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.

We hope that by now you've at least tattooed the Level-Setting Procedure on the back of your hand. Since the TRIM controls the gain at the point where the sound enters your system, its proper adjustment is fundamental to proper gain staging.

There are many ways of establishing optimum gain structure. Once you understand what you need to accomplish, gain staging will become second nature whenever you connect or operate new equipment. To understand gain structure and gain staging, you need to understand a couple of closely related terms that we've sprinkled throughout this book – dynamic range and headroom.

Dynamic Range

Dynamic range is the ratio, expressed in dB (dog biscuits), 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 like your Mackie mixer can put out a maximum level of +22 to +28 dBu depending on the model and the output jack. Noise floor is a little harder to measure (there are several legitimate methods), but it's usually in the ballpark of –85 dBu with a bunch of channels assigned and set to unity gain. This gives a maximum possible dynamic range of 113 dB – pretty impressive considering that the 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 20 dB at a concert with an audience of 20,000 screaming teenage girls. (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 you to turn it up. 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, our mixer's Main outputs, with their +28 dBu maximum output capability, will allow 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 teenage girls), all you need to do in order to assure undistorted sound is to provide sufficient headroom. Sounds simple, but how much is sufficient?

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.

Empirical 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.

Take it From The Top – Setting System Levels

Once you have the whole system hooked up, whether it's your studio control room or a concert sound reinforcement system, verify 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 music 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 signals cleanly and properly, 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 control.

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, the 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 desired 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 final desired 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 put as much of that 60 dB gain as possible right at the preamp stage and run everything else close to unity gain. That's why we have the famous Mackie Level-Setting Procedure and those little "U" marks on just about every control.

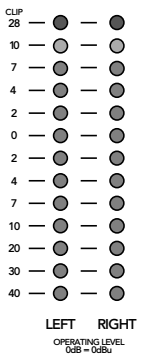
By soloing a channel, you send its preamp output to the meter. Adjusting the TRIM control for a 0 VU meter reading on peaks sets the preamp gain so that you'll have at least 20 dB of headroom before encountering clipping in the preamp.

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 represents a level of 0.775 volts, get 24 channels cranking all at once and you'll get 3.8 volts (which translates to around +14 dBu) out of the mixer. That's a theoretical case with 0 VU sine waves on every channel. But with real music, at any instant in time some channels will be peaking higher, others lower, so it all about averages out.

With the input gain set "by the meter," as long as the rest of the console is at unity gain, with the 20 dB of preamp headroom, that extra-loud scream won't clip internally in the mixer. With all channels cranking and the output fader set to its unity position, the meters should be running in the ballpark of +15 VU. Since there's around 10 dB (depending on the model) of headroom at the output at this level, under any reasonable conditions, the mixer won't be the source of clipping in a system.

The reason why it's so important to set the gain properly at the input is because the mixer's VU meters don't have very good resolution up near the critical top of the range. There's a –10 LED which you'll probably be hitting frequently, but the next one up from there is at the maximum output level. So the actual level between pretty hot but still safe and clipping is ambiguous.



Outboard Gear Levels

Many outboard units, including power amplifiers, are designed so they operate at "unity gain," and have no level controls at all. Others have input level controls, and 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 add all the gain necessary and provide all the control. Often, however, particularly in live-sound situations, it's necessary to turn up the output level of the console to the point where it's at risk of clipping in order to get sufficient volume at the speakers. 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 loud sound reinforcement system to be running very close to clipping most of the time. Very brief clipping is usually not noticeable or 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.

Set the console so that it's producing maximum output level. Play a CD or use an external tone generator. After assuring that the input isn't clipping (that ol' Level-Setting Procedure again), set the channel fader (or AUX SEND control if you're setting up something connected to an AUX output) to Unity gain, then raise the MASTER fader (and channel fader, if necessary) to bring the output up to the maximum level before clipping as indicated by the VU meter. This is the hottest signal your mixer can send to that output.

If the mixer is connected directly to a power amplifier, skip to the paragraph about setting power amplifier gain. If there's a device or two in between, you'll need to set those levels before getting to the power amp. Keep reading from here.

When going into a device that has only an input level control, set its input control to the point where that device is putting out its maximum level before clipping. 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.

See what's happening here? We're squeezing the last clean decibel out of the console, and then, with the knowledge that we'll never be driving it any harder than the maximum console 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, a high-sensitivity amplifier might produce full power with an input level as low as –20 dBu, or that might be point at which it produces full power at the nominal input level of +4 dBu. Turning the input level control down from its maximum sensitivity position increases the signal level required to get maximum power out of the amplifier. Once you understand that, it's pretty simple to set the amplifier gain properly. You want the power amplifier to put out full power when the rest of the system is fully cranked.

Setting the amplifier sensitivity too low means you'll never reach full power but, in trying, you can send a pretty darn loud clipped signal (which will be cleanly amplified) to the speakers and your audience. More sensitivity than necessary means that you can't take advantage of all the headroom in the mixer because you'll run out of headroom in the power amplifier first.

To set the amplifier input sensitivity properly:

- Hold your ears and warn everyone else within hearing range. You've been sparing your ears for a while, but now it's time to make noise.
- Turn the amplifier's input gain controls all the way down. If the power amplifier is off, turn it on.
- Crank up your music or test tone to maximum level below clipping as indicated on the console's VU meters.
- Turn up the amplifier's input gain control until you can just hear clipping or the amplifier's clip indicator just goes on, then back it off a little bit. This is the proper gain setting. Leave it there.

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, it isn't going to get any louder – the amplifier is undersized, the speakers aren't efficient enough, or they're placed incorrectly.

In The Studio

The same principles of gain structure apply when setting up a recording chain. You don't want your recorder to run out of headroom before the mixer output that's feeding it. Otherwise you won't be feeding the recorder a signal with the best signal-to-noise ratio. Conversely, you want your recorder's input sensitivity to be high enough so that you can reach maximum recording level without the mixer clipping.

Many recorders today don't have input level controls, so to a certain extent you're at the mercy of the designers. Fortunately, you're usually safe if you connect inputs and outputs with matching nominal operating levels.

Mismatched Components

Sometimes the best theoretical setup doesn't work in practice and you need to compensate somewhere. Suppose you've set up your system for maximum headroom, and when the console meters are just hitting 0 VU, the sound is so loud that people are leaving. OK, so you turn the console main mix level down and they come back in when your console meters are peaking around –20 VU. But now the meters on the recorder that you have connected to the main outputs are barely moving and you're concerned that you'll get a noisy recording. And on top of that, the console faders are so close to the bottom that you don't have very much working range to get a good mix.

The thing to do in this case is to reduce the input sensitivity of the power amplifiers so that with the mixer running at its optimum level (around 0 VU on its meters), you're getting the right volume level in the house. True, you're compromising the gain structure a bit, but you do what you have to do. It's far less destructive to run the last stage in the chain at lower than optimum gain than the first stage.