

**ASPI DIGITAL'S
GUIDE TO GOOD
AUDIO
CONNECTIONS**

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INTRODUCTION

In a perfect world, you would not have to worry about the audio connections between different pieces of audio equipment. You could buy your choice of equipment and a handful of cables (all the same type, of course), and connect it all together without giving a second thought to whether it would all work. Unfortunately, this is not the case! There are numerous ways to design audio connections, and manufacturers may choose any of them based on quality, compatibility, or economic issues. Care must be taken to ensure that no quality or operability is lost when putting together equipment with different connector types.

The physical differences in connectors are fairly obvious and it is easy to overcome these obstacles. A few dollars and a trip to the local electronics store can solve that problem. The possibility of a mismatch in audio signal levels, balancing, or impedance mismatch can be much more subtle and problematic. It can cause noise, hum, distortion, or even equipment damage. Even when

the same connectors are used between pieces of equipment, differences in audio levels can give you trouble. Most of these problems can be resolved with a little effort, but only if they are recognized.

This guide will provide you with some useful tips to help you minimize problems caused by mismatched audio connections. The following information will help you:

1. Understand the details of audio connections from the equipments' specifications
2. Find equipment that matches perfectly and avoids problems altogether, and if you can't get everything to match
3. Compensate for equipment differences and preserve the audio quality of your system.

BALANCED VS. UNBALANCED



A balanced connection provides excellent noise immunity from interference and ground loops. A balanced audio connection is accomplished by using a differential pair of signals, and isolating them from ground. While these connections provide great noise immunity, care must be used when connecting balanced and unbalanced equipment together.

A balanced signal has a positive version of the signal on one wire, and a negative version on the other (that is, they have opposite polarity). When

these signals are received, the negative version is subtracted from the positive. This helps in the following way: when noise is introduced onto the cable by electromagnetic interference, the noise has the same polarity on both wires. When the signal on one wire is subtracted from the other, the noise is effectively cancelled out while the original signal is preserved. An example of this can be seen in Figure 1.

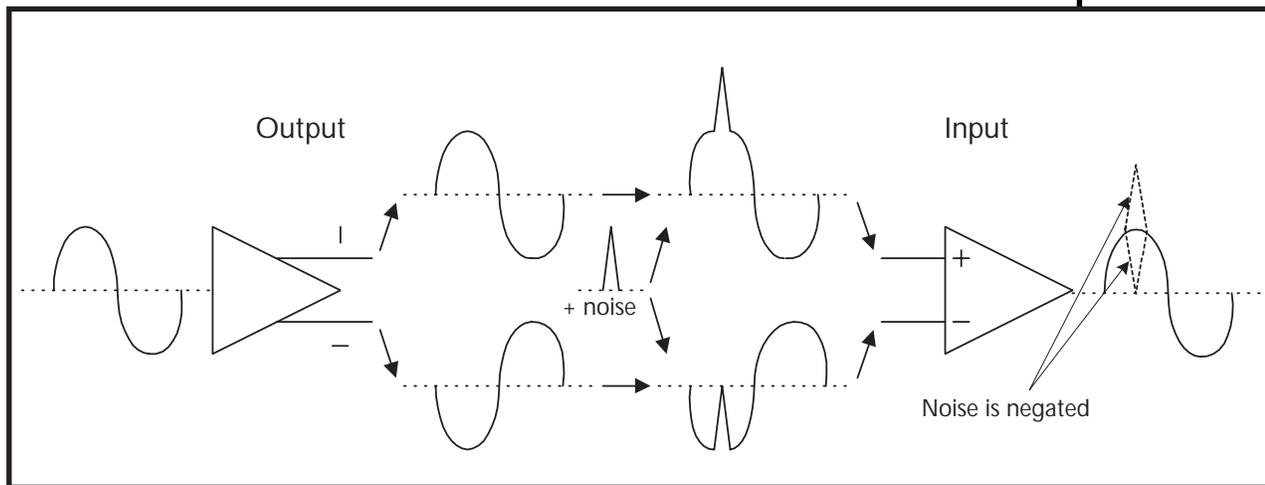


FIGURE 1. NOISE CANCELLING PROPERTIES OF BALANCED LINES. NOISE FROM ELECTROMAGNETIC INTERFERENCE IS ADDED DURING TRANSMISSION, BUT IS REMOVED BY THE DIFFERENTIAL INPUT AMPLIFIER.

Ground loops are caused when current flows from the analog ground plane of one piece of equipment to the ground plane of another. This happens when the ground plane of one piece of equipment is actually higher than the ground plane of the other. This causes a voltage difference between the two devices, so current flows. This can cause noise in an unbalanced signal because the wire carrying the signal is referenced to a ground wire. In a balanced connection, the positive and negative signals are referenced to each other, rather than ground. Since ground is not used as a signal reference, noise from ground loops can't affect the signal. It is best if you do not connect the ground planes of the two pieces of equipment at any point in order to prevent the addition of noise. Therefore, it is

recommended that you use only balanced connections between the two pieces of equipment.

Connections between unbalanced and balanced equipment should be made carefully. If possible, a transformer or direct box should be used. A direct box is a circuit which converts an unbalanced line to a balanced line and isolates the input from the output and prevents ground loops. It can be found in most stores that sell professional musical instruments. In the absence of a transformer or direct box, special wiring must be used. The wiring methods shown in Figure 2 illustrate how to connect unbalanced outputs to balanced inputs, and vice versa. This will work properly, but the noise immunity benefits of balanced connections will be lost.

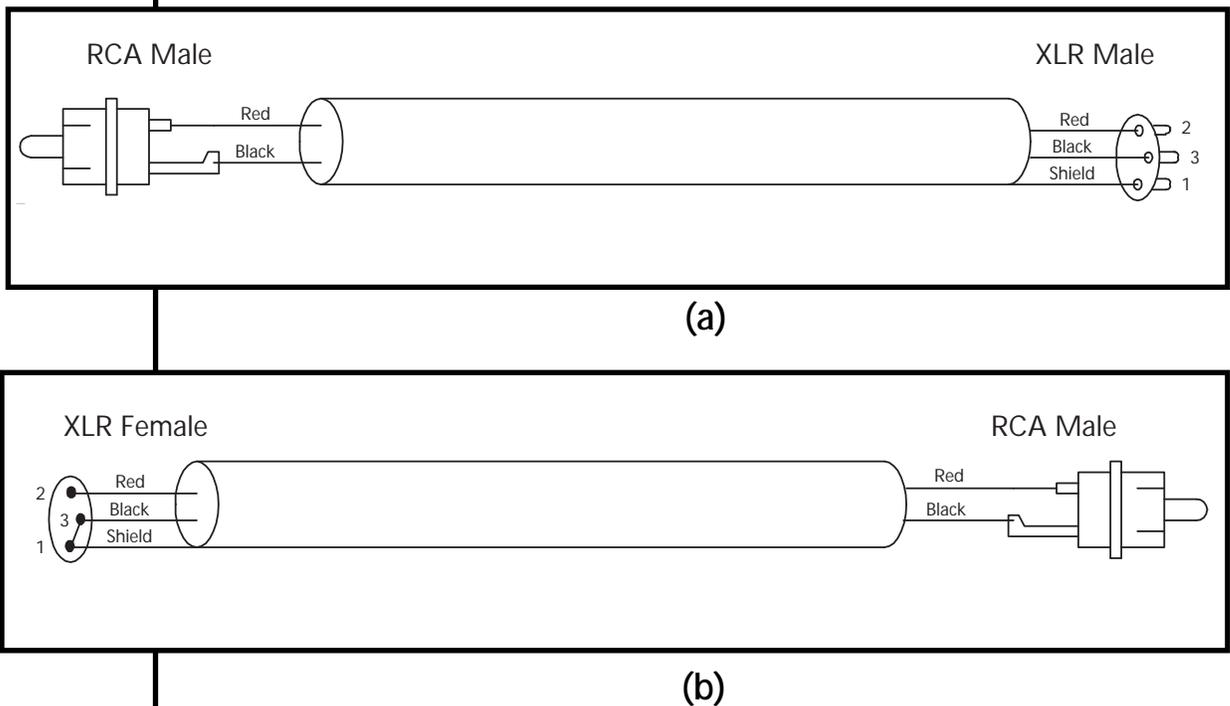


FIGURE 2. CABLE CONSTRUCTION FOR CONNECTING BALANCED EQUIPMENT TO UNBALANCED EQUIPMENT. (A) CONNECTING AN UNBALANCED OUTPUT TO A BALANCED INPUT. (B) CONNECTING A BALANCED INPUT TO AN UNBALANCED OUTPUT.

SIGNAL LEVELS



DECIBELS

A decibel is a logarithmic scale commonly used to express differences in signal levels. It is useful in audio because it can express a wide dynamic range with relatively small numbers (or a small movement on a meter), and it more closely matches how we perceive sound. The decibel scale is actually a measure of relative amplitude or power, rather than a measure of absolute power. This means that decibels are always comparing one quantity to another. For example, when we measure gain in dB, we are comparing the output level to the input level.

The formula for decibels when you are measuring amplitude (such as volts) is as follows:

$$20 \log_{10}(v1/v2) = y \text{ dB}$$

In this equation, we are comparing the level of $v1$ to the level of $v2$. If $v1$ is larger than $v2$, y is positive. If it is smaller, y is negative. For example, if $v1$ is 100 and $v2$ is 1, $y = 20 \log_{10}(100/1) = 40 \text{ dB}$. Note that if $v1$ is zero, y is negative infinity and if $v2$ is zero, y is infinity. If $v1 = v2$, y is zero.

For measuring power (such as watts) we use:

$$10 \log_{10}(p1/p2) = y \text{ dB}$$

where $p1$ and $p2$ are the power levels to compare.

Now, what happens if we want to express an absolute signal level in dB? In order to do that, we have to have some kind of reference signal level to which the level in question can be compared. We can choose an arbitrary reference, such as 1 volt. This reference goes in the place of $v2$ in the decibel equation. Then when we measure the signal in dB, we are really measuring the value of the signal compared to our chosen reference (in this case 1 volt). However, unless the reference level is obvious from the context, it must be explicitly specified; otherwise, people will not know how to convert from your value in dB back to a value in volts. This ability to refer to absolute signal levels in dB is very useful, and so there are several standard reference voltages that are widely used when measuring signals on a decibel scale. A few of these references are defined below.

COMMONLY USED DECIBEL REFERENCES

These decibel references are frequently found on datasheets of professional audio equipment.

dBm – Decibels relative to 1 mW (milliwatt). That is, 1 mW would be 0 dBm. This is defined regardless of the impedance of the load, so the voltages seen at the inputs would vary depending on the input impedance. For telecommunications applications, however, an input impedance of 600 Ohms is often assumed.

dBu – Decibels relative to 0.775 Volts RMS. That is, 0.775 Volts RMS would be 0 dBu. In applications where the load impedance is 600 Ohms, 0 dBu is the same as 0 dBm.

dBV – Decibels relative to 1 Volt RMS. That is, 1 Volt RMS is 0 dBV.

Since dBm is a power-related reference, it is widely used in applications where the input is current-sensitive, for example in some broadcast and telecommunications applications where a relatively low (600 Ohms) input impedance is common. dBu and dBV, being voltage-related references, are more widely used in applications where the input is voltage-sensitive, as is normal in consumer equipment with high input impedances.

OTHER DECIBEL REFERENCES

These decibel references are less commonly used, but may turn up in datasheets.

dB FS – Decibels relative to the full scale voltage of an analog-to-digital or digital-to-analog converter. The actual voltage will vary depending on the design of the converter.

dB SPL – Decibels of Sound Pressure Level. There are two commonly used 0 dB points for SPL. One is 2×10^{-5} N/m² (0.0002 microbar), and one is 0.1 N/m² (1 microbar). The first is more common for hearing and noise measurements. Using the first reference, 1 microbar is equivalent to 74 dB SPL.

dBr – Decibels relative to some defined reference (which should be specified somewhere). For instance, if the reference was 10 Volts RMS, a 1 Volt signal would be -20 dBr.

dBv – This is an archaic term used to refer to the voltage value corresponding to power indicated in dBm. When the load impedance is 600 Ohms, 0 dBv = 0.775 Volts RMS. This term should be avoided if possible, since it can be confusing unless the load impedance is clearly stated.

VU – A logarithmic meter commonly used on audio equipment. Generally, 0 VU corresponds to +4 dBu (the professional equipment audio level), or the saturation level of the device.



CONVERTING BETWEEN TYPES OF dB

Voltage to voltage conversions

Because all decibel measurements are based on the same logarithmic computation, you can convert between different types of decibels by using addition or subtraction. As an example, recall that 0 dBu corresponds to 0.775 Volts RMS, and 0 dBV is 1 Volt RMS. How do you convert between dBu and dBV? The difference between the two measurements is about 2.2 dB as computed as $20 \log_{10}(1/0.775) = 2.2$ so you convert the dBu level into a dBV level by subtracting 2.2 from the dBu level. In general, to find the difference d between any pair of reference voltages r_1 and r_2 , you can simply calculate $d = 20 \log_{10}(r_1/r_2)$. Then you can add d to voltages specified relative to r_1 or subtract d from voltages specified relative to r_2 to convert between them. In our example, 0 dBu = -2.2 dBV and 0 dBV = 2.2 dBu.

Power to voltage conversions

In order to convert between dBm (a power measurement) and dBu (or any other voltage decibel scale), you need to know the impedance of the load so you can convert between watts and

volts). Power is related to voltage and impedance by the equation $P=V^2/R$. For example, consider an output that has a nominal level of -10 dBm, with a load of 20 kOhms. This means that 0.1 mW is going into the 20 kOhms load, or $V^2 = 20kW * 0.1 mW = 2$. Thus, the nominal output voltage is 1.414 Volts RMS, or about 3 dBV.

Note that to convert between dB FS and some other scale, you need to know the full scale voltage of the A/D/D-A converter. Converting between dB SPL and a voltage scale can be done if sensitivity is specified in terms of voltage and sound pressure. For instance, a microphone may be rated with a maximum SPL of 120 dB SPL, and have a sensitivity of 5 mV/microbar. This means that 1 microbar (which is 74 dB SPL) is equivalent to 5 mV (which is -46 dBV). Since the maximum SPL of the microphone is 46 dB louder than 1 microbar, then the maximum output voltage level is 46 dB higher than 5 mV. This means the maximum output voltage of the microphone will be 0 dBV.

NOMINAL LEVELS, PEAK-TO-PEAK LEVELS, AND HEADROOM

When a piece of equipment has a nominal level of -10 dBV, what does this mean? On audio equipment, this means that the long term RMS voltage level of a speech or music signal shouldn't be more than -10 dBV. By itself, however, the nominal level of an input or output doesn't tell you what the peak voltage swing can be. Normally, peak voltage is measured as the peak-to-peak level of the largest sine wave that won't get clipped. This is usually quite a bit larger than the nominal level. This is because speech or music signals usually contain peaks that are much larger than the average level.

Headroom is a measure (usually in dB) of how much higher the peaks of a signal can be compared to the nominal level without clipping. That is, it compares the peak level (in volts RMS) to the nominal level (in volts RMS). The difference between the two (in dB) is the headroom.

Let's look at an example. If a piece of consumer equipment has a peak-to-peak input level of 2.8 Volts, this means that a 1 V RMS sine wave could be put into it without clipping since 1 V RMS means the signal has an amplitude of about 1.4 V which means the signal is 2.8 V peak to peak. This is equivalent to saying the peak input level is 0 dBV. Since the nominal level of most consumer equipment is -10 dBV, we have only 10 dB of headroom.

Most consumer equipment can handle 2 V RMS, giving it 16 dB of headroom. For professional equipment, headroom should be on the order of 20 dB.



CONSUMER VS. PROFESSIONAL: A CASE STUDY

Consumer and professional are two broad classes of audio equipment that may be used together at times. This distinction between consumer and professional audio is more than price or perceived quality. There are actually differences in audio signal levels that may cause problems. These are the same problems that occur with any signal level mismatch, but this problem is so common that we will give it special attention.

Professional audio equipment generally has a nominal level of +4 dBu, while consumer audio equipment usually has a nominal level of -10 dBV. This means that professional audio is about 12 dB louder (or "hotter") than consumer equipment. (Remember to compensate for the difference between dBu and dBV!)

This difference in levels can degrade audio quality in two ways, depending on how the equipment is connected. If the output of the professional equipment is plugged into the input of the consumer gear, the higher levels of the professional signal may overdrive the input, causing distortion. If the output of consumer gear is plugged into the input of professional equipment, the signal levels will be lower, which would mean an overall lower signal to noise ratio and the input signal may be barely audible. These problems to some extent will be present with any difference in audio levels

IMPEDANCE

Impedance can be tricky, because sometimes you want to match the load to the specified impedance of an output, and sometimes you want to exceed it. Impedance matching is important in radio and telephony, because it minimizes signal reflections when sending a signal over a cable run between two pieces of equipment. If you have long cable runs and an impedance mismatch the quality of your audio signal can be compromised.

Impedance matching is also important between audio amplifiers and speakers because it ensures the maximum transmission of power from the amplifier to the speaker. With line level audio connections, the signal information is transferred as a voltage level and there is no significant transfer of power (current) from one component to the other. In this case, it is simply necessary to meet or exceed the specified load resistance.

When connecting two pieces of equipment, you want to avoid a situation where the destination equipment's input impedance is lower than the source equipment's output impedance. This will cause too much current to flow from the output (source) to the input (destination), which reduces the output voltage. Also this may degrade signal quality or even damage the output

device due to the increased power dissipation. In general, the highest signal quality will be attained when the input impedance of the destination equipment exceeds the rated load impedance of the output of the source equipment.

Balanced connections are often used in applications which require careful impedance matching. If such signals are connected to equipment with incorrect impedances, severe distortion or signal loss may occur. For example, many microphones have very high output impedance and produce low-level signals that must travel significant distances before reaching an amplifier. If such a signal is connected to a low impedance input, it will be unable to drive the input, thus attenuating or possibly distorting the signal. Another example can be found in broadcast and telecommunications applications, where some types of equipment are designed to mate with 600 Ohms input and output impedances; again, signals may be attenuated and distorted if connected to the wrong type of equipment.

If a balanced cable must be modified to connect it to an unbalanced input or output, it is possible that this will cause impedance matching problems. Extreme caution should be exercised to verify that nominal signal level and impedance requirements are matched.



COMMONLY USED AUDIO CONNECTORS

There are a variety of audio connectors used on equipment. The most common are shown below. If the connectors on your equipment do not match, it is easy enough to make a custom cable or buy an adapter from your local electronics store. Keep in

mind, however, that different connectors are often an indication that there are other differences in the connection (such as balanced vs. unbalanced or consumer vs. professional).

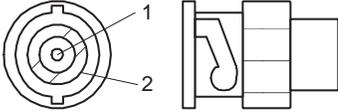
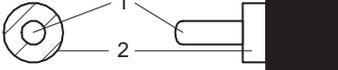
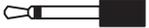
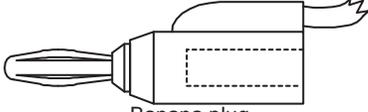
 <p>T R S 1/4" (Phone)</p>	 <p>1 2 BNC</p>	 <p>Male Female Tini Q-G</p>
 <p>T R S 3.5mm (Mini)</p>	 <p>1 2 RCA (Phono)</p>	 <p>Male Female XLR</p>
 <p>T S 2.5mm (Micro)</p>	 <p>Banana plug</p>	<p>1: Shield 2: Positive signal 3: Negative signal</p>
<p>T: Tip - positive signal or left R: Ring - negative signal or right S: Sleeve - ground or shield Ring is optional</p>	<p>1: Positive signal 2: Ground or shield Banana plug has no ground!</p>	<p>1: Shield 2: Positive signal 3: Negative signal</p>

FIGURE 3. AUDIO CONNECTORS. SOME OF THE MOST COMMON AUDIO CONNECTORS ARE SHOWN HERE. THEY ARE MALE CONNECTORS UNLESS OTHERWISE NOTED.

Banana plugs — These connectors have single conductors, and may not be shielded. Each connector may have both a male end and a female end; this allows multiple banana plugs to be connected together, and to the same jack. They are often found in pairs, and are sometimes used in speaker connectors.

BNC — This is an unbalanced connector designed for high-frequency signals, often found on laboratory equipment (oscilloscopes, etc) and on video equipment. Equipment using BNC connectors often requires impedances to be matched to the characteristic impedance of the cable. It has a twist-lock mechanism to keep cables in place.

1/4" (Phone) — These connectors are used on high-quality audio connections, often with high-quality shielded cable. They may be found on electronic music equipment, such as electric guitars and microphones, and on the headphone outputs of home stereo systems. They can have two conductors (or a single conductor plus shield) for unbalanced mono connections, or 2 conductors plus shield for balanced mono or stereo connectors. They may be found in low impedance balanced signal applications, or in high-impedance equipment. They are often used in place of XLR-type connectors.

3.5mm (Mini) — This is a smaller version of the phone plug, frequently found on computer sound cards and personal stereo headphones. It is usually used with a stereo cable.

2.5mm (Micro) — This is an even smaller version of the phone plug, but is not frequently used.

RCA (Phono) — This is an unbalanced connector, typically found on consumer equipment such as home stereo systems. The cables are often mated in a stereo pair, and are generally not well shielded. If shielded cable is used, the shield is usually used to carry the signal ground.

XLR-type — This is a balanced connector, with three pins for signal positive, signal negative, and shield. It is most often found on professional audio equipment and microphones. XLR cables have one male end and one female end.

Tini Q-G — This is a small version of the XLR connector, often found on tabletop microphones used in conferencing.



OTHER CONSIDERATIONS

PHANTOM POWER

Phantom power is a DC power source that is used to bias, or charge, the diaphragm of a condenser or electret microphone. This type of microphone needs phantom power to operate, while a dynamic microphone does not. The phantom power required by your microphone (usually between 15 and 50 volts) should be specified on the microphone's datasheet. Choose a microphone preamp or mixer that can supply the phantom power voltage needed by your microphone (or conversely, choose a microphone to match your other equipment). If none of your equipment supplies phantom power, you can buy a microphone preamplifier that supplies the appropriate phantom power voltage.

CABLE QUALITY

While it is not necessary to get the most expensive, audiophile quality cables for a conferencing system, you should avoid using cables of poor quality. It would be unwise to degrade the quality of an expensive, quality conferencing system by skimping on the cables. Whether you are constructing your own cables, or buying them off-the-shelf, here are a couple of things to look for:

1. Shielding is extremely important. Shielding protects signals from electromagnetic interference and cross-talk from other cables. As cable length increases, good shielding becomes more essential.
2. Balanced connections provide immunity from noise. Balanced connectors minimize problems due to electromagnetic interference and ground loops, and should be used whenever possible.
3. Durable cables and connectors. The durability of cables and connectors is very important. You don't want to waste time tracking down audio quality problems caused by intermittent connections or broken cables. Choose metal connectors, rather than plastic, if possible. Use durable cable, preferably reinforced near the connector to relieve stress at that point.
4. Run balanced as far as possible before converting to unbalanced. If it is necessary to connect unbalanced equipment to balanced, run the balanced as far as possible before converting and carry the unbalanced signal on a two-conductor shielded cable (rather than using the shield as one of the conductors). This helps get most of the benefits of a balanced connection.

SUMMARY



It is always a good idea to match all aspects of the connection. This causes fewer problems with audio quality, and require less effort to fix these problems. If matching audio equipment cannot be found, follow these guidelines for matching connections:

1. Phantom power. If a microphone needs phantom power, it simply will not work without it. If the other equipment in the system does not provide it, you will need to add something that does (or choose a different microphone).
2. Balanced connections. Use balanced connections wherever possible, especially for long cable runs. Connecting a balanced connection to an unbalanced connection can result in hum and impedance matching problems. If balanced connections cannot be matched, use a transformer, a direct box or a wiring scheme to compensate.
3. Signal levels. Signal levels should be matched to avoid distortion and noise. If levels cannot be matched, use appropriate volume levels or use amplifiers or mixers between the pieces of equipment to match the levels.
4. Physical connectors. A mismatch in physical connectors won't really harm audio quality, and can be compensated for easily. However, it is often an indication that there are other differences (such as nominal signal levels) in the connections that need to be addressed.

ABOUT ASPI DIGITAL

For over 17 years, ASPI Digital, a privately-held corporation headquartered in Atlanta, Georgia, has specialized in the development of new and innovative digital signal processing (DSP) products for real-time voice and audio systems. ASPI's echo cancellation and signal compression technologies are used by OEMs and other clients worldwide. ASPI is focusing its DSP and real-time system expertise on building solutions that improve the way people communicate remotely. ASPI also supplies its technology at the board and component level, enabling customers to incorporate these technologies into their product or system with a minimal amount of time and effort.

ECHOFREE™ EF400 ACOUSTIC ECHO CANCELLATION SYSTEM

The EchoFree™ EF400 is a stand-alone high quality acoustic echo canceller designed for simple set-up and automatic operation. ASPI Digital's superior AEC algorithm permits its use in the most demanding environments. It is ideal for distance learning classrooms, conference rooms, courtrooms, and other audio or video conferencing applications where the acoustic conditions demand improved AEC performance.