Audio Systems

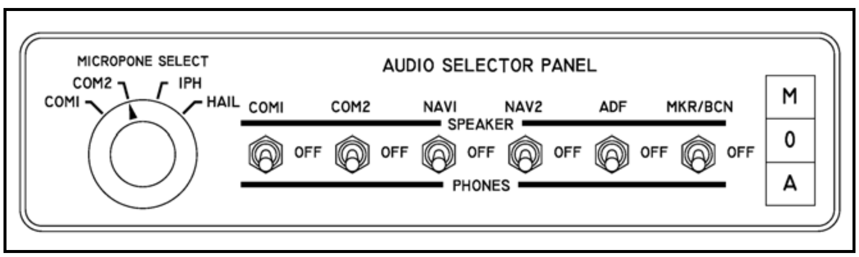

Figure 18-1. Typical Audio Selector Panel for Spam Can

If you have more than one source of audio to attach to your headphones, you'll need some manner of audio system. Many certified aircraft feature audio selector panels capable of managing audio output from a number of receivers and routing microphone inputs to two or more transmitters. They might also offer a marker beacon receiver and intercom features. A multi-engine aircraft might be fitted with a speaker in the nose wheelwell wired to a small public address amplifier in the audio panel. The pilot can select a "hailing" operation where it's possible to speak to persons on the flight line with sufficient volume to be heard over ambient noise. If one wished to play ATC communications or an AM radio broadcast through a speaker in the cockpit overhead, one simply moved the audio selector switch for that radio to the SPEAKER position. Aircraft manufacturers of yesteryear were loath to admit that their cabins were uncomfortably noisy . . . I wonder if current production single engine aircraft have cabin speakers?

In a more practical age, it's an easy sell to suggest that the cabin noise levels in piston engine aircraft are at best uncomfortable and worst unhealthy. Cabin occupants enjoy the experience more and land less fatigued when headsets and microphones provide ambient noise reduction and a conduit for more relaxed communication. Many commercial audio panels provide an interphone or intercom function as well.

The audio panel illustrated in Figure 18-1 is a sort of mid-range product that might be found on a well fitted single engine or light twin aircraft. Turboprops and bizjets are more likely to have independent audio selector panels for pilot and copilot where either crew can be listening and talking on their choice of radios.

If we're to understand audio switching philosophy, we first need to discuss the energy details of how audio systems work. In particular, we need to understand terms like "impedance" and how it is used and misused when speaking of the capabilities of system components. It's not uncommon to see the output specification for an audio amplifier stated as "100 milliwatts into 600 ohm load."

Many individuals including folks who sell these products believe this means the output impedance of the amplifier is 600 ohms. Not so . . . and it's important to understand why. Consider your ship's battery as an energy source. In previous chapters we've discussed the importance of low internal resistance. If you want your 12 volt battery to deliver 200 amps to a starter (an effective load on the order of 0.05 ohms) then we'd be very pleased if the battery had NO internal resistance. Of course, there's no such thing as a perfect battery but it's not uncommon for a 12 volt RG battery to have an internal impedance on the order of 10-12 milliohms or less.

Borrowing from the chapter on batteries, I've shown in Figure 18-2 how the battery delivers power to the starter with reasonable efficiency. In this case, about 20% of system power is expended in the battery's internal impedance of 12.5 milliohms with 80% of it being used to drive the motor with an effective impedance of 50 milliohms. In audio system parlance, we might say that the battery's output is capable of delivering 2,000 watts

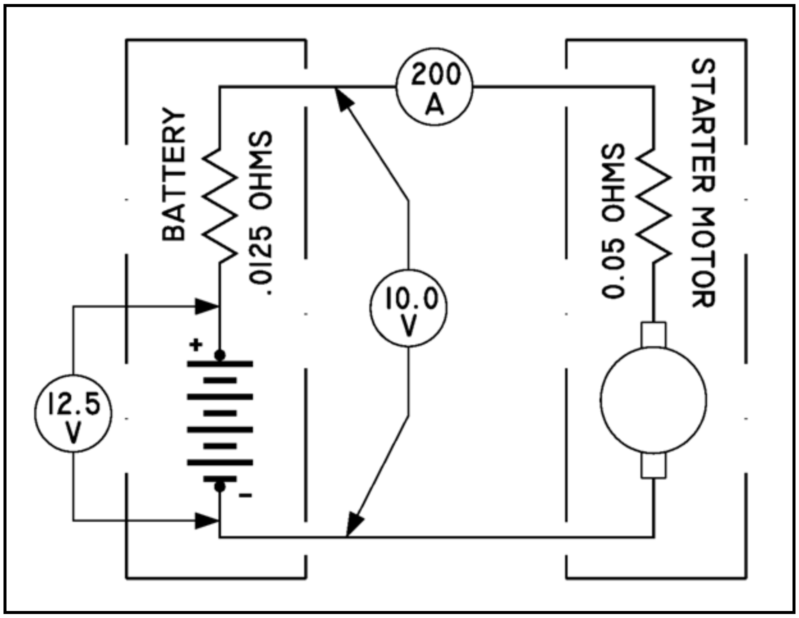

Figure 18-2. Battery Internal Impedance

into a 50 milliohm load. This does not mean that the battery's output impedance is 50 milliohms.

Suppose it WERE 50 milliohms. An internal impedance of 50 milliohms in series with the load impedance of 50 millohms makes for a total of 100 milliohms. This means that the MAXIMUM current the battery can deliver to the motor is reduced to 125 amps with HALF the total energy being dumped off as heat internal to the battery.

Okay, let's consider the case of an audio amplifier intended to deliver energy to a pair of headphones in Figure 18-3. The design goals for the amplifier are no different here than for the design of a battery. We'd like for the internal resistance (R) of the intercom to be as low as practical. Typically, a modern integrated circuit headphone amplifier will have an output impedance on the order of 5 ohms or less. This is an important consideration when we start to combine multiple audio sources into the headset system. The same rules apply whether the audio comes from a comm transceiver, an intercom amplifier, or a stall warning tone generator.

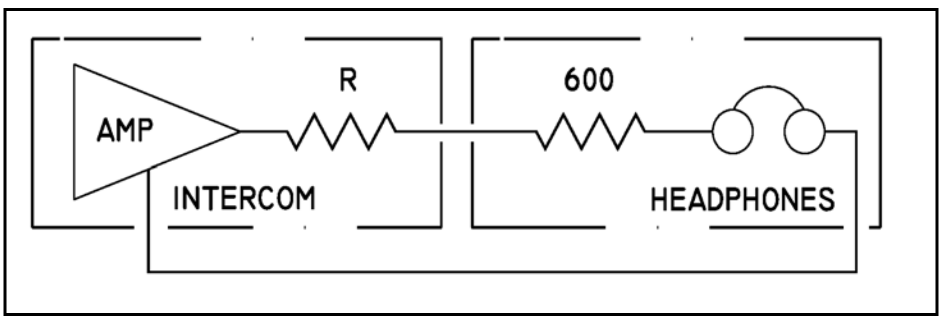

Figure 18-3. Audio Amplifier Internal Impedance

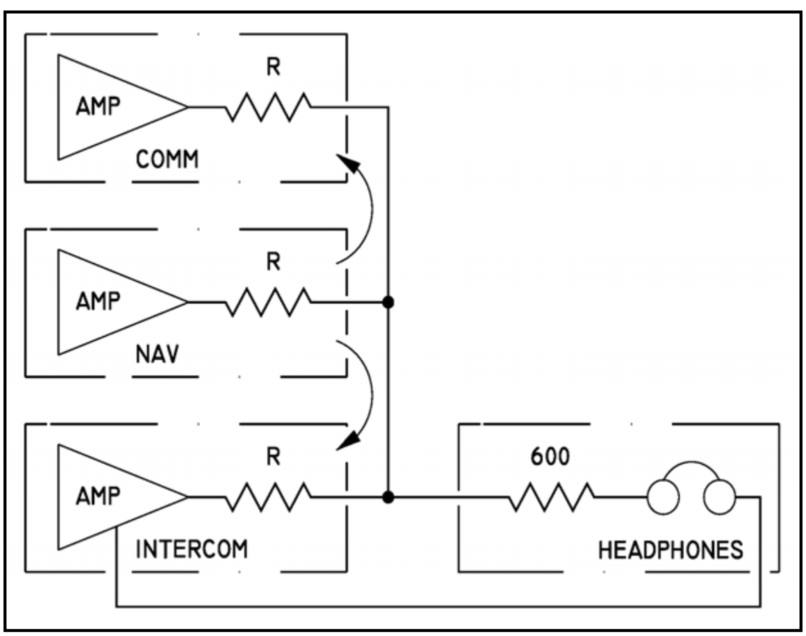

Figure 18-4. Paralleled Audio Sources

Let us consider potential problems with simple combining of audio sources to a single headset. Figure 18-4 I've hypothesized a comm transceiver, nav receiver and intercom outputs simply paralleled and connected to a headset. Let us suppose the nav receiver is trying to talk to us. Its output is indeed connected to the headset but what does the nav receiver "see" in the way of loads when looking back into the comm and intercom amplifiers? Two very low impedance values with a sum that is a small fraction of the headset load. Compared to the expected 600 ohm headset load, the amplifier sees what appears to be a nearly dead short as a load.

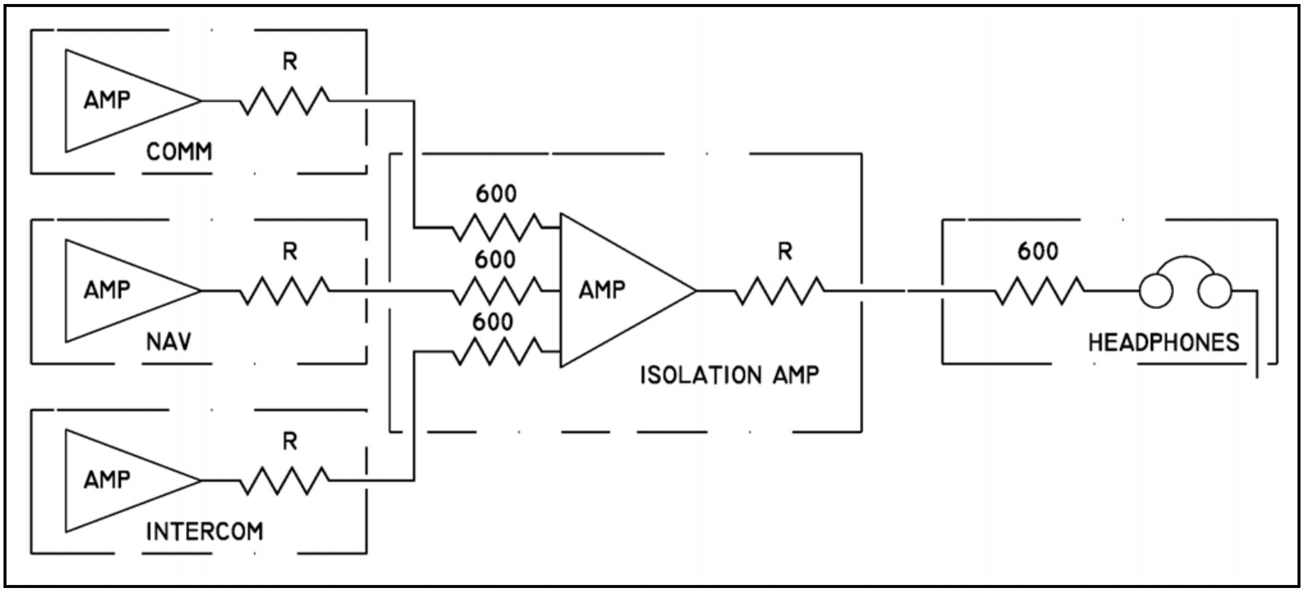

Figure 18-5. Audio Isolation Amplifier

Net result is that MOST of the audio energy is dissipated in the companion sources that are also low impedance LOADS with very little left over to tickle the headphones.

The solution is to craft a means of mixing multiple audio sources together in a manner that has each source believing that it's driving a pair of headphones. Headphones present some "load" to the source that a source can only identify in terms of its electrical characteristics. In this case, we're looking for a way to "load" each source with a reasonable impedance and do it in a way that isolates each source from the effects of loading by the low output impedance of companion sources - hence the term "isolation amplifier."

Figure 18-5 illustrates the functionality of an isolation amplifier. Multiple inputs (each having some characteristic that approximates headphones) are independently combined in a mixing amplifier which in turn drives headphones.

Stereo Audio Systems

Many pilots and their passengers enjoy listening to stereo music or radio while en route. The only difference between

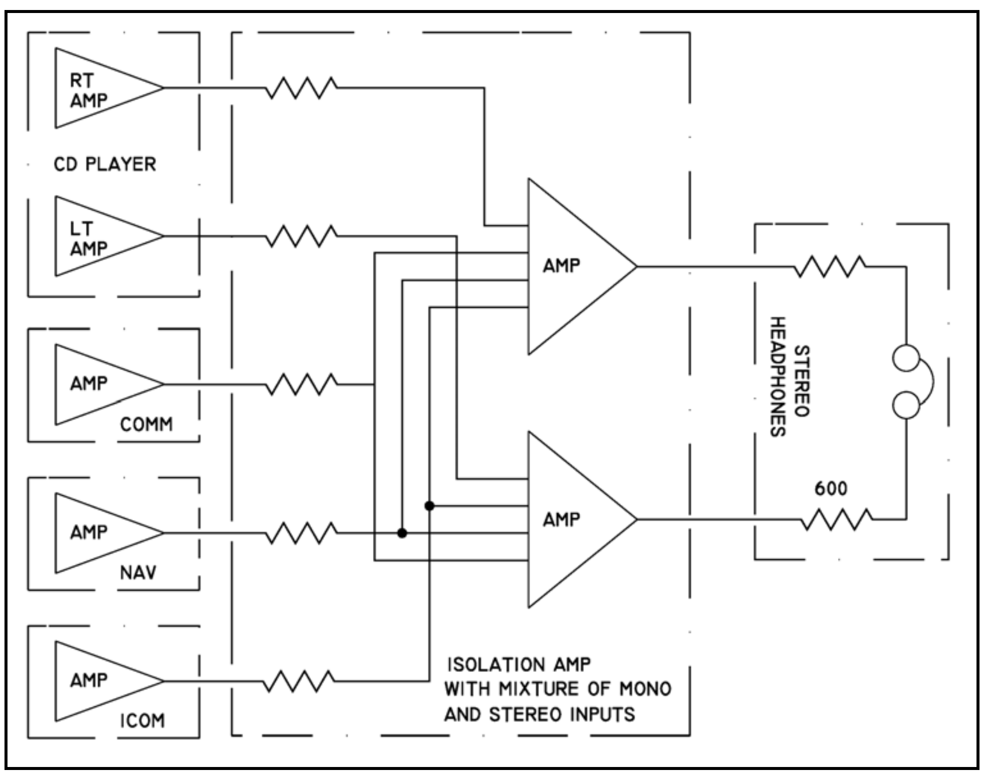

Figure 18-6. Stereo/Mono Isolation Amplifier

monophonic and stereo audio systems is that there are two channels of audio connected to right and left ear pieces of a headset. Figure 18-6 illustrates a technique for combining two monophonic isolation amplifiers in a single assembly. Stereo audio from the music source is routed to separate amplifiers while monophonic sources (avionics and warning tones) are routed to both channels simultaneously.

Note that I don't show the resistor that accounted for the output impedance of each amplifier. That doesn't mean they aren't there. I needed to simplify the drawing so it would fit nicely on the page. ALL sources of energy have an output impedance associated with them whether it's an alternator, battery, audio amplifier, microphone, etc, etc. ALL devices that load an energy source have a load or input impedance. If one is having difficulty achieving the desired behavior in any combination of components, characteristics of output and load impedance should be part of the consideration for trouble-shooting the design.

When you're installing plug-n-play hardware such as intercoms, radios, entertainment systems, etc. the manufacturer should do his reasonable best to describe a wiring scheme that produces acceptable results most of the time. However, when your game plan requires some departure from (or expansion of) the original system concept, be prepared to deal with the not-so-obvious issues like we're discussing here.

In the world of $high$ airplanes we call the chefs "avionics integration experts." Had a fellow working for me at Lear on the Gates-Piaggio program back about 1982. He had a wealth of experience with the input/output characteristics of most popular system accessories. He could sit down with the installation manuals of any combination of systems and produce wiring diagrams with 99% probability of successful operation first time it was turned on. A number of folks joined and left the group over my tenure at Lear . . . none of these transitions gave me heartburn. However, if my integration guy had suffered itchy feet, he would have been very difficult to replace.

It's not uncommon for a builder to post a note on a discussion group asking whether or not his particular box of goodies can be installed in his airplane. The answer is almost always a qualified "yes" but then he's disappointed that nobody can offer a turnkey description of the task. It's not a matter of lack of knowledge or skills on the part of respondents but a lack of experience with that particular combination of goodies. Just about any combination of accessories can be successfully integrated into your project but be aware that some interface issues may take some detective work where signal characteristics combined with energy transfer (output impedance vs. load) will have to be understood and accommodated.

Audio System Controls

There's something appealing about an airplane panel covered with dials, switches and knobs. But when you consider the pilot to be an integral and critical component of the low-risk flight system . . . consider the real value of any cockpit accessory. Does it increase work load or reduce work load? Will inadvertent misplacement of the control markedly increase risk? One time I came close to dying in an airplane was after I announced my intentions to back-taxi on a runway, I pulled onto the asphalt to find myself looking down the business end of a light twin that had just landed.

They say every accident is always a series of conditions that set up the end result. It was just before sundown on a cloudy day. The twin had made a flat approach and was below the tree-line beyond the far end of the field. I didn't see any traffic in the "sky" and he wasn't running forward shining lights. I was listening to the right frequency but my radio got tuned after he announced short final. My microphone selector switch was set to the wrong transmitter so my announcement to take the runway wasn't heard by the other pilot.

I gunned it and headed for the grass, he applied power and did a touch-n-go . . . we didn't really come close enough to yell at each other but that was only a matter of random good fortune in timing.

IF he had turned on landing lights, IF I had turned to local advisory frequency a few seconds earlier, IF I had selected the right transmitter, IF . . . . well, we all know how it goes. So just a word to the wise when you configure the controls for a sub-system that plays a role in setting the odds for an enjoyable day of flying. The switch set wrong or knob turned to the wrong position may be the last link forged in the chain that drags you into an accident.

Radios with audio outputs always have volume controls. Many audio sources in the form of alarm tones have screwdriver adjustments for volume so that the installer can set the warning tone level to harmonize with other sources. If you build a warning tone generator (stall warning, gear warning, canopy warning), consider inclusion of screwdriver adjustments for output levels on each tone.

Headsets often have volume controls built in. These are handy when headsets with different efficiencies are paralleled on a single isolation amplifier. If volume of all sources is optimized for one occupant of the cockpit, they may be too loud or too soft for the other.

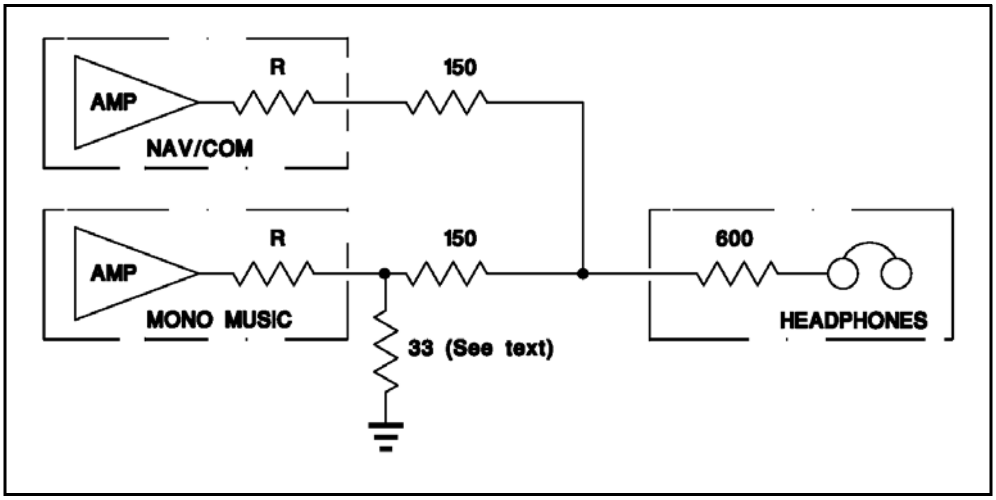

Figure 18-7. Headphone Audio for a Rudimentary Avionics System.

The very simplest audio system has no selector switches, no volume controls other than those provided on the audio source and headphones. In these cases, set up is also simple. Adjust headset controls for 2/3 of max volume. Set warning tones for a level just under comfortable listening levels for radios. After that, it's a simple matter of turning the volume up or down on the radio that you want to listen to or de-select.

This philosophy (assuming no cabin speaker and associated amplifier) makes it possible to craft an audio system without source selector switches like those shown in Figure 18-1.

Single Seat Rudimentary Avionics

Let us suppose your airplane is a single seat, day/vfr machine with a Nav/Com and a monophonic tape player. Your headphone mixing system may well be as simple as a pair of 150 ohm, 1/2-watt resistor wired as shown in Figure 18-7.

The biggest risk with this simple architecture is the potential for distorted audio from the tape player (or any other entertainment audio source) because its audio output system is designed to drive a much lower load impedance. In this case, one might have to artificially load the audio output line of the entertainment system. I show a 33 ohm resistor here (most lightweight headphones designed for portable use have an impedance in the 35 ohm range). The same condition may exist for stereo systems as well . . . you'll need a load resistor for each channel.

Two Seat Rudimentary Avionics with Intercom

Figure 18-8 climbs a little higher on the hill of audio system complexity. A two seat airplane is likely to have an intercom system. Further, many manufacturers offer aviation intercom systems designed to drive stereo headphones and to accept stereo audio from an entertainment system.

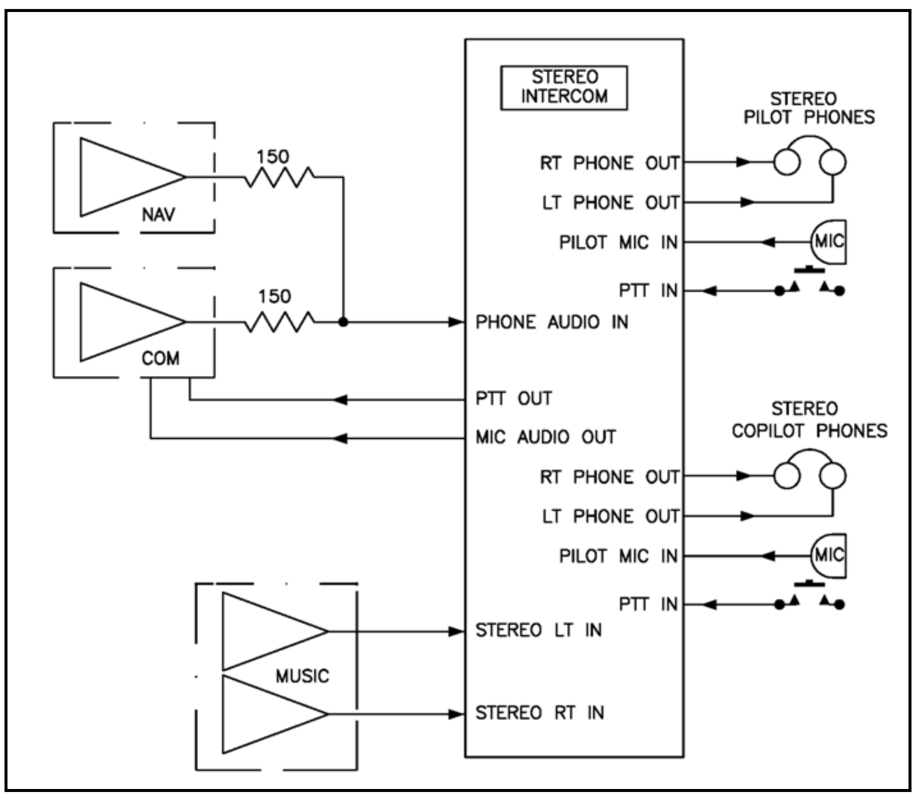

Figure 18-8. Rudimentary Avionics, Stereo Music and Intercom.

Some stereo compatible intercoms also offer a crew-isolate function switch that separates the pilot audio system from the copilot system so that the passenger can continue to listen to the entertainment system while the pilot is working with pilot duties and would do best without distractions from the entertainment system. Intercom systems are universally designed to accept a single monophonic audio source from the ship's radios. If you have only two sources of aviation audio as illustrated here, then the simple resistor-mixer network suggested in Figure 18-7 may be used here as well.

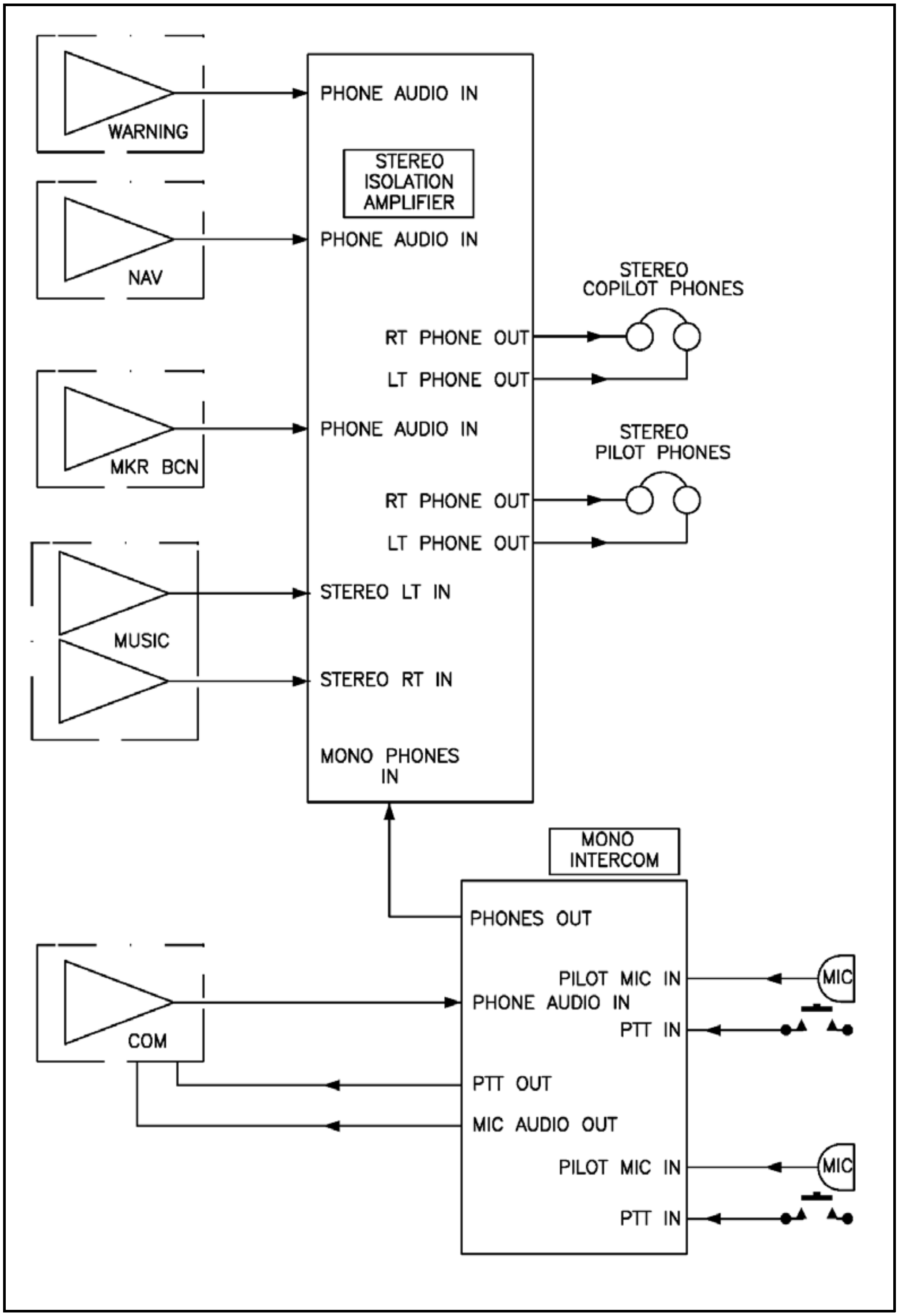

Figure 18-9. Mono Intercom, Stereo Isolation Amplifier and Multiple Avionics.

Intercom System Selection

It's my recommendation that whatever intercom system you choose to fly with, make it a panel mounted system as opposed to portable. Panel mounted systems will offer a means by which the intercom may be powered from the ship's electrical system.

Further, panel mounted intercom systems will be fitted with connectors, usually D-subminiature, that are a whole lot easier to wire to your radios than fussing with cords that come with portable systems. Finally, the panel mounted system will look like it belongs in your airplane.

Full-Up Audio Systems

Audio selector panels typical of that illustrated in Figure 18-1 will include an audio isolation amplifier. In fact, most.

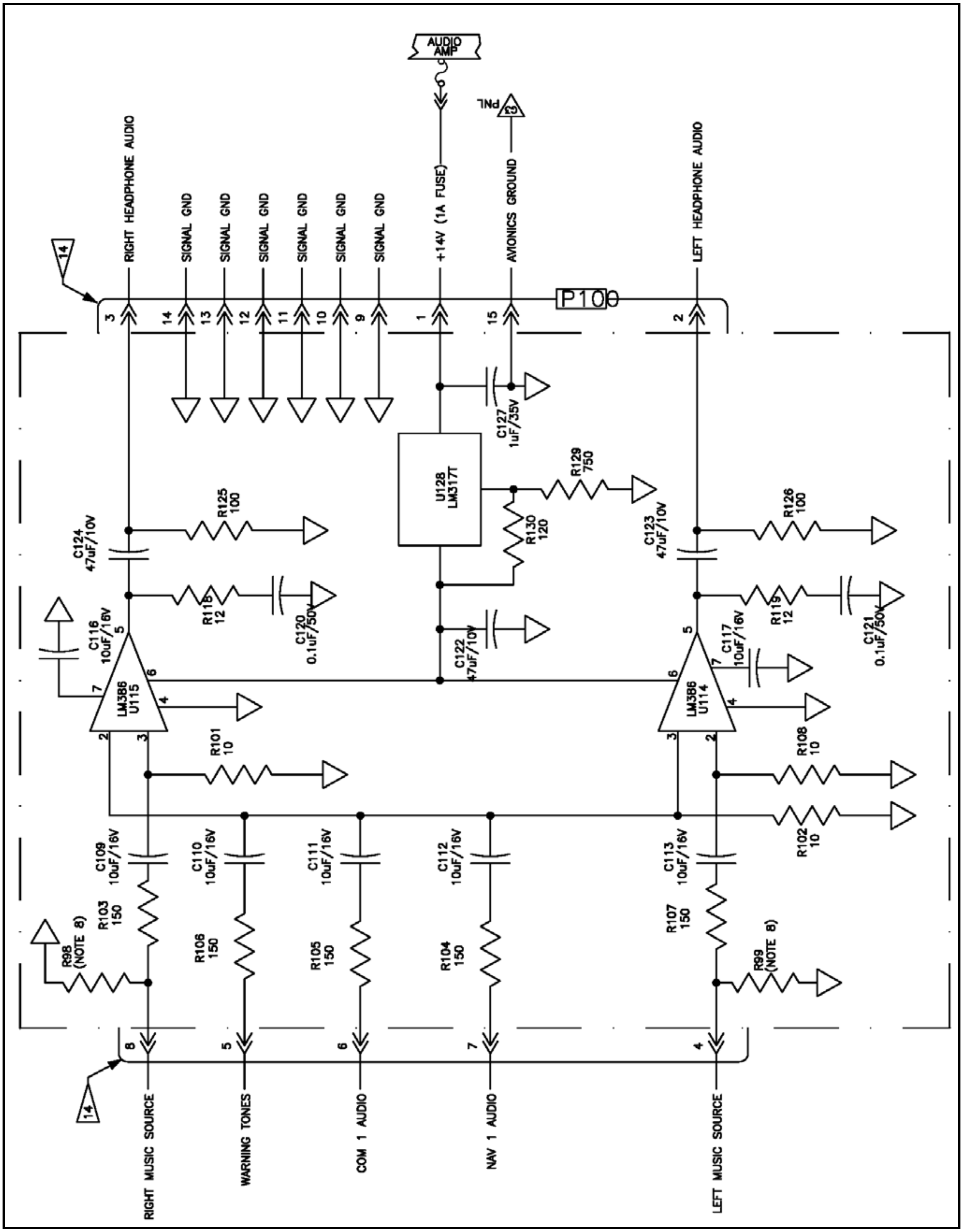

Figure 18-10. Schematic Exemplar Audio Isolation Amplifier

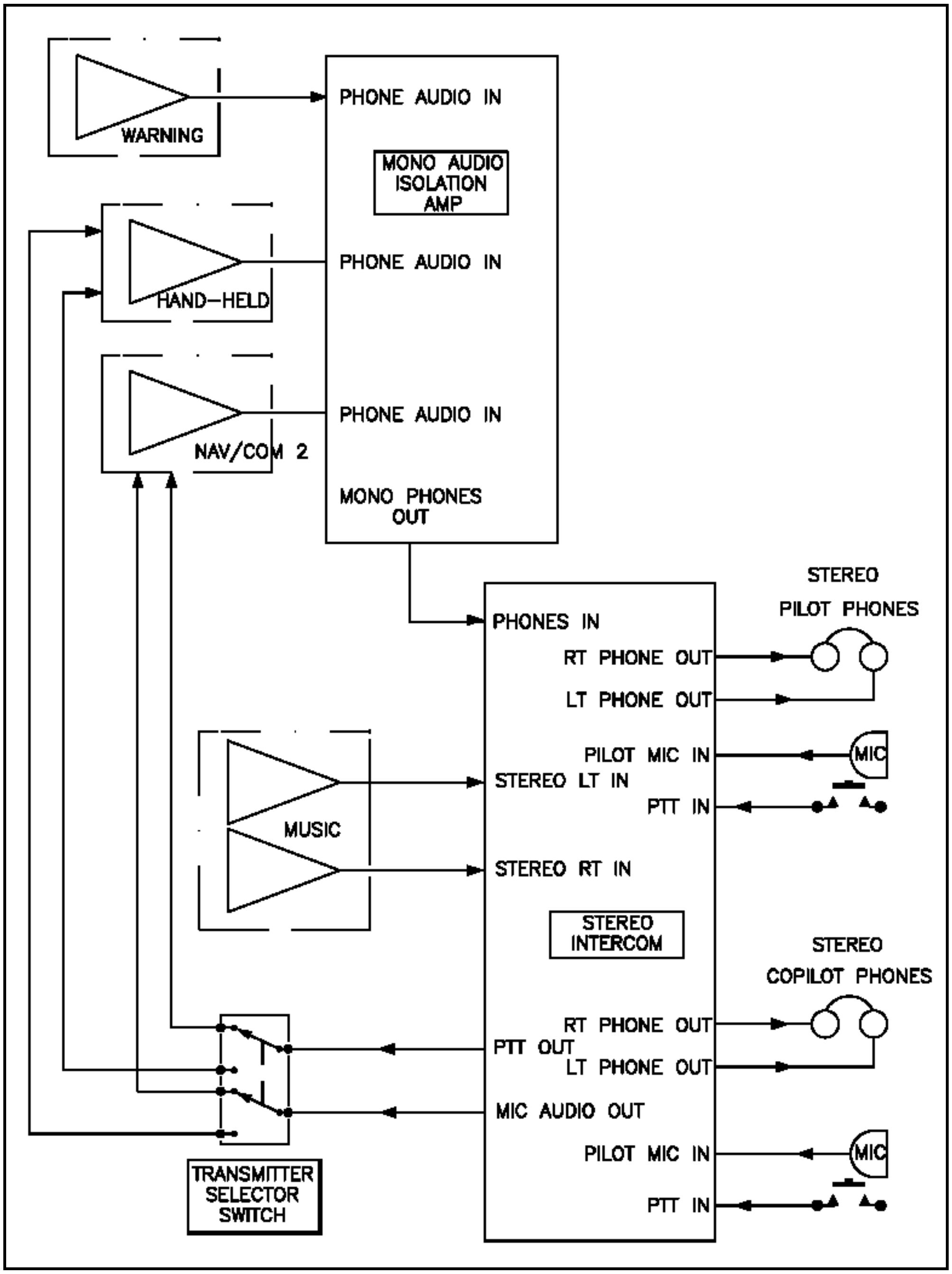

Figure 18-11.Two Transceivers, Stereo Intercom, Multiple Avionics Sources

offer TWO amplifiers. One to drive headsets and the other for cabin speaker.

Very few Owner Built and Maintained (OBAM) aircraft are fitted with cabin speakers so our first pass on a full-up audio system will feature a single audio isolation amplifier as first described in Figure 18-6. Let's take a more detailed look into use of the isolation amplifier. Figure 18-9 shows the system architecture for incorporating a simple audio isolation amplifier that will handle a number of aircraft audio sources along with a stereo entertainment source

Do it Yourself Audio Isolation Amplifier

Figure 18-10 is a more detailed schematic of how a useful isolation amplifier can be assembled. Parts for this project are readily available from suppliers like Radio Shack and Digikey. An etched circuit board for this amplifier along with bill of materials and detailed assembly information are available from the 'Connection's website at http://aeroelectric.com.

Figure 18-11 illustrates another variation for audio management. This system assumes that your intercom system will accept a stereo entertainment source such that your avionics sources may be mixed together in a monophonic isolation amplifier. This figure also illustrates a simple two-pole, double throw switch for selecting which of two transmitters will get push-to-talk and microphone audio signals. The second transmitter is shown as a hand-held but it could just as easily be a panel mounted radio. Switches and volume controls are a noteworthy exclusion from the architecture drawings. In a do-it-yourself amplifier, adjust the the 150 ohm resistors shown for each input to achieve proper balance of volume from various audio sources.

After your system is wired up and ready to test, compare

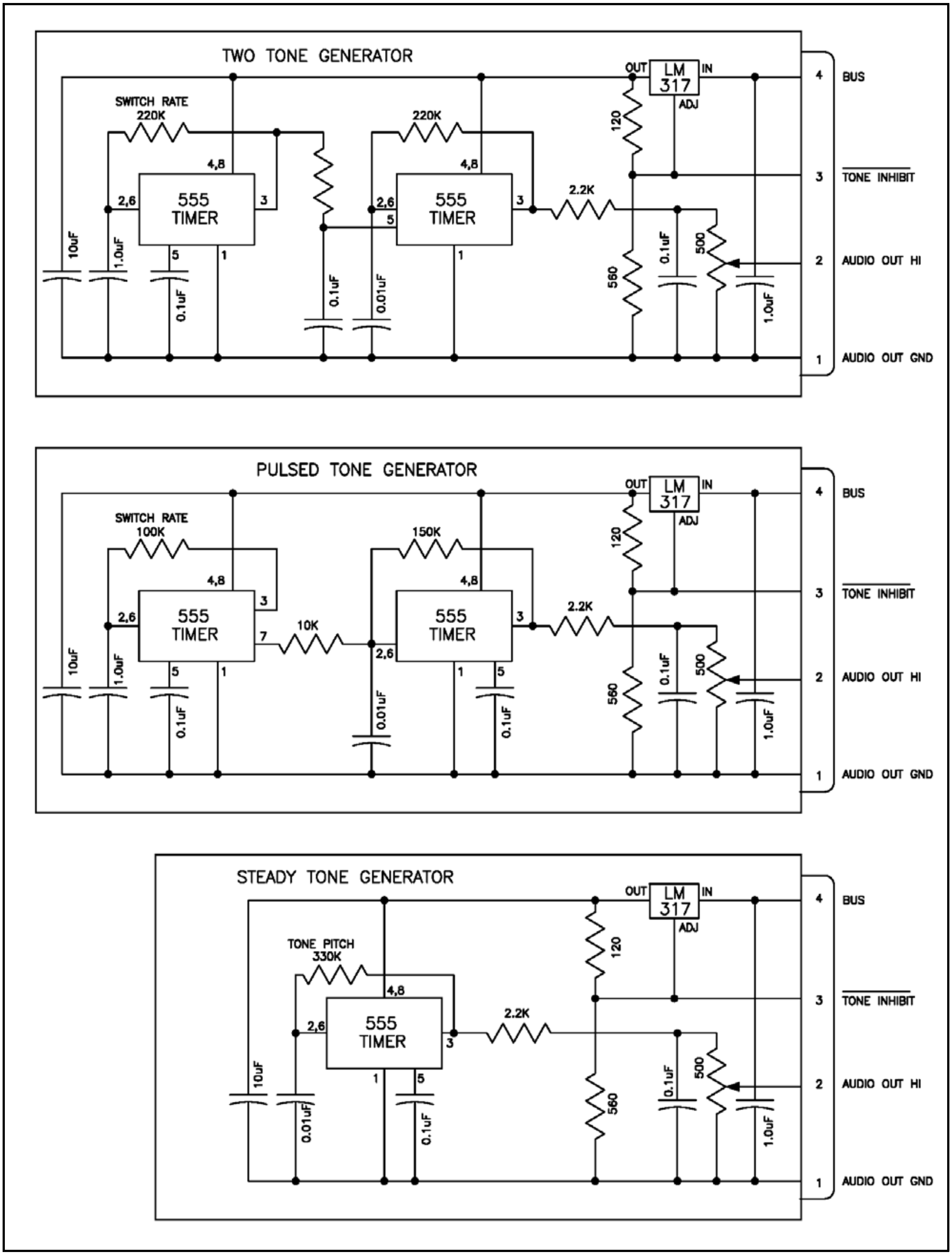

Figure 18-12. Schematics - Warning Tone Generators.

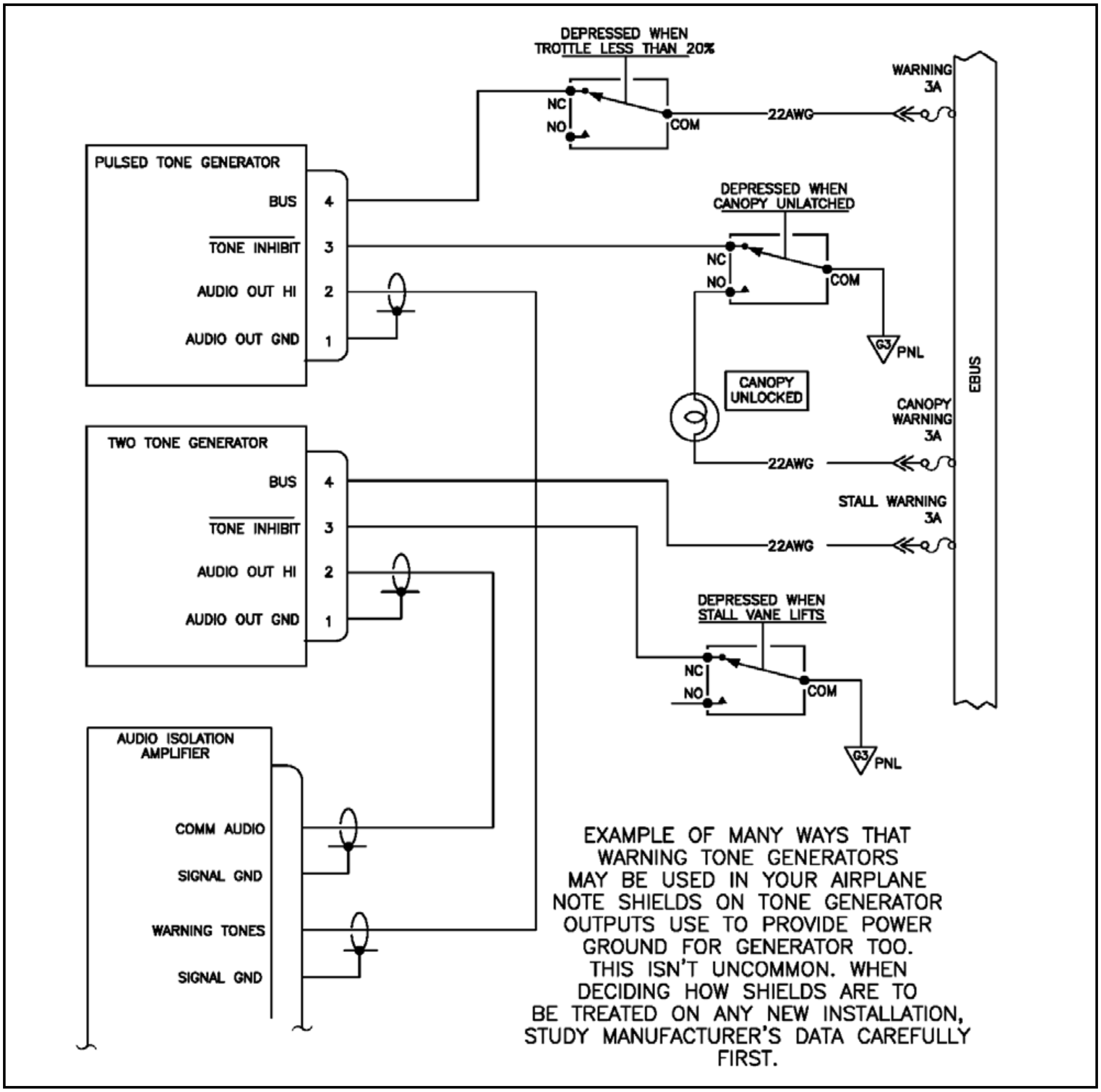

Figure 18-13. Exemplar Warning Tone System

the various audio sources for intensity. Receivers will have volume controls on the front panel. If you have a headset volume control, set it for about 2/3rd travel toward maximum. Radio receivers should be comfortable at some point between 1/4 and 3/4 travel on the front panel controls.

This leaves fixed volume sources like warning systems. Making the 150-ohm resistor larger reduces volume, making it smaller increases the volume. Make resistor adjustments in 2x or ½ jumps: I..e., if 150 ohms is too loud, try 300 next, if still too loud, go to 600 ohms. Conversely, if too soft, drop to 75 ohms and then 36 ohms. Once you're in the ballpark with one of these large jumps, you may find that some value between the too loud and too soft will get it right.

Once the proper value is determined, it can be permanently soldered in place of the 150 ohm resistor that handles that particular audio source. It's a bit time consuming but the design goal is to minimize the number of "stacked" controls. For example, in several airplanes I fly, headset volume can be adjusted by the radio's panel mounted control, the audio isolation amplifier's control, the intercom's control and finally, the volume control on the headset.

It's not a really big deal but I think it's good design to eliminate as many chances for error as possible in the interest of hearing things of interest on the radio or from your warning system.

Warning Tone Generators

Some off-the-shelf systems monitors may come fitted with alarm tone outputs. These are simply wired to one of the iso-amp inputs and adjusted for volume as needed. There may be instances where you'd like to generate your own alarm tones for things like stall, gear, or canopy warning. It's not difficult to build tone generators with distinctive characteristics so that several installed warnings are distinctly different.

Figure 18-12 illustrates three styles of tone generators easily fabricated with commonly available parts. These generators utilize the ancient but quite versatile 555 timer which is one of the oldest designs still in production. For a two-tone or pulsed tone generator, two timers are used. One to generate the tone, the other to modulate it either in pitch or in on-off rate. The last circuit is a single, unmodulated tone generator. Figure 18-13 suggests some ways that these generators might be used.

Avionics and Panel Ground System

For years, the OBAM aircraft community has taken advantage of the noise reducing qualities of a single-point ground system. This philosophy has been described in Chapter 5 on electrical system grounds.

The whole idea behind the single point ground is to avoid introduction of noise into vulnerable systems because the victim system is "grounded" in more than one place on

Figure 18-14. Manufactured D-Sub Ground Block

a conductor (usually the airframe) that is also carrying large and noisy loads like pitot heat, landing lights, battery recharge currents, etc.

The forest-of-ground-tabs technique described in Chapter 5 is entirely suitable and convenient for most equipment in the electrical system. However, while it is electrically

Figure 18-15. DIY D-Sub Ground Block, Rear View

correct to wire all the panel mounted equipment to the same ground block, the total number of wires can be significant.

Further, given that there are a number of small signal systems vulnerable to noise concentrated on the panel, it makes sense to create a separate and co-located ground system for these potential victims. Given that panel mounted equipment items draw relatively small amounts of current, the ground bus can be fabricated using very compact hardware compared to the forest-of-ground-tabs.

Figure 18-16. DIY D-Sub Ground Block, Wiring Side

This seems to be one of many applications for the D-subminiature series connectors.

Figure 18-14 shows a permanently mated pair of 37-pin D-sub connectors mounted to an etched circuit board where all the pins are bussed together. This device offers a compact means by which instrument panel equipment grounds can be brought to a single location.

Builders can easily fabricate their own D-sub panel ground by soldering a pair of reasonably fat wires 14-16AWG to all of the solder-cups on the back of a female D-sub connector. The male connector shell should be mated to the female connector in a manner that will make sure the mated

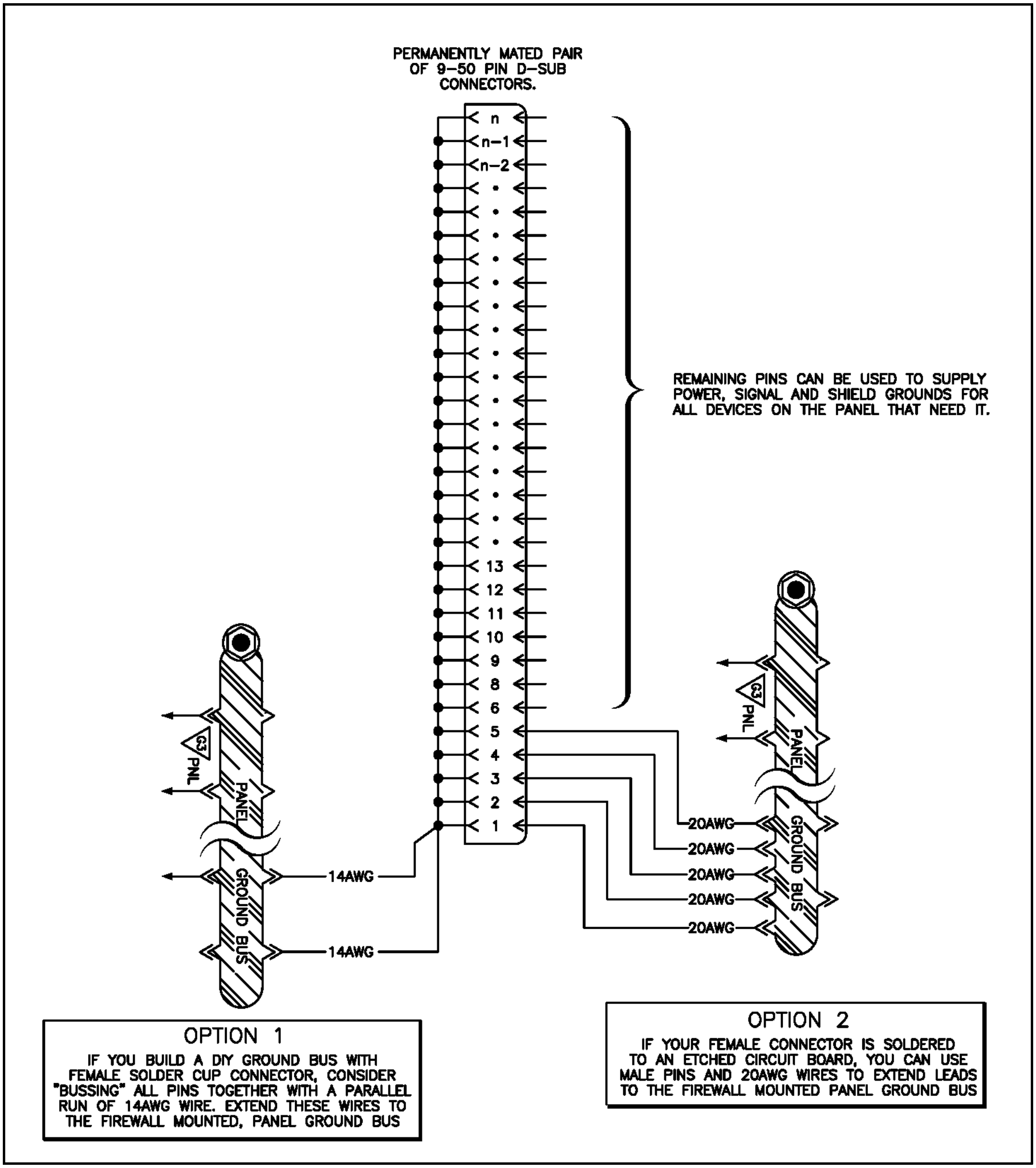

Figure 18-17. Electrical Architecture Options for an Avionics Ground Bus

connectors stay stuck together. I use a spot of super-glue on the threads of the mating screws.

Once the connectors are mounted on the panel assembly, ground wires from various accessories can be easily terminated in a male D-sub pin and installed in the ground block.

When installing your ground block, keep in mind that you need access to remove pins using the D-sub insertion/removal tool . . . so leave sufficient clearance for this operation. Some radios call for multiple grounds and will show them on the installation wiring diagrams. If you've picked a nice fat D-sub connector from which your avionics ground block is fabricated, you'll have plenty of ground pins to accommodate the needs of every system.

Except in cases for very simple panels, I'd install a 37-pin avionics ground as a minimum . . . and a 50 pin wouldn't be out of line. That's the really nice feature of this technology, you can have plenty of spare ground pins for very little expenditure of real-estate on the panel.

An array of five 20AWG or two 14AWG wires can be used to extend the avionics ground to the firewall ground block. See figure 18-17 for a schematic of this architecture

Some Notes on Shielded Wires

There are few materials materials used on aircraft that are so poorly understood and often mis-applied as shielded wire. As we mentioned in the chapter on noise, shielding a wire breaks a very specific coupling mode - electrostatic. Electrostatic coupling occurs because of the capacitive nature of two wires running in close proximity (in the same bundle) but separated from each other by virtue of their insulations which forms the dielectric of a capacitor. The value of this inter-wiring capacitance is measured in picofarads per foot. A picofarad is a 10^{-12} one million-millionth of a Farad . . . a very small capacitance indeed. The only kinds of signals that couple significantly across this tiny capacitance are characterized by very fast rise times (square waves or very spiked waves) and high voltage. It stands to reason that magneto p-leads with their approximately 300 volt signal across the open mag-switch and very trashy waveform would have some risk of coupling to other wires in a wire-bundle. Hence the practice which always suggests the shielding of magneto p-leads.

Are there other signals conducted on wires in the airplane which present a similar risk? Well, maybe the strobe wires running from power supply to lamp fixtures on tips of wings and tail.

How about potential victims? Well, the audio input wires to and audio isolation amplifier are somewhat vulnerable due to the very sensitive nature of the human ear. If you were to tie your intercom system wires into the same bundle as p-leads and assuming poor shielding practice of the p-leads, it's almost a certainty that you'll hear every plug firing in turn on your headsets. However, given the unique nature of avionics and strobe or magneto systems, it's both unlikely and poor practice to bundle these strong potential antagonists together with potential victims like audio wiring. The bottom line is that once the strobe and p-lead wires ARE shielded, the likelihood of any problems arising due to LACK of shielding is small.

I'll suggest that on small aircraft (no long bundles running 10, 20 40 feet through fuselage) one could substitute shielded wires with twisted pairs, trios and quads of unshielded wire for the whole suite of avionics components with no ill effects. I'll suggest further that there is greater risk that shielding improperly terminated at both ends is 100x more likely to be the root cause of a noise problem (due to ground loop) than if the wire had never been shielded in the first place (electrostatic coupling to some high noise wiring).

I've used shielded single-strand for simple tasks like hooking up the LED indicator on my Low Voltage Warning light kit. It's a natural for wiring to the back of a leaded LED. Polarity of the connections is preserved without use of colors or marked wire . . . center conductor is (+) and shield is (-). In this case, shielding is entirely unnecessary but the wire was attractive simply because of the mechanics of fabrication and installation.

Therefore, when installing a new piece of equipment where the use of shielded wire is indicated, follow the instructions. There are no hard and fast rules whether one or both ends the shield have connections and schematics that come with instructions are your best guide.

Summary

The audio system installation along with an avionics/panel ground bock are the central hub for much of what's on your panel. Very simple systems can mix two audio sources directly to the headphone circuit with a pair of resistors. However, if you anticipate multiple audio sources such as receivers, intercom, entertainment and warning tones, some form of audio isolation amplifier will be necessary.

If you have more than one transmitter, a transmitter selector switch for the microphone and push-to-talk will be needed. Finally, try to reduce the numbers of series volume controls and/or selector switches to a minimum. The fewer the controls, the less likely you are to miss some important information over the radio because some control wasn't set where it should be