THE PA BIBLE

ADDITION NUMBER FIVE
SYSTEM INTERCONNECTION

INTERCONNECTING THE SYSTEM

The importance of proper interconnection of components in a system can hardly be over-emphasized. Not only must the wire or cable be an appropriate type, but the compatibility of component input and output parameters must be considered. In this supplement we will discuss such parameters as signal level, impedance, and balanced versus unbalanced terminations. Our approach is to begin with the lowest electrical signal level and follow it through the line level stages to the power amplifier and speaker circuits. A short glossary of definitions appears at the end of this supplement to assist in reading this material.

LOW LEVEL CONNECTIONS

Microphone level circuits are potentially the most prone to hum pick up and noise interference because of the low signal voltages involved. Therefore, microphone cables and connectors must be shielded to prevent electrostatic pickup. Also, dynamic microphones, because they use a coil of wire, are sensitive to external magnetic fields, such as those produced by transformers, motors, fluorescent lamp ballasts, and high current wiring. If operation in the vicinity of such devices is anticipated, a model with a hum bucking coil or special shielding should be used. Magnetic phonograph cartridges, guitar and piano pickups also use coils of wire and may require physical separation or shielding to prevent hum pickup.

Attenuators

Although the voltage levels in low impedance microphone circuits often run in a low millivolt or microvolt region, it is possible to encounter substantially higher levels, even exceeding one volt, when a high output microphone is used in extremely loud sound fields. This might occur, for example, when a condenser microphone is used for close pickup of a rock vocal or trumpet soloist. The high level microphone output may overload the input of the microphone mixer or preamplifier. To eliminate this problem, a built-in or external attenuator can be used. These attenuators usually allow a selection of 10, 20, 30 or even 40 dB signal reduction. It should be noted that some external attenuators cannot be used with a phantom powered microphone. See Figure 1.

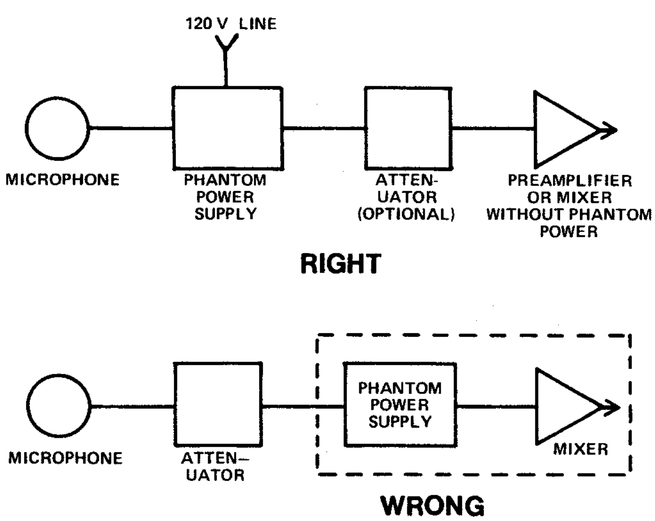

FIGURE 1 — Phantom Powering

Input overload creates raspy distortion when severe, but it is more difficult to detect if marginal, especially under live P.A. conditions. To assist in determining overload, some equipment is provided with LED input overload indicators. When using such equipment, simply insert enough attenuation so that the LED seldom flashes under the loudest signal conditions.

Impedance

Modern microphones can be segregated into two general classifications: high and low impedance types. High-Z microphone impedances lie in the range of 10,000 to 40,000 ohms, and are typically around 20,000 ohms. Low-Z values range from 50 to 500 ohms, and are frequently a nominal 150 ohms. Because transformers with very low DC resistance are often an integral part of the microphone, it is not meaningful to attempt to measure microphone internal impedance with an ohmmeter.

An exact match between microphone impedance and its associated equipment is not necessary. However, high-Z and low-Z microphones must be connected to separate inputs; and, where required, matching transformers are available to convert from high to low, or low to high. Such transformers may be plug-in options provided on the electronics, or be add-on, in-cable types. To minimize hum pickup, these transformers must be designed with adequate magnetic shielding, and be positioned well away from motors, power transformers, and other equipment generating large AC magnetic fields. High-Z microphones have become less popular in recent years because cable lengths greater than ten or fifteen feet cause a reduction of high frequency response; and, in addition, high-Z connections have somewhat greater susceptibility to hum and noise pickup, even though a good grade of low capacitance, single conductor, shielded cable is used. To avoid ground-loop noise and hum, the housing and stand of a high-Z microphone should not be allowed to come into contact with other grounded items (conduit, metal flooring, other equipment, etc.).

Low impedance microphones are recommended for all permanent installations and wherever cable lengths must exceed fifteen feet (see Chart I). Two conductor shielded cable is required for the hookup. The shield, which totally surrounds the signal conductors, may consist of a thin, metallized foil and "drain" wire running the length of the cable, or alternately, a braided mesh woven of fine wires may be used. The braided construction has a longer flex life, so is preferred in applications involving frequent cable movement. Avoid the use of a widely spaced mesh or a spirally wrapped shield, since they are more prone to interference pickup, particularly SCR hash from lighting circuits. Stretchable coil cords, such as those used on guitar pickups, are frequent offenders in this respect.

Microphone Impedance (ohms)	Cable Length (feet) Causing 1 db Loss at 10 KHz
50	920
150	310
250	190

CHART 1 — Cable Capacity Loading

Phantom Connection

Some types of microphones require power to operate internal electronic circuitry. Such power may be supplied by integral or external batteries, or it may be provided from the following mixer or preamp by feeding the required DC back over the same cable conductors which carry the signal (see Figure 2). This is called a "phantom" connection. If required by the microphone, and no provision is made in the following equipment, a separate phantom power supply module may be placed in series with the mic cable. Although the balanced nature of the phantom supply minimizes interaction (and noise) between the DC and signal, a severe transient can be generated during insertion and removal of connectors in the circuit, so this should not be attempted on a live channel.

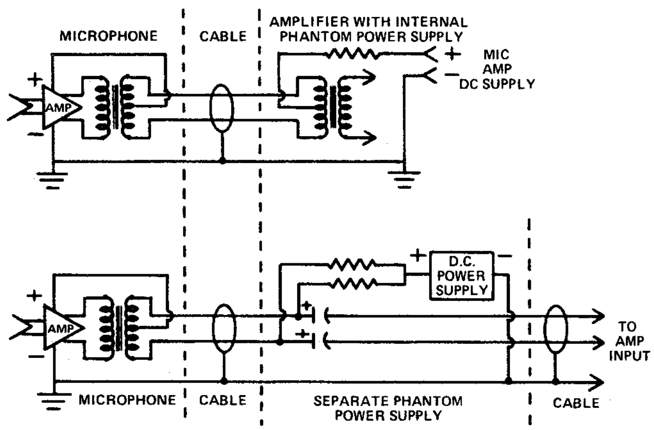

FIGURE 2 — Phantom Connections

Connectors

Usually, 1/4 inch phone plugs are used for high-Z microphone connections, and 3-pin XL style connectors are used for low impedance balanced lines. By convention, the cable ground braid, or shield, is always connected to pin 1 or to the phone plug shell. On XL connections, pin 2 is the in-phase terminal (positive pressure produces positive voltage on pin 2), in accordance with EIA standard RS-221-A. These same connectors are also popular for line level use, and the same comments on polarity apply. Figure 3 illustrates some of the most popular connectors suitable for low level and line level connections.

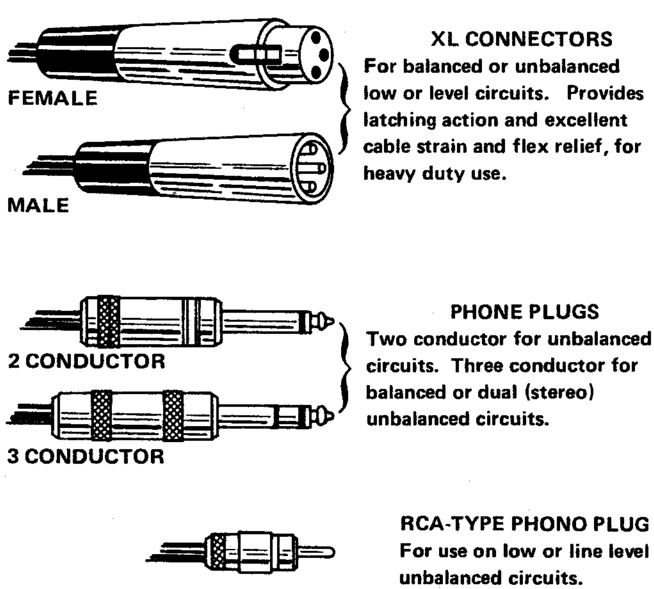

FIGURE 3 — Industry Standard Connectors

LINE LEVEL CONNECTIONS

The output of a typical microphone mixer usually provides a signal level on the order of one volt, which is considered to be "line level." If such equipment has VU meters, they are often calibrated so that zero VU reading corresponds to an output level of +4 dBm (decibels relative to one milliwatt).

Frequently, several pieces of line level equipment may be interconnected to yield the desired system performance. For example, a microphone mixer, equalizer and low level crossover may all be connected in series. Often these units are designed with a gain of unity between their input and output and have compatiable level requirements. This is not always true and it is essential that the equipment specifications be checked to assure compatible input and output levels.

Another consideration regarding compatibility of units relates to input and output impedances. It is particularly important to connect each piece of equipment to its recommended *load impedance.* Recommended load impedance, as its name implies, is that value which the device should "see" when looking forward into the circuit it is driving. Usually a *minimum* recommended load will be specified, meaning that the unit will operate properly as long as it sees a load of any impedance above this limit.

The internal impedance of an active device is not necessarily related to its load. It is that value which we would "see" looking back into the output terminals of the device. Internal impedance tells us, among other things, how much the gain will vary with changes in the external load. As stated above, active line level devices do not operate properly below a minimum *load impedance,* a value often above the device's internal impedance.

Balanced Versus Unbalanced

Another consideration when interconnecting electronic components is whether their inputs and outputs are balanced

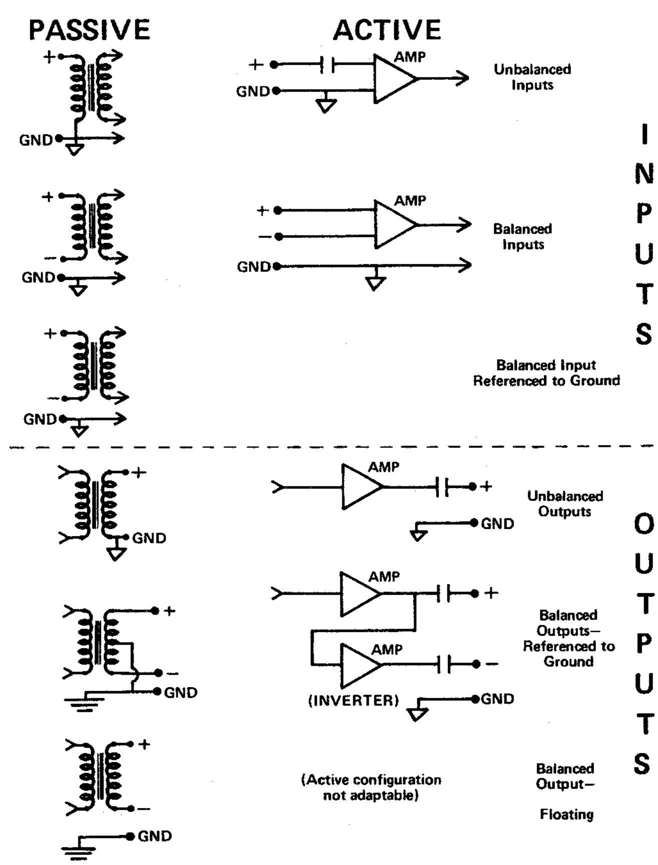

FIGURE 4 — Balanced Versus Unbalanced Connections

or unbalanced with respect to ground. A balanced system is usually preferred, particularly in more complex and sophisticated systems, due primarily to its superior freedom from interference and avoidance of ground loops. This is achieved by separating the signal and its return from the ground and shielding both paths. Figure 4 shows typical input and ouput variations.

Unbalanced systems utilize the ground for a signal return and require only two terminals, variously referred to as "hot" and "ground", "high" and "low", or "+" and "–". Balanced connections require three terminals, with ground being separate from the high and low. In preparing balanced cables, it is wise to make an ohmmeter check to insure that neither signal lead has been inadvertently shorted to the cable shield or the shell of either connector. The positive and negative terminology often used on balanced units refers to the polarity of a signal at any instant, allowing the user to tell if a signal is being reversed in phase in the equipment. This becomes important in multiple channel systems where the same phasing between reproducers must be maintained.

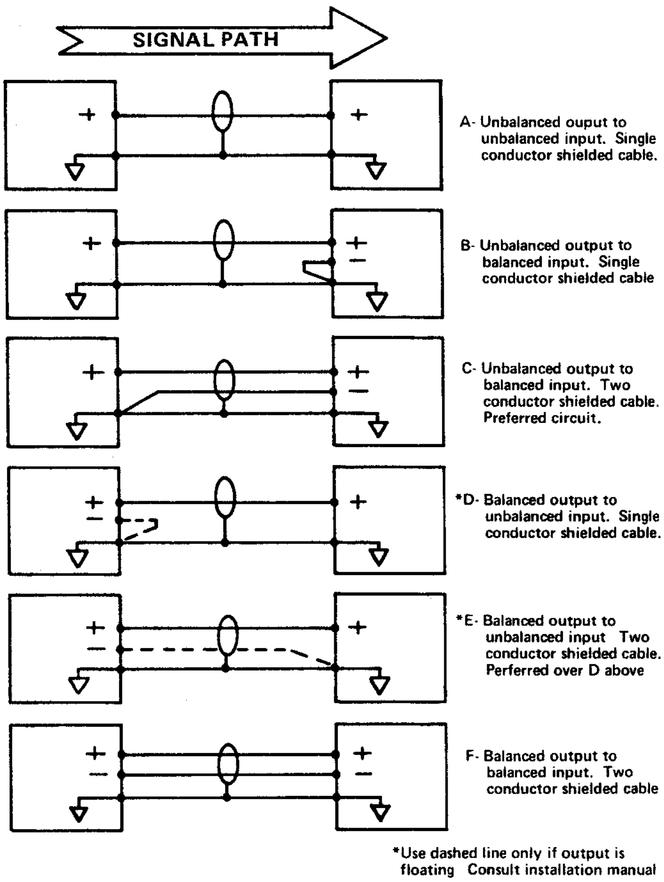

FIGURE 5 – Interconnecting Circuits

Some equipment is designed to allow either balanced or unbalanced operation. In other instances, transformers may be added as an outboard module or as a plug-in option. Figure 5 illustrates some typical connections. If hum is introduced using circuit B (as when the two pieces of equipment are separated by a long distance), circuit C can be used to avoid noise from ground currents in the shield. Similarly, circuit E may be used to advantage, but only if the output is not referenced to ground (for example, an ungrounded transformer secondary). Note that in circuits C and E, the "low" signal wire and the shield braid must be tied together only at one end, as shown. Otherwise, ground and signal currents will be combined in the signal path return, defeating the advantage of these circuits.

Circuit F, showing a completely balanced input and output provides the best interconnection and should always be selected, if compatible with the equipment involved.

It is desirable to place all line level equipment at one physical location, such as in one or more adjacent equipment racks, thus minimizing connecting cable lengths and providing good grounding. This is helpful in minimizing interference such as SCR hash and RFI (see "Definitions").

One or two-conductor (as required) shielded cable should normally be used for all line level interconnections. However, because the voltage level is typically 40 dB greater than in a low-Z microphone circuit, noise pickup is somewhat less troublesome. In fact, unshielded terminal strips can be employed as connectors, particularly when fed from a low internal impedance device. The presence of large grounded areas of metal in the vicinity, such as the chassis, adjacent equipment, equipment racks, etc., also help to minimize any electrostatic interference pickup by exposed signal terminals.

Interference Pickup

Interference from the outside enviroment (as opposed to hum and hiss generated within the equipment) may include hum (usually picked up from nearby power wiring) and radio frequency interference such as AM or FM broadcasting, citizens band transmitters, television sync buzz, or X-ray diathermy equipment. Also, it may include the sharp buzz generated by nearby lighting control dimmers, i.e. SCR hash.

A system may pick up interference in three ways: 1) electrostatic coupling, 2) electromagnetic induction, and 3) ground loop conduction.

Two conductors in space exhibit an electrical capacitance between them, which increases as their area becomes greater or as they move closer together. Electrostatic pickup occurs by means of this capacitance (capacity coupling, if you will). It can be largely eliminated by placing a grounded metallic shield between them, or around either one.

When two insulated wires are run next to each other for a distance, and an AC current is caused to flow through one of them, an AC voltage will appear across the ends of the other wire. This effect is called electromagnetic induction. The amount of energy transferred is a function of the mutual inductance between the wires, which increases with closer spacing between wires or with greater length. When the wires are wound into coils, the mutual inductance is further increased. This is why signal transformers are so susceptable to external magnetic fields. To reduce the coupling into (or from) a wire or coil, a magnetic shield must be employed. Such a shield is made of a magnetic material such as soft iron, mu-metal, or a number of special alloys manufactured for the purpose. The shield should enclose the part, forming a closed cylinder or box around it. If this magnetic shield is grounded, it may also serve as an electrostatic shield at the same time. Magnetic shielding is ordinarily required around all microphone and line level signal transformers. Even so, it may be necessary to separate them from equipment producing high magnetic hum fields. If such a problem exists in an equipment rack, try increasing the spacing between low level and high power equipment. Even five inches can often make a substantial improvement. For the same reason, avoid running signal and power cables in the same bundle or conduit.

System Grounding

The term "ground" refers to conductors with a common potential. Usually, it refers to any connection to the chassis or external metal cabinet of a piece of equipment, with the ground terminals on each piece of equipment tied together forming a common "system ground." An "earth" ground is the zero or reference potential of moist earth as measured in a system of conductors buried in the earth. The metal pipes of a water supply system usually provide an excellent earth ground.

The ground, or third, wire of a power line also provides an approximation of an earth ground. However, due to ground currents flowing through the finite resistance of such wires, no two points are usually at exactly the same potential. For this reason, ideally, the system ground should be tied to an earth ground only at one point. In an enviroment where strong RF signals are present, additional care in grounding may prove beneficial. The sequence in which these connections are made can be important in preventing the formation of a ground loop, which may introduce hum and noise into the system.

Various safety requirements mandate that most professional equipment be supplied with a three wire power line cord. This connects each of the various chassis to the power line ground, and largely eliminates the possibility of incurring a potentially lethal shock when touching a defective piece of equipment and a true ground at the same time. Unfortunately, it can also complicate the elimination of ground loops. This subject becomes quite involved, and will be discussed in a later supplement.

Crossovers

It is sometimes advantageous to divide an electrical signal into two (or more) frequency bands and connect each band to a transducer optimized for a limited frequency range. The device which divides the signal into these appropriate

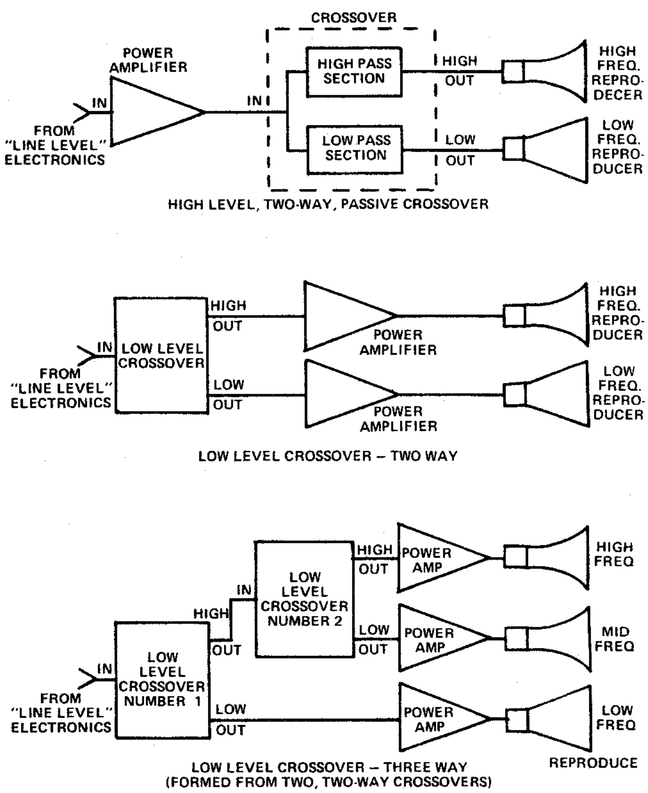

FIGURE 6 — Crossovers

frequency bands is called a crossover. A crossover may be connected between the power amplifier and reproducers as shown in Figure 6. Passive circuitry, consisting chiefly of capacitors and inductors, is employed in a high level crossover, so named because of its circuit location following the power amplifier. In some instances, it may be built into the transducer or into the system enclosure.

Low level crossovers, on the other hand, may be either active or passive, and are wired as shown in Figure 6. The low level crossover system offers a number of advantages over high level crossovers, but requires additional power amplifiers. The term "low level" indicates a crossover operating at line level in front of the power amplifiers.

POWER AMPLIFIER CONNECTIONS

The signal input to most present day power amplifiers is considered to be line level, requiring in the region of 1/2 to 2 volts to drive the unit to its full output. Power amplifier output levels are much greater than those at line level; and, in addition, the impedance is considerably lower. These factors combine to eliminate the need for shielding of the output circuit wiring. To avoid excessive power losses, however, a much heavier gauge of wiring must be employed.

Two distribution methods are in use to deliver the audio power from the amplifier to the speakers. Where it is necessary to adjust the comparative loudness level of a number of speakers, a 70 volt line distribution system is popular. Let us first consider the other method, however, in which a direct connection from amplifier to voice coil is used. Since the impedance of a horn driver or speaker is typically only eight ohms, any small resistance (impedance) in the wiring, which is effectively in series with the load, will result in a voltage drop and hence a power loss. Unlike most transducers, the impedance of this wiring is almost identical with its DC resistance, so these terms may be used some-what interchangeably. Also, readings from an accurate low-range ohmmeter are valid for checking losses. To measure wiring resistance, remove system power, place a heavy jumper wire across the load, and after disconnecting at least one lead from the amplifier output, measure the resistance at the amplifier end of the wiring. As an extreme example, wiring having a 3.3 ohm resistance, driving an 8 ohm load, will rob half (3 dB) of the amplifier power output. This power loss shows up as a slight heating of the wires. A more reasonable design would allow a power loss of 1/2 dB (approximately 12%). Total resistance with an 8 ohm load would then be held to less than 1/2 ohm.

Wiring resistance should vary with load impedance, with a 4 ohm circuit requiring heavier conductors, and with proportionately relaxed requirements for 16 ohms. A wire table (Chart 2) tells us that for a distance of forty-eight feet between amplifier and a 4 ohm load, 14 gauge wire is required. This wire may be either solid or stranded copper, depending upon flexibility requirements. Of course, halving the distance will also cut resistance in half, just as doubling it will increase resistance by a factor of two. In calculating resistance using Chart 2, do not forget that since there are two wires in the circuit, the total wire length is twice the distance between the components. For permanent installations, 12-2 or 14-2 house wiring is popular, while the flexibility of 14 or 16 gauge "zip cord" is favored for portable setups.

Obviously, the terminals used in these low impedance circuits must not contribute appreciable resistance. For permanent installations, solder lugs, binding posts, and heavy screw terminals are ideal. For portable equipment, banana plugs and phone plugs can also be used.

AWG Size	Resistance (Ohms/1000 Feet)	Low-Impedance 4 Ω	8 Ω	16 Ω	High-Impedance Systems 100 W/70.7V 12½ W/25V (50 Ω)	50 W/70.7V 6¼ W/25V (100 Ω)	25 W/70.7V 3 1/8 W/25V (200 Ω)	5 W/70.7V 5/8 W/25V (1000 Ω)	1 W/70.7V 1/8 W/25V (5000 Ω)
10	1.00	120	240	480	1,500	3,000	6,000	30,000	150,000
12	1.59	75	150	300	940	1,800	3,800	18,000	94,000
14	2.50	48	96	190	600	1,200	2,400	12,000	60,000
16	4.02	30	60	90	370	740	1,500	7,400	37,000
18	6.39	19	38	76	230	460	920	4,600	23,000
20	10.1	12	24	48	150	300	600	3,000	15,000
22	16.2	7	14	28	93	190	380	1,900	9,300

CHART 2 – 2-Wire Copper Cable Lengths For 0.5 dB Loss in SPL

Load Impedance

Unlike microphone circuits, a power amplifier should be matched to its rated load impedance by a factor of two to one, or closer. Too high a load impedance will simply reduce the amount of power which the amplifier can supply. Too low an impedance may not only reduce available power, but may cause protective devices (fuses, thermal cut-offs, etc.) to open, interrupting system operation. Increased distortion can also result. Some amplifiers provide multiple taps to match a variety of load impedances, while others are designed for only one, or a narrow range of values. The impedance of a typical transducer varies widely with respect to frequency, but the nominal rating is usually close to the minimum value obtained within its normal operating range. When more than one transducer is to be driven from a single amplifier, the effective load impedance may be altered, as shown in Figure 7. Parallel connection of two eight ohm transducers would match a four ohm amplifier output, for example. The series connection should be used only with identical units, which are to be driven at equal power levels.

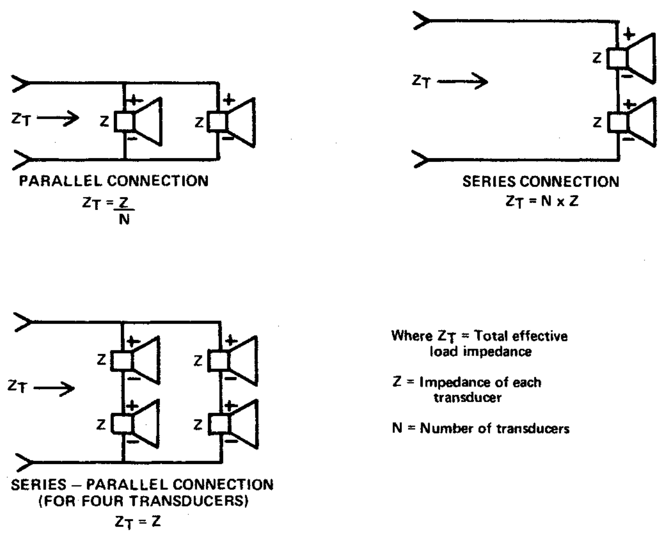

FIGURE 7 – Loudspeaker Connections

Polarity

It is important that the loudspeaker systems in a multiple array be connected in phase with each other. If one or more units is reversed in polarity from the others, frequency response, polar pattern, and/or sound levels may be adversely affected.

Output Impedance Matching Transformers

Some installations require a very large number of speakers to be operated at a relatively low level. In such applications, the 70 volt speaker line can be utilized to advantage, and is connected as shown in Figure 8. The amplifier is designed so that it will deliver 70 volts (RMS) of signal when adjusted for full power output. A transformer, with multiple taps to adjust level, is associated with each speaker. Often, these taps are labeled directly in watts corresponding to maximum amplifier output (70 V RMS). In this way, the level of each speaker may be independently adjusted. Each transformer need handle only the power drawn by its associated speaker. There is no limit to the number of speakers which can be so connected, as long as the sum of their power settings does not exceed the amplifier's rating. Not all power amplifiers operate satisfactorily into a transformer load. Therefore, unless a 70 volt output is specifically provided, the manufacturer should be consulted as to its suitability for this application.

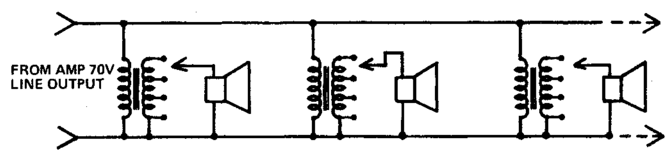

FIGURE 8 – Typical 70 Volt Line Connection

Decibel (dB)
Fundamentally, a unit of loudness. However, it is convenient to express *ratios* of electrical voltage, current, or power in terms of dB. For example, a 6 dB voltage increase to a speaker voice coil would produce a 6 dB increase in sound level, regardless of the starting point. A 3 dB increase represents the doubling of power, and a 6 dB increase, a doubling of voltage. Voltage gain of equipment is often expressed in dB.

dBv
The electrical voltage level compared to a one volt reference level. Thus, –6 dBv corresponds to 1/2 volt, +6 dBv to 2 volts, or +12 dBv to 4 volts.

dBm
The electrical power level compared to a reference level of one milliwatt. If dBm is used to indicate a voltage, the circuit impedance must be stated or understood. For example, in a 600 ohm circuit, 1 mw = 0 dB = .775 volts. Thus, at 600 ohms, a level expressed in dBm is always 2.2 dB greater than if expressed in dBv.

Active Devices
Devices requiring operating power (battery or other) in addition to the signal. Usually contain transistors, tubes, or IC's. Includes amplifiers, mixers, equalizers, etc.

Passive Devices
Devices requiring only signal power, and containing only resistors, capacitors, transformers, etc. Includes dynamic microphones, high level crossovers, speakers, etc.

Impedance
In an alternating current circuit, the ratio of the voltage to the resulting current which it causes to flow. The counterpart of resistance in a DC circuit.

Ground Loop
A condition existing when components in a system are tied to each other or to ground with more than the minimum number of wires to accomplish the connection. The duplicate paths can form a loop, which may allow circulating interference currents to flow, resulting in possible hum and noise.

RFI
Radio Frequency Interference. High frequency signals may enter at various points in the PA system. They include AM and FM broadcasts, television (continuous buzz), citizens band, nearby radar, and diathermy.

SCR Hash
Silicon controlled rectifiers, triacs, and various other semiconductors are finding increased application in light dimming and motor speed control. They generate extremely sharp wavefronts which, like RFI, can result in audible background buzz in sound systems if proper precautions are not exercised.

Signal
An AC voltage or current, representing the desired input to the system. The signal is amplified and conditioned by various system components, and appears at the output.

NOTE TO THE READER
We hope this addition of the "PA Bible" has shed some light on the diverse subject of interconnections. We appreciate receiving your comments and suggestions. Send them to

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