point X and the W db tap. In a similar manner the resistance of each resistor in the volume control may be calculated.

A more simple method of calculating the resistance between taps after R_o is determined is as follows. In calculating R_o it was found that

$R_x : R_o :: 1.26 : 1$

$1.26R_o = R_x$

where $R_x = R_o + R_1$

then $1.26R_o = R_o + R_1$

$1.26R_o - R_o = R_1$

$.26R_o = R_1$

Each added resistance will then be 26 per cent of the total resist-

ance between point X and any given tap. Thus

$$R_1 = .26R_0 = .26 \times 199 = 51.7 \text{ ohms}$$

$$R_2 = .26(199 + 51.7) = .26 \times 250.7 = 65.2 \text{ ohms}$$

$$R_3 = .26(250.7 + 65.2) = 82 \text{ ohms, etc.}$$

This method reduces the calculations to simple arithmetic and avoids reference to log tables after R_0 is calculated.

By using the procedure as explained above it will be a simple matter to design any desired type of volume control. It is only necessary to determine the total resistance to be used, the number of taps it is desired to use, and the db variation between taps. Where an almost continuous variation of volume is desired the variations should be in steps of not greater than 2 db each.

If one of the resistance units in a volume control in use should open up and require replacement it is only necessary to calculate the total resistance between point X and the tap below the break and between point X and the tap above the break. The difference will be the value of the resistor that must be replaced. The type of volume control explained above is suitable for use between a transformer secondary winding and the input of a vacuum tube where the tube input impedance is very high. It is sometimes necessary to insert the volume control elsewhere. as between a telephone line and a transformer winding, or between two transformer windings, where the impedances on each side of the volume control are comparatively low, and where for undistorted energy transfer it is necessary that the impedance facing each end of the line does not vary with volume control adjustments. In such a case the volume control should consist of a variable attenuation constant impedance attenuation pad, either of the T or H type.

The design of such a pad, while the calculations are quite tedious, is not particularly difficult, particularly where the pad is used, as it should be, between equal impedances. Fig. 11 shows a variable constant impedance attenuation pad for use between two 600 ohm impedances. The total attenuation varies from 0 to 20 db in 11 steps of 2 db each. This is an H type pad in which five sets of resistors are required. Five contacts rotated simultaneously from a common shaft vary all pad members at once. The upper row of figures designates the attenuation in decibels, 2 db per step. The other figures designate the values of resistance between contacts.

It should be noted that in the circuit of Fig. 11 provisions are not made for center-tapping the Y or parallel resistor to ground. If such an arrangement were required, it would be necessary to use another set of resistors; that is, the Y or parallel resistance should be divided into two sections in which each resistor in each of the two sections would be one-half as great as shown in Fig. 11. One end of the two sets of parallel resistors would be connected together and grounded and the two contact arms would decrease the parallel resistance in equal amounts with respect to ground for each increased step of attenuation. The circuit would then be as shown in Fig. 12.

Volume controls of this type are commonly used on high grade speech control panels in broadcasting stations and in public address systems.

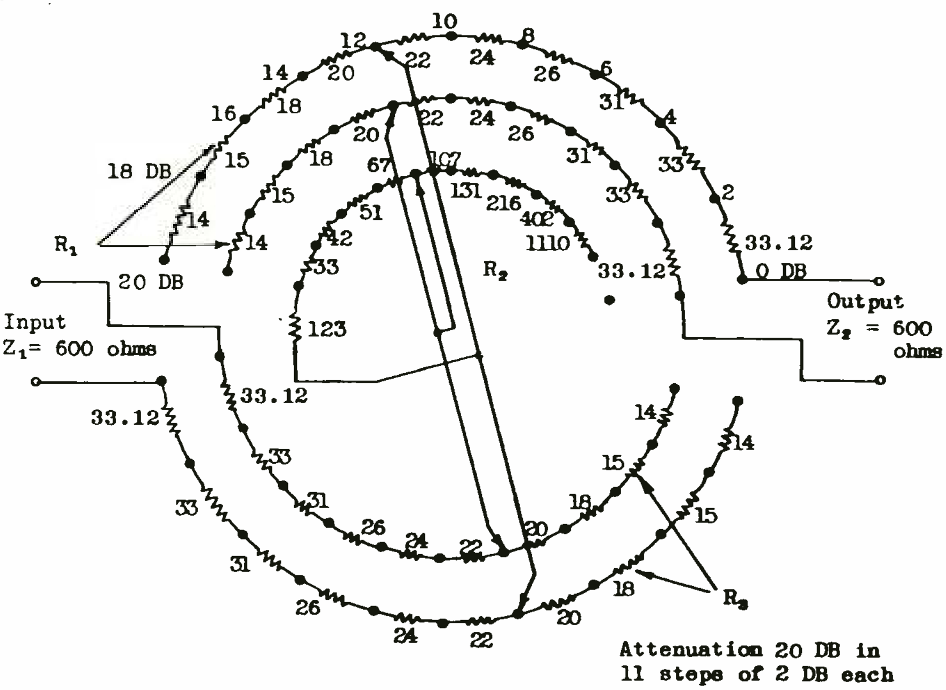


Fig. 11.—Variable type constant impedance pad for use between 600 ohms lines or impedances.

Fig. 13 shows the commercial form of volume control of the ladder type. Fig. 14 illustrates a volume control of the T pad type. In this model only one of the series resistance members and the parallel member are variable. In the H type attenuator the unit is somewhat more complex due to the necessity for simultaneously varying a greater number of resistances.

In broadcast transmission it is very desirable that all volume adjustments of the actual program be made at the studio control and not at the transmitter. A program signal of sufficient amplitude to over-ride line noises is placed on the wire at the control room; at the transmitter both the signal and noises are attenuated by means of an attenuation pad. The signal is then fed into the speech amplifier which is provided with a volume control as explained above. This volume control is so adjusted that at the peaks of the program signal the transmitter is modulated at the maximum desired percentage. If all the controls at the transmitter are kept at these settings it will only be necessary for the studio control operater to deliver a signal within the measured limits in order to completely modulate the transmitter.

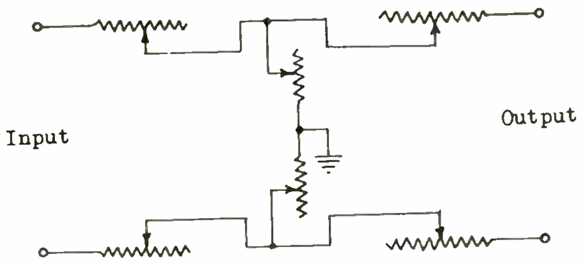


Fig. 12.—Circuit showing a grounded center tap on the variable type constant impedance pad.

The adjustments at the transmitter should not require further change except in the case of emergencies, such as greater than normal line noises, etc., where it becomes necessary to change the signal level placed on the wire at the control room, or where radical changes are made in the voltage applied to the transmitter so that the former adjustments would over or under-modulate. All normal volume adjustments during a program should be made at the studio control room.

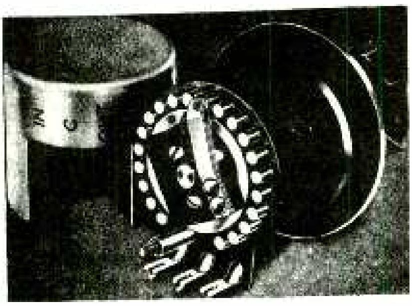


Fig. 13.—Commercial ladder type volume control.

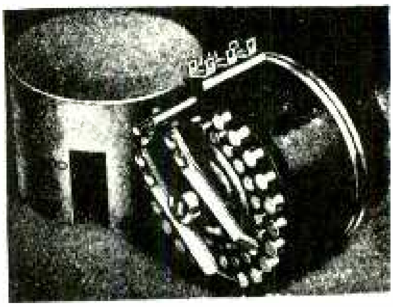


Fig. 14.—T pad type of volume control.

LINE TERMINAL AND INPUT EQUIPMENT

EXAMINATION

1. (A) What is meant by the 'transmission unit'?

   (B) On a power basis what does 1 DB represent?

   (C) What is 2 VU?

   (D) What voltage ratio is represented by 4 DB?

2. Why is it essential that the impedance of the line terminal equipment be matched with that of the line itself? Under what conditions may the characteristic impedance of the line be neglected? Why?

2. *(Continued)*

3. (A) What is an attenuation pad? Where is it used?

(B) Show by sketch an 'H' type pad and a 'T' type pad.

4. What is the difference between a balanced and an unbalanced attenuation network? Why should a system be grounded?

5. Show by sketch how you would transfer signal energy from a 500 ohm ungrounded line to an amplifier having an input impedance of 300 ohms. One side of the amplifier input is grounded.

6. Design an 'H' type pad to have an attenuation of 15 DB between impedances of 500 ohms.

7. Design a T type pad to have an attenuation of 10 DB between impedances of 600 and 300 ohms. Draw equivalent circuits and prove your work.

7. *(Continued)*

8. Explain the principle and operation of a line equalizer. Using a capacity of .15 μF design an equalizer for equalization up to 10,000 cycles. Show sketch of circuit.

8. *(Continued)*

9. (A) Where is a mixing circuit used? What are the essential characteristics of a good mixing circuit?

(B) What are the characteristics of a good volume control? Why is a logarithmic calibration used in such controls?

10. Design a ladder type volume control having a total resistance of 40,000 ohms and a total variation of 30 DB in two DB steps. Sketch circuit showing value of each resistor.