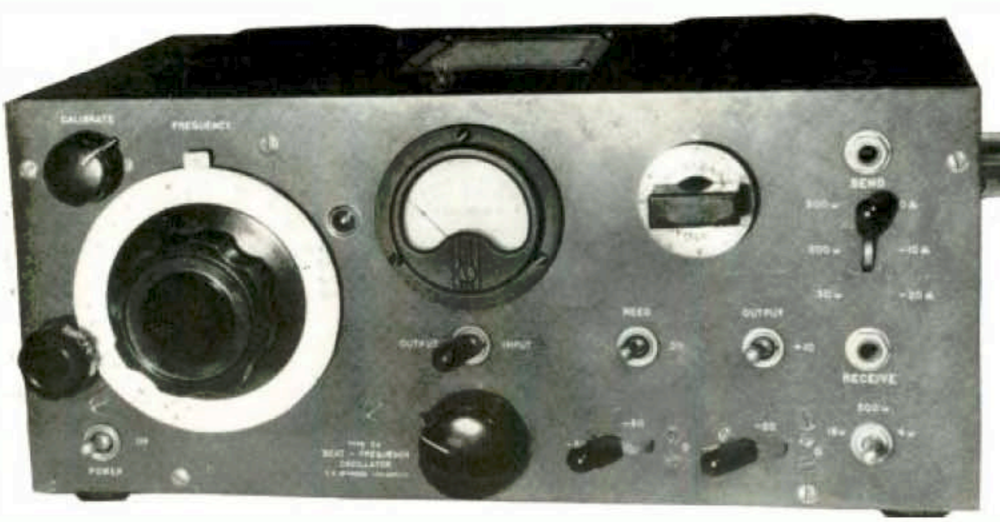

The author's combination beat-frequency oscillator and gain set. The latter section is practically identical with the unit described.

A Practical Gain Set

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Design and construction of a simple gain measuring instrument suitable for the small laboratory or the experimenter.

SUCCESSFUL experimentation with audio equipment demands the use of certain types of measuring equipment, although the writer has often pointed out that the ultimate object is "how it sounds." However, once a piece of equipment is completed, it may be desirable to determine its characteristics in order that performance may be maintained over a period of time at the original standard without raising a doubt as to the quality of the amplifying system or any of the components.

One of the most important instruments used in audio work is the gain set. This term is given to a specific form of calibrated losser which introduces a known amount of loss into a circuit. Its principal use is in the measurement of amplifier gain, since it requires gain of some sort in order to function properly. When used for the measurement of filter or equalizer characteristics, the level measuring meter at the output may be an audio voltmeter having facilities for the measurement of levels from 40 to 60 db below the common zero level, which provides the necessary "gain."

This paper describes a simple gain set which can be constructed by the careful technician with the assurance that it will permit the making of various types of measurements with reasonable accuracy. When used with a variable-frequency audio oscillator, frequency response measurements are possible, together with performance measurements on filters and equalizers. When only a single-frequency source is available, the gain set will measure the actual gain of an amplifier at that frequency. Under these conditions, its usefulness is somewhat limited, and there is relatively little need for it, since the same information can be obtained more easily. When numerous measurements are to be made, however, with a variable-frequency oscillator as the source, the gain set is practically indispensable.

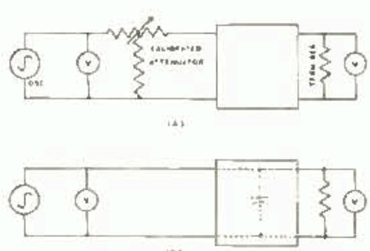

Fig. 1. (A) Basic method of measuring the gain of an amplifier or other component. (B) Resulting circuit when component is a simple capacitor.

Theory of the Gain Set

Primarily, the gain set serves only as a calibrated attenuator. In use, it is connected between the source of tone and the input to an amplifier. The voltage of the source is measured, and the voltage at the output is adjusted by means of the gain set to be exactly equivalent to that at the source. When this is done, it is obvious that the loss in the gain set is equal to the gain in the amplifier, and the gain is thus indicated immediately. For use with filters or equalizers which have no gain of themselves, it is usual to follow the component to be measured with an amplifier of known characteristics, in order to provide sufficient gain to make up for the maximum loss of the filter or equalizer.

The gain set has one principal difference from the simple calibrated attenuator. To understand this, it is first necessary to review theory momentarily. In the first place, a circuit in which the voltage is held constant is said to be of zero impedance. This is the case at the output of the generator shown in (A) in *Fig. 1*, when the gain control is adjusted to maintain a constant output voltage. The metered output of the generator is fed through a calibrated attenuator to a component, and thence to the proper termination across which another voltmeter is bridged. If the setting of the attenuator is reduced to zero, the impedance at the output terminals of the measuring equipment is at zero impedance. As the attenuation is increased, the impedance gradually increases until at losses of over 10 db it may be said to approximate the impedance of the attenuator itself. This will introduce no particular trouble provided the component is an amplifier so that the attenuator is set at a loss greater than 10 db, although the measurement will not be truly accurate because the attenuator is not matched to the impedance of the source.

Now, what would happen if the component consisted simply of a capacitor

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across the line as shown at (*B*)? Obviously a capacitor in shunt with an audio circuit will affect the frequency response because of the decrease in impedance of the circuit with increase in frequency. In this instance there will be no attenuation inserted since it is common practice to use the same meter for both source and output voltage measurements. Therefore, since the voltage is held constant across the input it will also be constant at the output, as there is a direct connection between input and output, and the capacitor is simply shunted across the circuit.

This gives a reasonable explanation of the functioning of a calibrated attenuator used for measurement purposes. With such an arrangement, any variation in the input impedance of the equipment being measured is not taken into account, whereas it actually affects the performance to a marked degree.

The circuit arrangement can be modified only slightly by the addition of the resistor R_1 as shown at *A* in *Fig. 2*. Assuming that the impedance desired is Z, this resistor will have a value equal to Z, and the impedance of the following attenuator is also Z. Since it is common to use a standard impedance, such as 500 ohms, for this value, and since 500 ohms is also a common output impedance for the generator, the additional resistor R_2 is added across the circuit with a value of $2Z$, making the input impedance of the gain set equal to Z. Now when a measurement is made with the capacitor of *Fig. 1(B)* in the circuit, its change in impedance with frequency is reflected in the output measurement, since with increase in frequency this value decreases, and since the output is measured across this impedance in parallel with the load resistor R_3, also equal to Z, the voltage indication is reduced.

Conventional Design

The common form of a gain set is shown in *Fig. 3*, with one meter being used to measure both the send and receive levels. It will be noted that the meter is tapped down on R_2, because the voltage required from the source is divided between the resistor R_1 and the load, and is therefore equal to twice the voltage at the input to the attenuator. Therefore, the meter is tapped down at the center of R_2, making a voltage divider composed of two resistors each equal to Z. With this arrangement, the same meter is used for both input and output levels, and consequently any frequency error in the meter itself is eliminated. If two separate meters were used, it would be necessary to check them to ensure accuracy throughout the entire frequency range over which the gain set were to be used. Since both send and receive levels are the same at the points at which the meter is connected, there is no question of leakage across the switch; as the level is fairly high, it is not necessary that an especially fine switch be used for this application.

Circuit Elements

In order to design a gain set for practical and inexpensive construction, it is—as always—necessary to make several compromises. In the first place, it is usual for high quality laboratory gain sets to be built with the send and receive circuits balanced to ground. Unfortunately, this necessitates greater expense in the construction of the attenuators, and for the non-professional user, it does not seem to be essential. Most circuits that the experimenter will have occasion to measure are unbalanced; if the gain set were balanced, it would be necessary to insert a transformer between the send terminals and the equipment being measured. For those rare instances in which the input circuit is balanced, it is much simpler to insert the transformer, since such circuits are usually those of high-gain amplifiers, and sufficient resistance isolation can be included in the measuring circuit that the effect of the transformer can be neglected, provided it is of reasonably good quality. Thus it is argued that if a transformer must be used part of the time, it is more desirable that it be used the least number of times, and the unbalanced gain set provides this facility at the least expense.

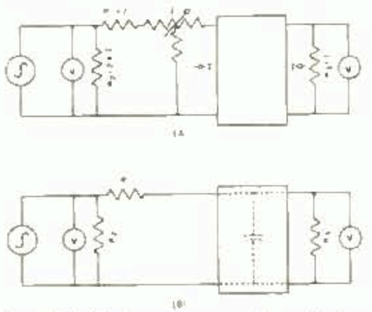


Fig. 2. (A) Series resistor R_1 added to overcome zero-impedance of source when voltage is held constant. (B) Effect of capacitor when gain set resistor R_1 is added.

The next step in the design is to determine how much attenuation is to be provided. Since amplifiers used for public address work often have gains of the order of 120 db, it is desirable that this figure be approached. However, such high losses increase the problems of construction, and it is simpler to increase the range by another method. Normally, any amplifier having 120 db of gain is also capable of putting out a fairly high power level. Therefore, if the low-impedance output terminals are measured, there will be an increase in the range due to the differences in impedances between the 500-ohm meter and the 4, 8, or 16-ohm transformer terminals. For instance, the correction of a 4-ohm circuit is 21 db.

With these considerations, therefore, the total range of the send circuit of a gain set can be limited to 90 db with reason, since an additional 15 to 20 db can be accommodated with the different output impedances of the amplifier to be measured, and a 10-db key in the receive circuit will increase it still further.

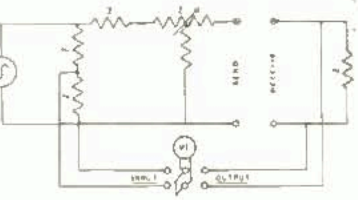


Fig. 3. Simplified schematic of standard type of gain set.

Single pads with losses of over 30 db are considered undesirable, so the attenuator portion will be divided up into two 30-db sections, two 10-db sections, and a switch with ten 1-db steps.

Naturally, it is possible to design a gain set around any desired impedance. The use of high impedances again increases the problems of construction, since the voltages are higher, and the losses throughout the attenuator section are apt to vary with frequency. Common impedances for a gain set are 500 and 600 ohms, with the former value being chosen for this design, since much of the equipment encountered is of that impedance. The addition of two resistors, and the application of a correction factor, will permit its use on 600-ohm lines with equal facility, if the most accurate measurements are desired.

One other facility is also desirable—that of being able to "send" at different impedances. Some commercial instruments provide plug-in networks for this purpose, and others employ transformers. However, a simple resistor network will provide two lower impedances at fixed losses, and with a minimum of switching. Using a nominal impedance of 500 ohms for the main attenuators, a 200-ohm output can be provided at a loss of 10 db, and a 50-ohm output can be provided at a loss of 20 db, both impedance values being common in communication circuits, and the loss values being easy to handle.

Final Circuit

With all these considerations settled, the final circuit for the gain set becomes as shown in *Fig. 4*. R_1 provides for the adjustment of the signal level from the oscillator, and is arranged so as to give a vernier action to facilitate setting the level accurately. The adjustable attenuators are composed of two separate switches, one providing attenuation of 0, 30, or 60 db, while the other provides attenuation of 0, 10, or 20 db. These switches are followed by a 1 db/step attenuator constructed on the "scaling hook" arrangement which eliminates the possibility of poor contact on the shunt section of the switch when a three-arm switch is used to vary the loss in a "T" pad. The output pad furnishes three impedances, 500, 200, or 50 ohms at losses of 0, 10, and 20 db respectively. The output is available on two jacks, one being terminated for connection to high-impedance inputs so as to maintain a load for the attenuators, thus ensuring accuracy of the output voltage; the other jack is connected so as to remove the termination when the plug is inserted.

The receive section of the gain set consists of another pair of jacks, one of which connects directly to the meter switch through a series resistor and a shorting switch, while the other provides a termination of 500, 16, or 4 ohms, as selected by another switch. The series resistor is used to increase the output indication of the meter by 10 db, and is used when higher output levels are to be used. This provides a total of 121 db loss in the gain set when sending at 500 ohms and receiving at 4 ohms, or 141 db when sending at 50 ohms and receiving at 4 ohms.

Construction Details

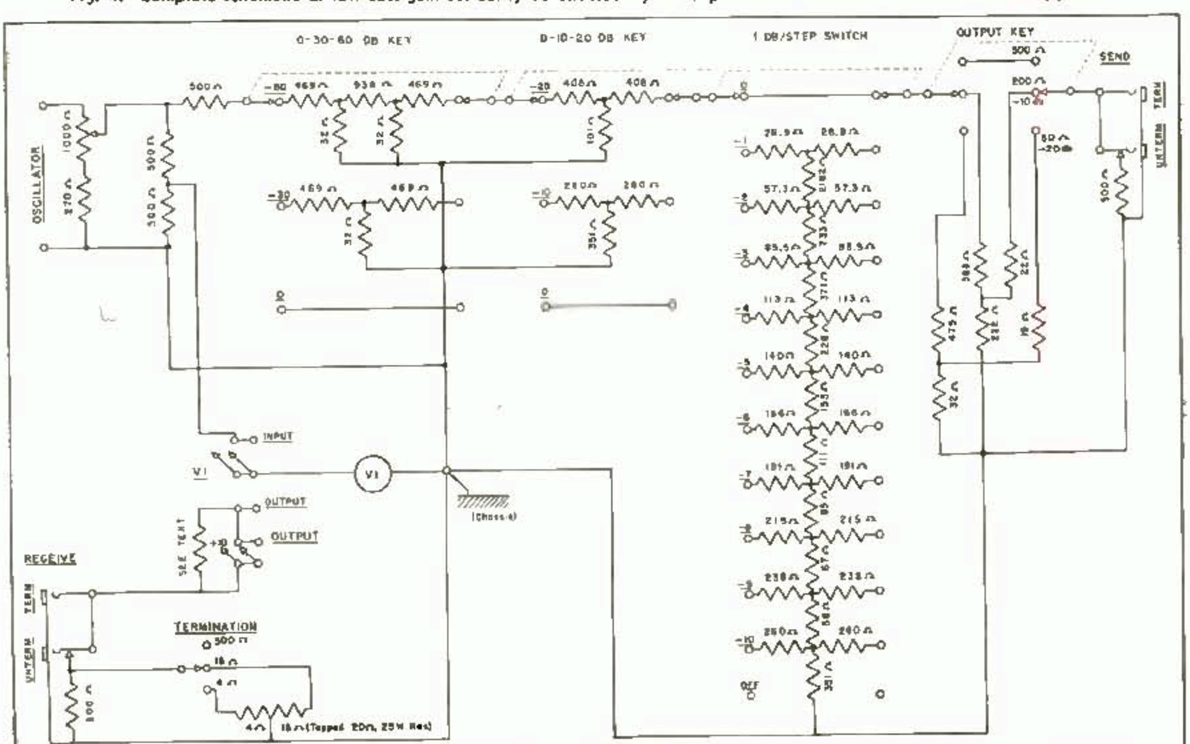
The construction of a gain set should follow standard practice, considering that there is quite a difference in level between the receive jacks and the send jacks when high gain amplifiers are being measured. All connections between the switches should be with shielded wire, and only one point in the entire circuit should be grounded to the cabinet. It is suggested that the unit be constructed in a small metal cabinet, entirely enclosed, and that the jacks be insulated from the panel. The unit shown at the heading of the article utilizes the same type of gain set as described, in combination with a beat-frequency oscillator, and has been in use for a number of years. This model uses key switches for the fixed pads, but this construction is considered rather more expensive, and the keys used necessitate some maintenance. The switches recommended for this use are the Centralab lever type, 2-pole, 3-position. The 1-db step attenuator can be built up on a Mallory 1231L switch with the stop removed so as to permit rotation through 360°. The rotor of the center section should be removed, and the taps used simply as tie points for the resistors. The meter transfer switch can be a DPDT toggle switch with both sections in parallel.

The one problem which may trouble the constructor will undoubtedly be that of obtaining accurate resistor values for the various pads. This may be solved easily if an accurate bridge is available for the measurement of a number of 1/2-watt resistors to obtain the exact values. Another method is to order them wound special by one of the many companies which do this type of work. However, it should not be too difficult to select ordinary 1/2-watt resistors with sufficient accuracy for the job. Obviously, the over-all accuracy of the gain set depends upon the accuracy of the individual resistors comprising the pads, and it is suggested that the resistors be selected with an accuracy of at least 2 per cent.

The resistors used in the receive circuit should be of somewhat higher power-carrying capacity, since they may be required to dissipate considerable energy. The 500-ohm load resistor R_7 should be a 2-watt unit, while R_8 and R_9 can be a single 20-ohm, 25-watt adjustable resistor with the sliding tap set so as to provide the 16- and 4-ohm sections. The value of R_6 depends upon the type of meter used, and it is easily selected. Simply connect an amplifier to the send terminals, with the output connected to the receive terminals. Then with the gain set adjusted so as to provide a zero indication on the meter with Sw_7 at OUTPUT, open Sw_8, and decrease the loss in the send section so as to raise the output level of the amplifier by 10 db. Then bridge a resistor across Sw_8 which will just give a zero indication on the meter again. The value will depend somewhat on the resistance of the meter, but for the usual meter with a resistance of approximately 5,000 ohms, this value will be of the order of 10,800 ohms.

The final selection, which has not been mentioned so far, is the volume indicator meter itself. A standard type of rectifier meter, calibrated in db, is desirable, and

Fig. 4. Complete schematic of low-cost gain set easily constructed by the experimenter to facilitate measurement on apparatus.



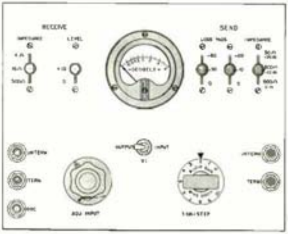
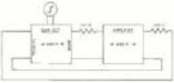


Fig. 5. Suggested layout for the gain set of Fig. 4.

Fig. 6. Method of making measurement on 600-ohm equipment with a 500-ohm gain set.



many are available from surplus stocks at reasonable prices. The most useful calibration is −10/0/+6, and the meter should be of the type adjusted for 6 mw across 500 ohms. This will give a known output voltage (with zero attenuation in the gain set) of 1.732 volts, and this value may be used for many measurement applications. When measuring the gain of an amplifier, however, this value is not important, since the gain is indicated directly by the switches, and the total loss in the gain set equals the gain of the amplifier.

Layout

A suggested layout for the construction of a gain set of this type is shown in *Fig. 5*. It may be considered desirable to combine the unit with an audio oscillator, as shown in the photograph. However, it is not necessary since any available audio oscillator may be used with this unit simply by connecting its output to the OSC terminals of the gain set.

The gain set reduces the time required to make measurements on amplifiers, filters, or equalizers, and provides a simple rapid measuring tool for the experimenter or engineer. While the use of a sensitive direct-reading audio voltmeter simplifies certain types of measurements, such an instrument is not always available. The gain set provides the information with a minimum of effort, and when carefully constructed, will repeat its measurements accurately.

This instrument is designed on the basis of a 500-ohm nominal impedance. With some equipment, it is desirable to make the measurements at 600 ohms, and in order to match the sending impedance with a 600-ohm load, a series resistor may be added, as shown in *Fig. 6*. This gives an increase in the output voltage available at the terminals, since the calibration is correct with a load of 500 ohms. The new load will be 600+100, or 700 ohms, and the voltage across the output terminals is thus equal to 2.02 volts, assuming a meter indication of 1.73 volts at zero level. The 2.02-volt signal is divided between the 600-ohm load and the 100-ohm series resistor, so that the voltage across the load is again 1.73 volts. However, for zero level across 600 ohms—with a reference of 6 mw—the voltage should be 1.9, which represents a loss of 0.8 db. Thus, when a measurement is made with a 600-ohm load and a 100-ohm series resistor, a value of 0.8 should be added to the measured gain. At the output circuit, the same arrangement should be employed for the correct termination of a 600-ohm output, with another 100-ohm series resistor, also shown in *Fig. 6*. This reduces the measured voltage by a factor of 3.6, and the voltage applied to the meter is 0.7 db low. Therefore, the loss in the attenuators must be decreased by this amount. Therefore, when measuring an amplifier having input and output impedances of 600 ohms, the actual gain is 1.5 db more than indicated by the attenuators, assuming that the two 100-ohm series resistors are connected into the circuit. If the output is measured at 500, 16, or 4 ohms, the actual gain is 0.8 db greater than indicated, with additional factor added for 16 or 4 ohms, if these values are used for terminating outputs of these impedances. For 16 ohms, the factor to be added is 15 db; for 4 ohms it is 21 db.

The convenience of the gain set can only be appreciated when one is available for measurements of all kinds, and once it is used, it will be considered almost indispensable for audio development work.