A Short Discussion on Summing Busses and Summing Amplifiers

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The summing network in mixing consoles is an easily misunderstood area of design. It is the purpose of this discussion to shed light on some of the important factors that should be considered when designing the summing buss section of a mixing console.

There are two types of summing busses. One is called a "*passive*" summing buss and the other is called a "*virtual ground (or earth*)" summing buss. The latter is also sometime called an "*Active Combining Network*" or *ACN*.

A typical passive summing buss is shown in Figure 1. It features a summing resistor placed between the channel output and the summing buss. This resistor provides load isolation and improves channel to channel isolation. The gain make-up amplifier which follows the buss is configured as a *non-inverting* amplifier operating with a closed loop voltage gain that is equal to the loss across each summing resistor. Since the voltage gain of the amplifier and the signal loss across the summing resistor cancel each other, the gain across the summing buss and amplifier is 1 or unity gain. While the entire network has a gain of 1, the actual gain of the amplifier will be greater than 1. This gain is sometimes called the "noise gain" of the summing network. You must keep the number of channels attached to the buss constant without switching channels on and off the buss.

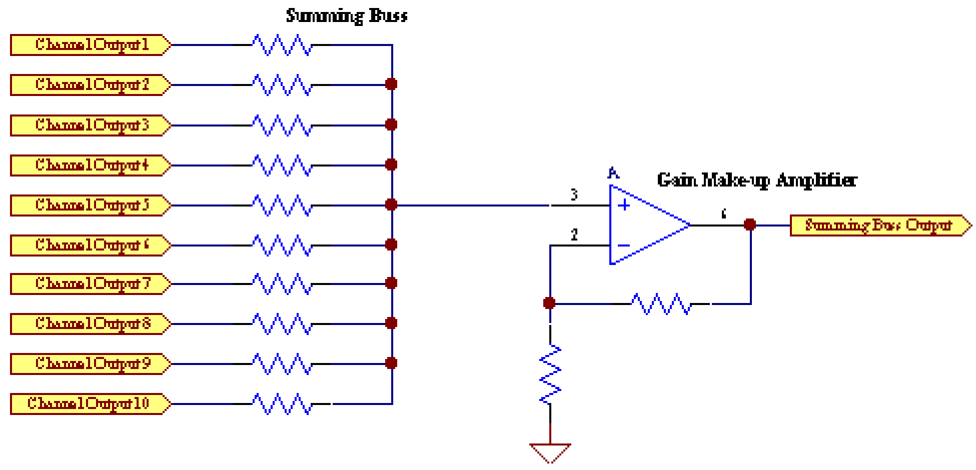

Figure 1
A Passive Summing Network

A typical ACN (or active) summing topology is shown in Figure 2. At first glance this circuit looks very much like the passive buss shown in Figure 1. However, with this topology the amplifier is operating as an *inverting* amplifier and this dramatically changes the operating conditions of the entire summing network

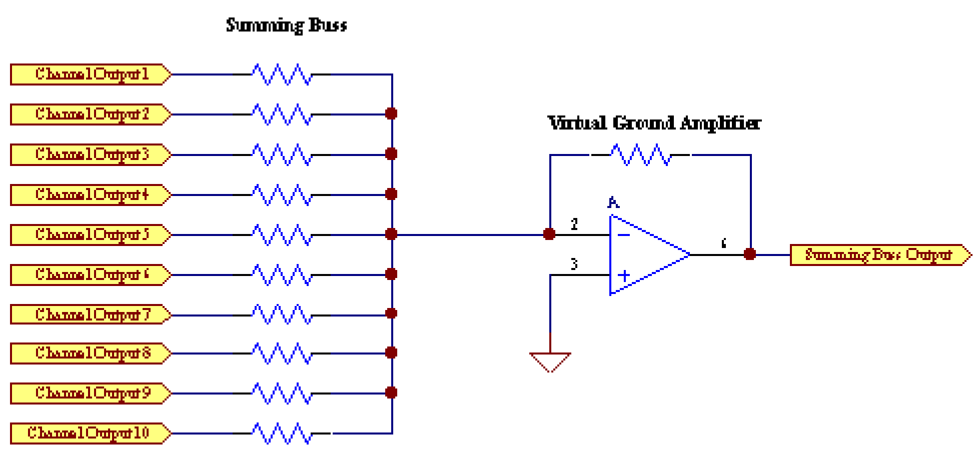

Figure 2
Active Combining Network (ACN)

Let’s look at each of the two summing configurations separately, starting with the passive buss design shown in Figure 1.

Passive Summing

Obviously we cannot just connected the output of two (or more) channels together without placing a resistor in series with each output. If we don’t use the resistors, the output stage of one channel would directly load the other channel with its source impedance. The source impedance of a given channel is typically too low for any other channel to drive in a linear fashion. In a multi-channel mixer, the load seen by any given channel would be the *parallel* source impedance of all of the other channels connected together. If the source impedance of each channel is 50 ohms and, there are 10 channels, the load seen by any given channel would be about 5 ohms. Five ohms is too low for anything but a power amplifier to drive properly and we obviously can’t put a power amplifier in each channel of our mixer. However if we increase the load impedance by placing a series resistor between the output each channel and the buss, then each channel can drive the buss to high level without problem.

With such a resistor in place for each channel, the impedance seen by any single channel is now the value of its summing resistor *plus* the parallel value of all the channels hanging on the buss. If we use 1k ohm resistors for these resistors in a 10 channel mixer we would have a parallel source impedance of 100 ohms (1k/10= 100). This is the *buss source impedance*. Each channel will now see its summing resistor in series with the buss source impedance. That means each channel will see 1k (the summing resistor) plus 100 ohms (the source impedance of the buss) or 1.1k ohms as its load. Using larger value summing resistors will increase the load impedance seen by each channel.

Our little 10 channel mixer now has all of its channel outputs tied to the buss via the summing resistors. If we measure the signal level at the buss (not at the output of the summing amplifier, but at its input) we will see that it is much lower than the level that is at the output of the channel feeding the summing resistor. This is because of the signal loss created by each channel's summing resistor being loaded by the buss source impedance. In our 10 channel mixer we would have a loss of 10, which equals 20 dB of signal loss (log(10)= 1, 1* 20= 20 dB). When equal value summing resistors are used, we can simple look at the number of channel and that number will be the loss, which we can convert to dB with the standard voltage ratio conversion formula. Get out your calculator and try it. A 6 channel mixer would have a loss of 15.56 dB, a 24 channel mixer will have a loss of 27.60 dB, 36 channel loses 31.1 dB, etc.

It should be obvious from the above discussion that we cannot drive a recorder or any other line level input device directly from the buss output because of the signal loss. Why not just turn the level up at the channel and make up for some of the loss? The reason that won't work is that we run out of headroom in the channel electronics. To drive our 10 channel mixer's buss output to +4 dBu, we'd have to have the channel output operating at +24 dBu. The problem created by that should be obvious.

One way to address this problem is to add a gain make-up amplifier after the passive summing buss. If this amplifier is set-up so that it has enough gain to counter the loss in the summing resistors (20 dB), then we will have the same level at the output of the amplifier as we do at the output of each channel (prior to the summing resistor). A channel driving the summing resistor with a +4 dBu signal will now produce +4 dBu level at the output of the summing amplifier. We will not have a headroom problem with the channel amps because they will be operating at +4 dBu, as is the gain make-up amp.

All of this works well, doesn't it? We've combined all of our channel and we haven't lost anything. However it turns out that we may have lost some noise performance during this process. This is because gain make-up amplifier is actually operating with voltage gain and amplifying its own internal noise as well as the thermal noise of the buss itself. This probably isn't a problem for a small mixer like our 10 channel design example, but what about a mixer with 32 channels? The gain make-up amplifier now needs to have 30 dB of gain. If the amplifier that we are using has a unity gain noise floor at -100 dBu, then when it is set for 30 dB gain its noise floor will be about -70 dBu, which is not very good. Adding more channels to the mixer obviously makes this problem worse.

We'll get back to noise performance in a moment. Let's look at the channel to channel isolation of a passive mixing buss. What is it that creates isolation between channels in a mixing buss? There are two signal drops that determine the isolation. The first is the signal drop across the summing resistors (20 dB in our example) and second is the drop created by the adjacent channel's summing resistor working against its own channel source impedance. If the channel source impedance is really low (as you'd have if the summing resistors was driven from the output of an opamp), then the signal drop is high. If the channel source impedance is not so low (summing resistor driven directly by a pan pot) then the signal drop is not as high. It is the sum of these two drops that determines the inter-channel isolation in a passive summing network. The actual amount of isolation will be determined by the value of the summing resistors and the source impedance of each channel at the point from which the summing resistor is being driven. We don't know the value of our summing resistors just yet, and we don't know the source impedance of each channel just yet, so we cannot calculate the channel isolation in our design just yet. We'll get back to that in a moment, but it should be obvious that driving the summing resistors (regardless of its value) from a low source impedance will result in improved channel isolation. This is not always practical for a variety of reasons, as we will see.

Active Summing

The ACN summing network is shown in Figure 2. As we said before, this circuit looks quite similar to the passive configuration except for the fact that the gain make-up amplifier is an inverting amplifier. Other than a polarity reversal what’s the difference between the two? The short answer is "a lot". The long answer is just that, long and complex.

The input to an inverting amplifier acts like ground. This is because of the fact that the output of the amplifier is connected to the inverting input. Since any signal applied to this input is subtracted from the output, all of the gain of the opamp works to force this point to zero or ground. The input impedance at this point is also very low. How low depends on how much open loop gain the amplifier has and how much negative feedback (called the feedback factor) is applied around the amplifier. The open-loop gain performance is pretty much a static figure and is determined by the internal design of the opamp. The feedback factor is a variable figure and is determined by operating conditions external to the opamp. This part of the discussion could get rather detailed, but we can avoid that by assuming that the impedance at the inverting input of the opamp will be less than 100 ohms. That is a safe figure to use for our design calculations.

The fact that there is low impedance at the input of the gain make-up amplifier provides an improvement in channel isolation when the ACN topology is compared to the passive topology. It also lowers the buss source impedance, which means that there is less thermal noise present in the summing buss.

The ACN topology also allow the console designer to switch channels on and off the buss, something that you must not do with the passive design. As channels are switched on and off the buss, the actual gain of the gain make-up amplifier changes. The is because the parallel impedance presented by the summing resistors is part of the feedback network of the amplifier. Therefore, the noise gain (actual gain) of the amplifier changes as channels are added or removed. This can be a good aspect of a console design, but it may also result in sonic quality changes due to differing amounts of negative feedback. We won’t go into the sonic effects of negative feedback here because it is outside of the scope of this discussion. However, it is my feeling that once a design is finalized, it is best to have its operating conditions remain as constant as possible. Having a variable feedback amplifier anywhere in a console design should be avoided, in my opinion, especially in a location as critical as the summing network.

Right about now, you are probably thinking that the ACN topology is the logical choice for a console summing network. However the ACN topology has an addition noise source when compared to the passive circuit. This noise source is the ground system.

The amplifier used in the ACN circuit must have its non-inverting input tied to ground. Any noise present on this ground will be amplifier by the gain of the amplifier. If the console has a good grounding system and the ground noise is -100 dBu, then in a 32 input console, this noise will be amplified by 30 dB resulting in noise at -70 dBu at the output of the summing amplifier. The ground noise is a result of signal current and utility current (lamps, LED, relays, etc.) flowing through a non-zero impedance ground system. If you are careful to design your grounding system to provide a low impedance by using a heavy buss-bar type ground and star grounding schemes wherever practical, you may be able to get a lower noise floor. It is very important to return the reference input of the summing amp to ground point that has the least amount of current flowing through it as you possible can. An example of this could be a separate ground wire return to the central ground point in the console. Still, any noise present at the non-inverting input will be incoherent compared to the audio present at the inverting input and will therefore be amplified. But there is also another approach that can be used to improve noise performance.

An opamp really only wants to amplify only the difference between its two inputs. Signals that appear simultaneously on both inputs (and that are in phase with each other) will not be amplified to the same degree. The ability of the opamp to reject these common mode signals is called the *common mode rejection* performance of the opamp and is often expressed as a ratio (CMRR). (When expressed as a ratio, it is compared to the voltage gain of the amplifier.) If we can get the ground noise to be the same kind of noise present at each channel, we can use this CMRR to help reject the overall noise. This is done by running a ground trace along with the summing buss signal trace and tying to each channel's ground via a resistor.

Another way to accomplish this type of noise reduction is to use a true balanced/differential summing buss. This result in a +6 dB increase in signal level, with only a +3 dB increase in noise, resulting in a +3 dB improvement in signal to noise. This improvement is not dependent on the CMRR of the opamp, but is a result of the differences in the square law summation models for noise and signals. A major drawback to this topology is that you need an additional amplifier in each channel to drive the differential buss, and any switching becomes more complex.

Something that gets overlooked in ACN circuit design is the fact that the gain make-up amplifier has to source and sink all of the signal current present on the buss. It is important sonically that the amplifier linearly source and sink this current. In our little 10 channel design with 1k summing resistors, the total signal current could be around 50 ma. This figure is arrived at by using 5 Vrms as the output voltage. I used this figure because it is about ½ the maximum output voltage swing that is possible from opamps running on bipolar 15 VDC power supplies. It is a design center figure and you can choose to use it or not. If we increase the value of the summing resistors from 1k to 10k, then the total signal current goes down by a factor 10 to about 5 ma. There are many more commercial opamps available that can handle 5 ma output currents then there are that can handle 50 ma, so this may be a better value for the summing resistors in our design.

However, if we use 10k summing resistors in our 10 channel mixer we now have a buss source impedance of 1k ohm. This will cause most opamps with bipolar transistors front-ends to have higher internal noise. A low noise JFET input opamp would be a better choice as a summing amplifier under these conditions. A 32 channel mixer with 10k summing resistors would have a buss source impedance of about 312 ohms, allowing use of a bipolar input stage opamp, but the signal current is now 16 ma, so our opamp must be able to sink/source 16 ma linearly. While high output current is not usually a trait of monolithic opamps, additional current drive output stages (hybrid) can be added that will greatly increase the output stage current capabilities. You could also use an opamp made from individual (discrete) components that has a high output stage current design. These are the trade-offs to using an ACN type summing network.

So should our summing network be passive or active (ACN)? Should we use bipolar or JFET input opamps for the gain make-up amplifier? Should we use monolithic, hybrid, or discrete opamp devices? These are the trade-offs and compromises with which each designer must wrestle. Now aren’t you glad that you decided to become a designer? Hey, that’s what it’s all about. Have fun.