Gain Structure - Setting the System Levels

One of the most important things you can do to make an audio system sound good is to set up its gain structure properly. Conversely, improper gain setting throughout the system can really make it sound bad.

Gain Structure is the term we use for the collection of various gain adjustments throughout the system – the mic preamp, the fader, the main mix output level, the input gain of a power amplifier or recorder, and so on. Setting all of those gain/level controls to work together properly isn't difficult, but so often it gets ignored. You may run across the term *Gain Staging*. That's the process of setting gains throughout the system to achieve proper gain structure.

There are many ways of establishing optimum gain structure. Once you understand what you need to accomplish, gain staging will become second nature when you're faced with new equipment. To understand gain structure and gain staging, you need to understand a couple of closely related terms which I've sprinkled throughout these articles – *dynamic range* and *headroom*.

Dynamic Range

Dynamic range is the ratio, expressed in dB (decibels), of the level of the loudest undistorted signal to that of the quietest audible signal. Dynamic range can apply to a single piece of equipment or to a complete system.

For electronic equipment, the maximum output is ultimately determined by its power supply – If the power supply provides ±15 volts to the integrated circuit opamps, the maximum possible peak-to-peak signal voltage is 30 volts. It will never be 31 volts - you can't generate what's not there, at least not without adding more components.

The noise floor limits the lowest audible signal we can use in the system. In general, the better the design, the lower the noise floor. Reducing the noise floor increases the available dynamic range.

Typical professional audio equipment has a maximum output level in the range of +22 to +28 dBu depending on the manufacturer and the output configuration. Noise floor is a little harder to measure (there are several legitimate methods), but for a mixer with a bunch of channels assigned and set to unity gain, it's typically in the ballpark of –85 dBu. This gives a maximum possible dynamic range of 113 dB – pretty impressive considering that the practical dynamic range of human hearing (threshold of hearing to threshold of discomfort) is around 120 dB.

It's convenient that electronic system noise is usually considerably lower than ambient noise such as traffic and air conditioning. *Usable* dynamic range is rarely greater than 100 dB in a quiet studio and may be as little as little as 25 dB at a

concert with an audience of 20,000 screaming teenage fans. (More civilized concert venues usually allow for dynamic range on the order of 55-70 dB.)

Headroom

Headroom is the ratio of the largest possible undistorted signal to the *average* signal level. Average level is subject to some interpretation depending on whether you're the sound reinforcement engineer at a concert or the promoter asking for the sound to be louder. At a loud concert, the average sound pressure level may be very close to the maximum possible level (very little headroom). If you're writing the spec sheet of a console, however, you want to be able to show the greatest possible headroom above the nominal level.

When it comes to electronics, the average level is generally considered to be the equipment's nominal operating level. If the nominal level is +4 dBu, a mixer with a maximum output level of +28 dBu will have 24 dB of headroom.

Since there's little you can do about the system's dynamic range once you've chosen your equipment (short of turning off the air conditioner or gagging the screaming fans), all you need to do in order to assure undistorted sound is to provide sufficient headroom. Sounds simple, but how much headroom is enough?

Crest Factor

Crest factor is the ratio of the peak to the RMS average value of the signal. It's a micro-measurement though, not a long term average like sound pressure level or a sine wave voltage measurement. Crest factor is measured within the waveform cycle. As a simple example, the RMS value of a sine wave is 0.707 times the peak value. So its crest factor is 1/0.707 = 1.4, or 3 dB.

Studies have shown that typical pop music has a crest factor in the range of 4 to 10, which translates to 12 to 20 dB. This means that we need to be able to provide 12 to 20 dB of headroom for peaks over the average level in order to avoid clipping. This is a requirement for every link in the chain.

Taking it From The Top – Setting System Levels

Once the whole system is hooked up, whether it's your studio control room or a concert sound reinforcement system, check that you have all the proper connections and it will pass audio. Do this before you start setting gains so you don't get sidetracked with troubleshooting. Put on a CD, make sure it gets to the output(s), and then listen for hum and buzzes that will eat your noise floor for lunch. Once you're sure the system is passing audio and there aren't problems that need immediate attention, you can start gain setting.

Pre-flight Check List

- Turn down all the power amplifier input level controls
- Turn the power amplifiers off (so you can run test signals through the system all the way to the amplifiers without driving yourself bonkers)
- Set all gain/level controls to their minimum gain positions.
- Bypass or zero out any equalization, both channel EQ and overall EQ on the outputs.
- Bypass any compressors or limiters, or set their threshold all the way up so they don't compress.

Console Gain Settings

All mixing consoles consist of a mic/line preamp stage, equalization, a channel fader, and channel routing controls (PAN pots and ASSIGN switches). There may or may not be a submaster stage depending on the model and whether a channel is assigned to a SUB or directly to the MAIN outputs. Finally, all channels are mixed together to various outputs (MAIN, AUX, Control Room, etc.) most of which have their own level controls.

To set gain structure properly, you want to maximize the *signal-to-noise (S/N) ratio*. This requires some thought and care, as each stage along the path contributes some noise as well as gain. The pessimist looks at this and sees that each stage contributes to the degradation of S/N ratio – and, you know, he's right. But the amount of noise a stage contributes is fixed, so the higher the signal level is at its input, they better the S/N ratio at the output.

It's generally good practice (and this is as much a designer's issue as an operator's) to bring the input signal up to the designed operating level (say +4 dBu) as early in the signal chain as possible. If you need to amplify a microphone by 60 dB in order to get to the necessary output level, it's best not to do it in steps – 20 dB at the preamp, 20 dB in the equalizer section, and another 20 dB at the output. You want to get as much of that 60 dB gain as possible from the preamp stage and run everything else close to unity gain. Typically the channel and master gain controls (faders) on a mixer will have a marking, perhaps a U (unity gain) or 0, as a guide to their nominal setting. Obviously you'll diverge from that a bit to create a balanced mix, but not a whole lot once you have the input gain set properly.

On most mixers, soloing a channel, in addition to sending that channel's signal to the headphones or control room outputs, sends the channel's preamp output to the meter. Adjusting the TRIM control for a 0 VU meter reading on peaks sets the preamp gain so that you'll have about 20 dB of headroom before encountering

clipping *in the preamp.* This may seem like plenty, but remember, you'll be adding up a bunch of channels by the time you get to the main output bus.

Audio signals add as the square root of the sum of the square of their amplitudes. Since 0 VU on the meter typically represents a level of 0.775 (0 dBu) or 1.23 volts (+4 dBu), get 24 channels cranking all at once and you'll get 3.8 to 5.5 volts (which translates to around +14 to +17 dBu) out of the mixer. That's a theoretical case with 0 VU sine waves on every channel. With real music, at any instant in time some channels will be peaking higher, others lower, so it all about averages out.

With about 10 dB of headroom left at the output and 20 dB of headroom in the mic preamp, that blood curdling scream from the lead singer won't result in either the preamp or the mixer output clipping. But when all four guitarists hit a chord that just barely doesn't clip the preamp while the rest of the chaos is going on around +4 dBu, the mixer could be trying hard to put out +29 dBu and might not make it. The result is clipping. This is a good reason to know your sources and be a bit conservative if you know they're likely to get a whole lot louder than normal occasionally. Either that, or patch a limiter into the channel.

Managing Outboard Gear Levels

Many outboard units (including some power amplifiers) are designed to operate at "standard operating level", and have no level or gain controls at all. Others have input level controls, electronic crossovers, equalizers, compressors, or other in-line signal processors often have both input and output level controls.

In a perfect world, having no input level control would be OK. The console would provide both all the gain and all the control necessary. Often, however, particularly in live sound situations where shows typically get louder as time goes on, the only volume control you have handy is the master output level of the console. You may find that when you have sufficient volume at the speakers, the console is very close to clipping. This is not a good situation and indicates that the power amplifier isn't properly matched to the system.

It's not uncommon for a live sound reinforcement system to be running very close to clipping most of the time. I don't know why, but that's just the way it seems to work out. Most likely it has to do with how much they can carry. Very brief clipping is usually not noticeable nor harmful, but sustained clipping sounds awful and can damage your speakers.

Setting Outboard Levels

Begin by turning the power amplifiers off or setting their input gain controls to minimum. Otherwise, you'll be in for a lot of noise.

Connect a CD player to the console, play a CD, and set the trim so you have some preamp headroom, set the channel fader to Unity gain, then raise the

MASTER fader (and channel fader, if necessary) to bring the output up to just below clipping, as indicated by the VU meter. This is the hottest undistorted signal level your mixer can put out.

If the mixer is connected directly to a power amplifier, jump straight to the paragraph about setting power amplifier gain. If there's a device or two in between (equalizer, compressor, crossover, or all-in-one "speaker manager"), you'll need to set those levels before getting to the power amp.

When going into a device that has only an input level control, set its input control to the point just below clipping. This will set it to its maximum output level. If it has a clip indicator or level meter, rely on that to tell you when you're there. If not, crack the gain on the power amplifier (hopefully there's one) just enough to hear and listen for clipping. It'll be pretty obvious.

If the in-line device has both an input gain and an output level control, it's important to set the *input* gain first. Do this by turning the output level up just enough to hear the signal, set the input gain to the point just before clipping, then finally set the output level so the output is just below clipping. This is essentially the same process as setting the Trim control on a mixer's mic preamp.

See what's happening here? We're squeezing the last clean decibel out of the console, then, with the knowledge that we'll never be driving the next device in line any harder than the console's maximum output level, squeezing the last clean decibel out of the next unit in line, and so on. By feeding the outboard chain with the maximum clean console output level, we're assuring that we'll be getting the largest gain boost up front where it belongs, and the rest of the system will be loafing and not amplifying noise.

Setting Power Amplifier Gain

First, understand that the input gain controls on your power amplifier are *sensitivity* controls. They have nothing to do with the amount of power the amplifier can produce. That's fixed by the design. What the control (or the manufacturer, if there's no input gain control) determines is how much input voltage is required in order for the amplifier to produce its full rated power.

With the control turned up full, the amplifier might produce full power with a +4 dBu signal at its input, or it might require +20 or +24 dBu or even –20 dBu to get to full power. Once you understand that, it's pretty simple to set the amplifier gain properly. You want the power amplifier to be able to put out full power (or at least be loud enough for the gig) when the rest of the system is fully cranked.

Setting the amplifier sensitivity too low means you'll never reach full power, but if you've followed this setup procedure, at least you won't be trying to amplify a clipped signal. If you cheat on the setup and allow something in the chain to be driven into clipping, you could be amplifying that clipped signal, which won't

sound very good. Similarly, you don't want the amplifier input to be too sensitive. Otherwise you can't take advantage of the full headroom in the console because you'll run out of headroom in the power amplifier first.

To set the amplifier's input gain properly:

- Hold your ears and warn everyone else within hearing range. You've been kind to your ears for a while, but now it's time to make noise.

- Turn the amplifier's input gain controls (if it has them) all the way down.

- Crank your set-up music up to maximum level below clipping as indicated on the console meters. If your amplifier has no input sensitivity control or switch, don't turn it on yet. Bring the mixer's master fader down so the meters are well below the 0 mark on the meters.

- If the amplifier has input level controls, with the mixer running at its maximum output level, turn up the amplifier's input control until you can just hear clipping or its clip indicator just goes on, then back it off a little bit. This is the proper gain setting for the amplifier. Leave it there..

  If the power amplifier has no input level controls, turn it on and bring up the mixer's master fader until you can just hear clipping. Note the meter reading. This is as hot as you can run the console. Hopefully it'll be close to the maximum level. If it's very low, consider adding an attenuator in line between the mixer and amplifier.

If the volume is too loud (Hah! In your dreams!), it's fine now to turn down the master level at the console. You don't have to turn on all those meter lights just because you paid for them. If it's not loud enough, sorry, but it isn't going to get any louder – that suggests that the amplifier is undersized, the speakers aren't efficient enough, or they're placed incorrectly.