A Detailed Look at Feedback Prevention & Suppression

dbx®
by HARMAN

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1. The Nature of Feedback

It is common to think of feedback as a single tone growing in strength at a specific frequency, because that is usually what we hear. The reality is that there are a large number of frequency regions that are potential feedback problems waiting to happen.

These problem regions occur near any frequency where your sound system's total output is added back in phase with its input (via microphones or instruments), causing constructive interference. These in-phase locations are dependent on the round-trip delay in your feedback loop, as well as the frequency responses of every component of your setup (your mics, equipment, speakers, and even the room itself).

To illustrate the issue, a plot is shown of a very simple case (a single mic pointed at a single speaker, very close together). This is a magnitude frequency response plot, which illustrates how strongly the system responds to each frequency. Four plots are overlaid on one another, with varying amounts of feedback loop gain per plot.

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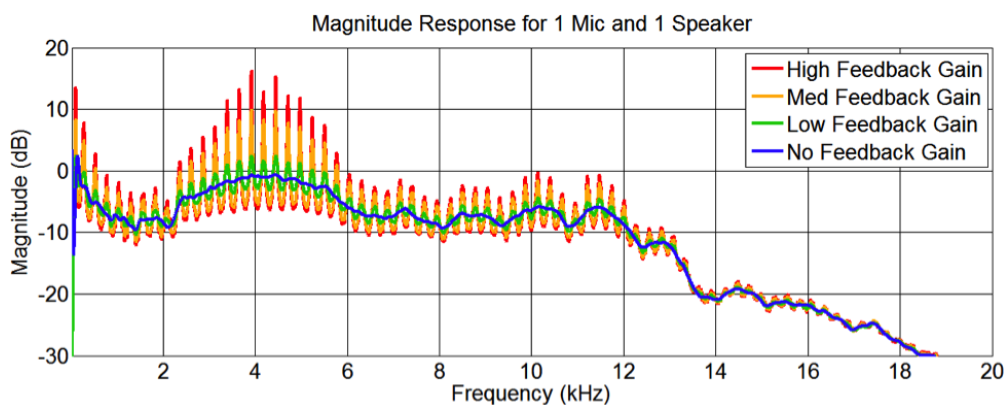

Figure 1 – Magnitude Responses for Various Feedback Loop Gains

The highest gain scenario was very near feeding back, but still stable. This is akin to a performance where the sound engineer has cranked the levels as high as he could while still avoiding feedback. It is obvious from the plot that this causes quite a change in the response of the system. Note that increasing your microphone gains by 1 dB can cause an increase of several dB in your whole system's response due to feedback loops.
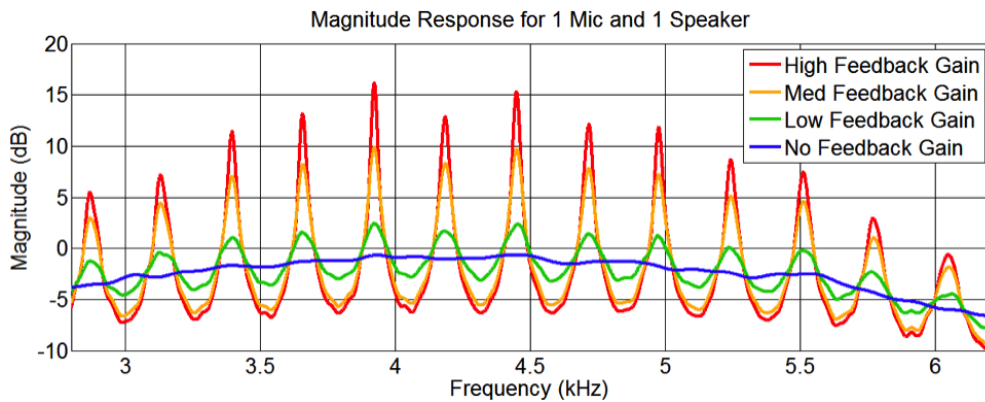
Figure 2 – A Zoomed Look at the Comb Filter Effect

Figure 2 shows a zoomed in version of the plot. Why do these problem feedback regions occur with such uniform repetition in the frequency domain? This is due to the fact that the round-trip delay in a feedback loop causes a linear phase change with respect to frequency. The longer the delay, the steeper the slope of the phase change. Remember that your system's output is in-phase with its input as long as the phase response is a multiple of 360 degrees at the frequency in question. The longer your delay, the steeper your phase slope, and the more often your system's output and input are at a multiple of 360 degrees (in-phase), causing a potential feedback region.

Figure 3 shows the same sound system, but with a delay of 10 more milliseconds introduced for a total delay of 42.125 milliseconds. Now we see many more potential problem regions for feedback.
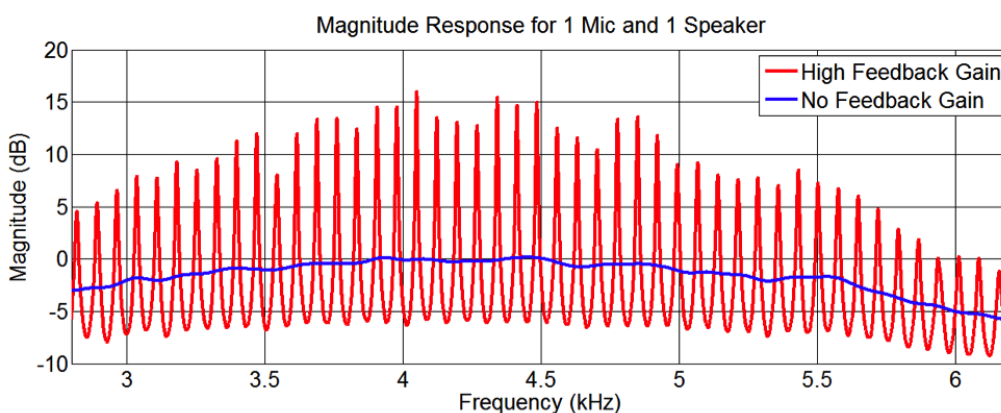
The longer the delay, the steeper the slope of the phase change.

Figure 3 – A Zoomed Look at the Comb Filter Effect with 10 ms Additional Delay

From this figure, it is easy to see why sometimes several notch filters are needed to address a particular frequency region. You may have more than one problem in the frequency band of interest. It is even possible that multiple adjacent feedback tones will grow at the same time. You may have heard this before without realizing it. Often, two simultaneous tones are so close in frequency that you only perceive one tone whose amplitude oscillates (or "beats") at a low frequency which is the difference between the two feedback frequencies.

A Slightly More Realistic Scenario.

So far we've only looked at a very simple case. Even just adding another speaker to the setup is going to make things a lot more complicated. Now with another speaker we have introduced another feedback path. The two feedback paths also interact with each other, potentially causing feedback at much lower levels than either feedback path individually.
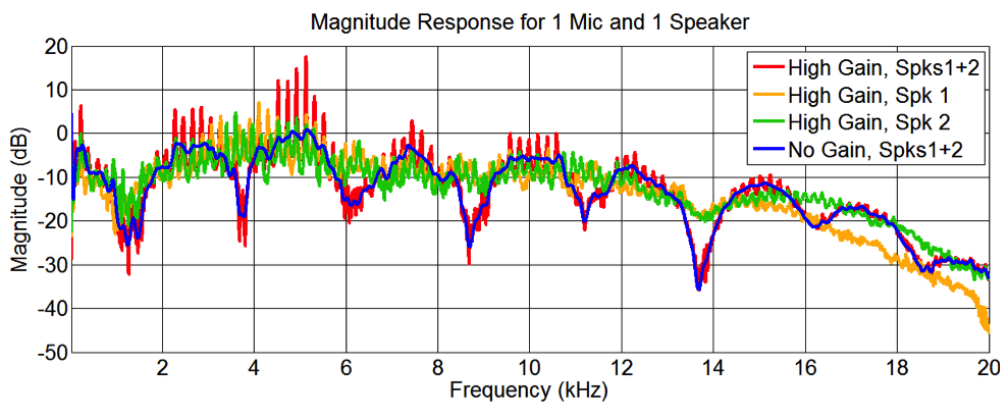
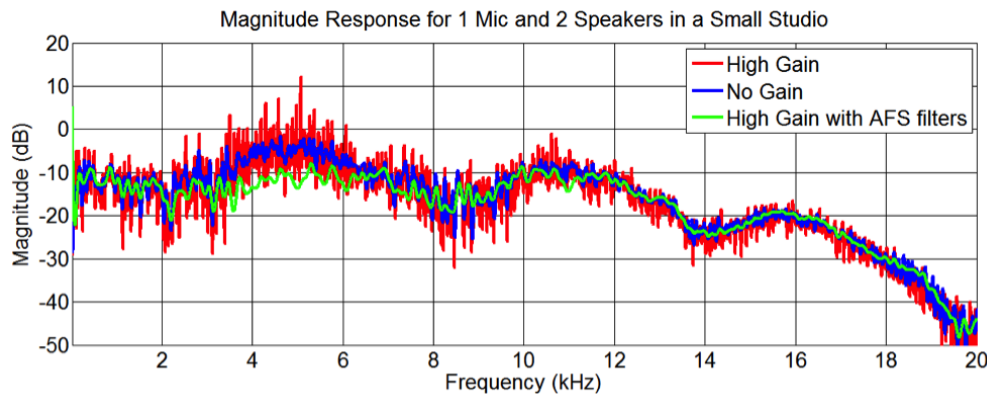**Figure 4 – Responses from Two Speakers and One Microphone**

Figure 4 shows magnitude responses for each individual speaker as well as the combination of the two. One of the speakers is farther from the mic than the other by about 1 foot. When both speakers play simultaneously, this causes phase cancellation problems which can be seen as the large dips in the response.

In all three high gain plots, the feedback loop gain is identical. Note that having both speakers on at the same time causes feedback much sooner than having either of the speakers on alone. This is due to constructive interference at frequencies where the two speakers and two feedback paths are in phase with one another. With this in mind, you may want to consider how many feedback paths are in your system and if there is any practical way to reduce that number. You might just find that less is more.

Having both speakers on at the same time causes feedback much sooner than having either of the speakers on alone.

This setup is still a bit contrived since the microphone is very close to the speakers. Figure 5 shows a more realistic scenario where the microphone is at one end of a small studio and the speaker pair is at the other end. Reflections from the room make the graph noisier, but we can still see the potential feedback areas. The problem areas don't seem so uniform now, but they still tend to occur in the same regions as during the more ideal tests.

Figure 5 – Responses from Two Speakers and One Microphone at a Realistic Distance

The green plot shows the system's response after 12 medium-width AFS (dbx's Advanced Feedback Suppression) filters have been set on the areas that fed back first. The net result is that we can now operate at the same high gain as before, but without fear of eliciting feedback. Notice that these semi-wide filters effectively flattened the system's response in the low frequencies. This can be looked at as either a good or bad thing, depending on your goals. The next section will discuss more about this relationship between EQ and feedback suppression.

2. The Importance of Room Equalization

Even if you could have a room and microphone with perfectly ideal responses, we would still see the problem illustrated in Section 1 due to the time delay. In the real world, though, you will never have an ideal response. Many microphone responses are not close to flat (and sometimes intentionally so), and no room/speaker response will be perfectly flat. Because of this, some frequencies are naturally boosted with respect to others. If your room or microphone has a big emphasis in a certain region (say around 2 kHz), that is where feedback is likely to occur first (e.g. higher room/mic gain contributes to higher feedback loop gain). It is at this point that we reach two conflicting objectives: to achieve the maximum gain-before-feedback, or to achieve the tone ideal for your performance.

If your room or microphone has a big emphasis in a certain region, that is where feedback is likely to occur first.

Maximum Gain-Before-Feedback.

A perfectly flat response will allow you to push your system as loud as it can go before feeding back. However, as you push your mic gains to the limits you will suffer from significant comb filtering effects (the equivalent of applying hundreds or thousands of narrow PEQ filters to your system).

Ideal Tone.

You may find that a totally flat response is not ideal for your listeners. In this case, your ideal response will be louder at some frequencies than others. You are most likely to experience feedback in these emphasized regions since the gain is higher there. When tone is your main concern, you must also be careful not to operate near your maximum possible gain to avoid the "artificial" peaks caused from high feedback gains.

In either case, the first and most important step in achieving your goal is to properly set up your room before applying any sort of compensating equalization. What you are doing is proactively minimizing the worst-case gain of all of your feedback loops, thereby creating less potential problems to deal with later.

Room Setup

If your room has obvious problems in certain frequency regions, consider treating the room appropriately with diffusers, bass traps, etc. Do what you can to make your room sound good naturally before you lay a heavy hand on the EQ. The following two paragraphs illustrate some other ways in which you can increase your maximum gain-before-feedback before applying any equalization.

In acoustics, the power of audio signals drops off quickly in proportion to the distance between the receiver and the source. A good rule of thumb for the attenuation proportion is $1/d^2$, where d is the distance between the source and receiver. This is known as the inverse square law. It implies that a microphone which is 4 meters away from a speaker will have a feedback gain of roughly ¼ of what it would have been if it was placed 2 meters away. Use this to your advantage, and place your mics sufficiently far from the speakers when possible.

Another important principle is the concept of directionality. Most microphones used for live sound are highly sensitive to audio coming from the front of the mic, while rejecting the majority of audio from behind the mic (cardioid pattern) or at other specific angles (hypercardioid, etc.). You can use this principle to your advantage by ensuring that your microphone's lowest-gain location is pointing at your speakers. If you are using omni-directional microphones and are experiencing problems, try a microphone with a hypercardioid-style pickup pattern or any other pattern that has good off-axis rejection. You are likely to see a large amount of improvement in feedback rejection during your performance.
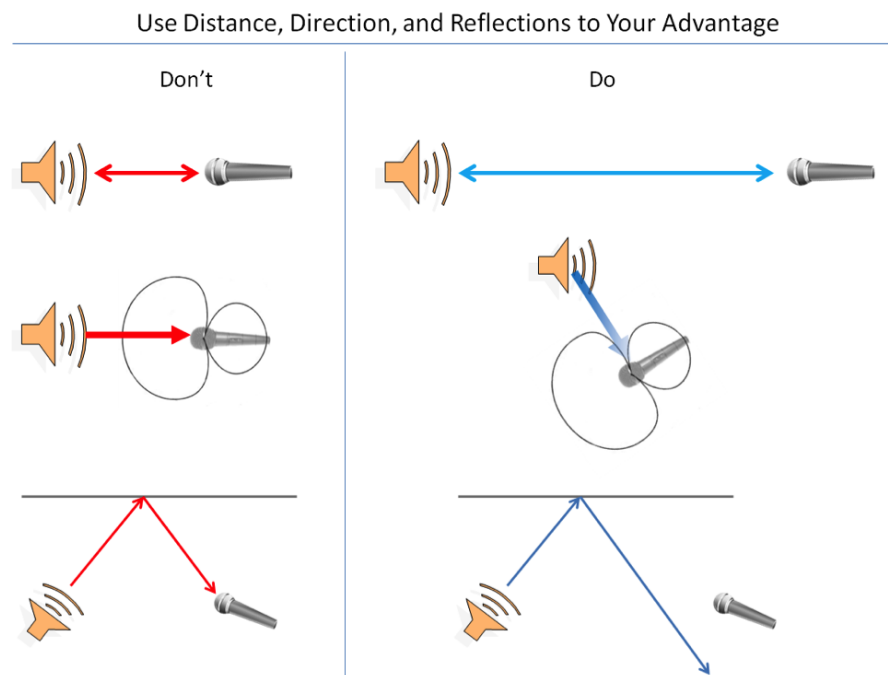
> When tone is your main concern, you must also be careful not to operate near your maximum possible gain to avoid the "artificial" peaks caused from high feedback gains.

Speakers are also directional. You'll get the highest gain directly in front of the speaker, so avoid putting the microphone there if possible. If you can offset the mic from the speaker, you can significantly reduce your feedback loop gain, especially at higher frequencies.

You may have to be careful of strong reflections as well. If you have a speaker and mic both pointed at a reflective surface like a stone floor or wall, that audio path might have significant enough gain to cause feedback.

Use Distance, Direction, and Reflections to Your Advantage

Figure 6 – Some Do's and Don'ts for Microphone Placement
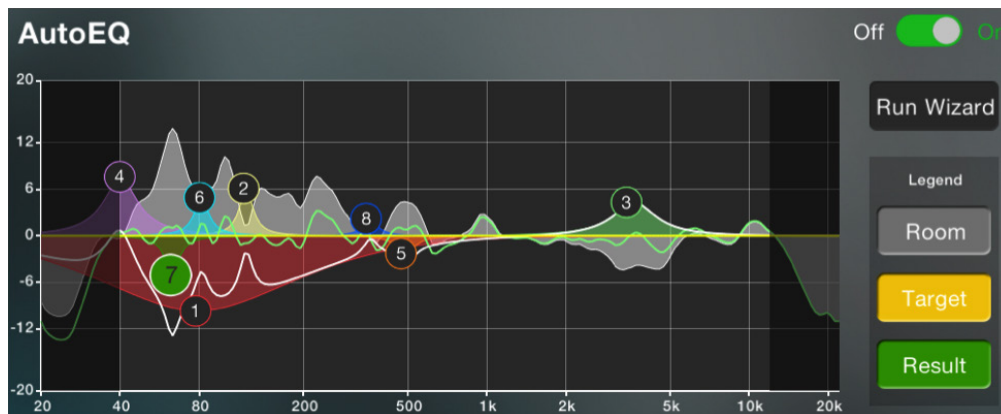
Room Equalization

After you've done all you can with your room, it's time to apply EQ. An important concept to keep in mind as you begin is that your frequency response will differ depending on where you are in the room, due to standing waves. This means that even if you dialed in the perfect EQ to make the response totally flat at the mix position, the response will not be flat in other parts of the room. Because of this, it is important to check the tonality of the room in all points of interest to ensure that the EQ you're applying is having a net positive effect. Keep in mind that if you're trying to get maximum gain-before-feedback, you'll want to focus on EQ-ing the area around the microphones. If you're trying to get a certain tonal response where the audience is, you'll want to focus on that region.

Remember that your room can respond very differently when empty than when it is full of people, so your setup ahead of time will never be perfect. This is one way that AFS comes in handy, by handling any new problems caused by events you can't plan for ahead of time.

People will have their own preference as to how to apply EQ, but we recommend starting with the Auto-EQ system in dbx's latest DriveRack line, such as the DriveRack PA2. It uses an RTA microphone to measure multiple points of interest in your room and automatically dials in a set of Parametric Equalizer filters to address your room's specific needs as a whole. It is fast, accurate, and it takes multiple measurement positions into account, which is a more painstaking process when done manually. If your goal is maximum gain-before-feedback, you can use a flat target response curve that it will attempt to match. If you are going for a more tonally pleasant experience for the audience, other target curves are provided which can result in a more natural-sounding response for your venue. Figure 7 shows AutoEQ results for a bass-heavy room and a flat target response. The light grey area is the measured room response, and the light green line is the final response after AutoEQ has been applied.

Figure 7 – DriveRack PA2 AutoEQ Results for a Bass-Heavy Room

If you have some form of spectrum analyzer, check your newly EQ'd room. It should be a bit smoother now, but any remaining peaks in the response (there will always be some) will be likely places for the feedback to occur. It is those remaining problem areas that AFS will help you to control so that you can squeeze a few more dB of gain out of your system before feeding back.

3. Pre-Performance Setup (AFS Fixed Mode Setup)

Now that your room is EQ'd, it's time to do a sound check. Set up your mics and instruments and get the mixes right. The next step is to activate AFS in Fixed mode so that it can catch any problematic feedback that may occur.

After you activate AFS in fixed mode, start increasing your output gains and test how high you can go before experiencing feedback problems. If you can get all the way to performance levels without setting any notch filters, congratulations! This is a good sign that your system is set up well (or that you don't want to rock quite as hard as the other sound guys). Still, make sure you have fully tested your setup. When possible, it is recommended to have all of the performers stand in their positions (with ears covered) while you raise the sound levels, since oftentimes just the act of approaching a microphone will reveal a problematic feedback region that otherwise wouldn't be there. Have them move around wherever they would naturally go during the performance in order to reveal any feedback that might spring up later.

Tapping the mics or clapping is sometimes done to help provoke the feedback into growing. Be careful that the performers don't play instruments or sing into the mics during this time, as feedback suppressors may mistakenly set filters on the music when in their setup mode (Fixed mode for AFS).

If you find that all of your notch filters are clumping together in a group, this is an indicator of a larger EQ problem. You may want to do a second round of EQ to fix the problem and then try again.

There are diminishing returns for each notch filter placed. It is likely that you have a few highly problematic regions that will be addressed by the first handful of filters. After that, you may find that you can't increase the gain much before running into a lot of new feedback tones. This is a good indicator that your system is nearing its maximum functional gain. This is usually a good time to stop setting filters, but if you really need to, you can try and push your system for another dB or two of gain.

> It is recommended to have all of the performers stand in their positions (with ears covered) while you raise the sound levels, since oftentimes just the act of approaching a microphone will reveal a problematic feedback region.

4. Performance Setup (AFS Live Mode Setup)

Now you have set up the venue and found your maximum operating level. Your actual performance level should be at least a few dB below your maximum. In general, the lower your mic and speaker levels can be, the less coloration you get in your tone due to feedback loops.

You shouldn't be experiencing a lot of feedback during your live performance (especially if you went through the pre-performance setup properly). If you are still experiencing a lot of feedback, you are probably pushing your system too hard and will have to reduce your levels.

AFS's Live Mode is a good emergency backup plan. You never know when the vocalist is going to point the mic straight at the speaker, and when that happens every millisecond counts. AFS should quickly kick in and place a notch filter on the offending frequency. Every common feedback suppressor has a mode for live performance wherein there is logic in place to help distinguish between music and feedback so filters don't get placed on the music. They are not perfect, but they are all much better than they were ten years ago.

5. Myths about Feedback Suppressors

Myth 1:

Feedback suppression filters destroy your tone – It is possible, but often a well-placed notch filter may actually get you closer to your desired sound than you were before. Even if you are proactively avoiding feedback by making a naturally flat room, you have already somewhat "destroyed your tone" there too (most people don't like listening to a truly flat room). It's all about what is most important to you, higher gain or the ideal sound.

Figure 8 shows a stable system with high feedback loop gain and different AFS filters applied. When using narrow filters in this high-gain scenario, we see that we actually get closer to our desired response than without the filters. When using the wide filters, less are used, but to greater effect. Tonality is affected, and we see that in this mode AFS is effectively trying to solve a broader EQ problem that should have been solved appropriately with speaker time alignment and maybe some system EQ.
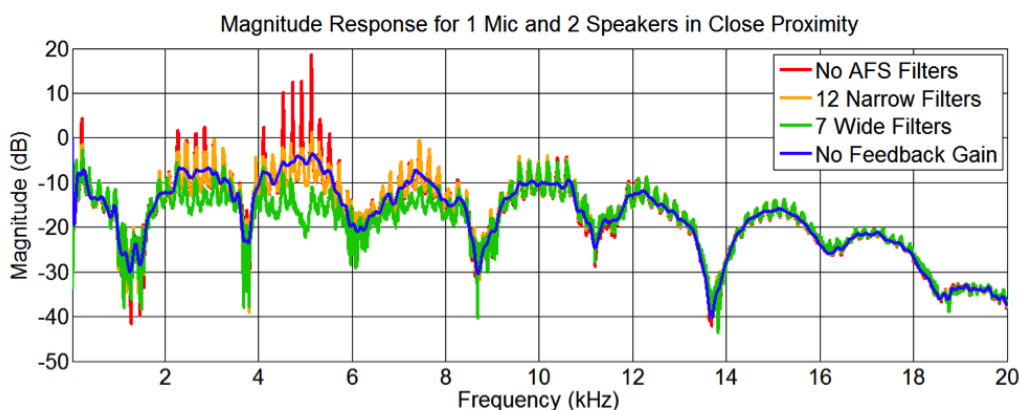

Figure 8 – **Narrow and Wide AFS Filters With High Feedback Gain**

Most likely you will not be operating your system at the feedback threshold. Depending on your operating feedback loop gain, the same AFS filters will help/hurt your tonality in different ways. Figure 9 shows a magnitude response of a 1 mic, 2 speaker system with 9 narrow AFS filters applied at various feedback loop gains. We can see that if you operate with no feedback loop gain, the filters are notching out parts of the response (but probably still inaudibly). You probably won't be operating with zero loop gain though (the equivalent of turning the microphone off). A more realistic scenario is the medium or high gain case where the microphones are on and filters are active. In these cases the filters are actually helping the response to be more balanced than it would have been without them (Compare to Figure 2 which shows the responses for med/high gains and no AFS filters). It is not hard to see that operating at near-feedback levels can be more damaging to your tone than the average notch filter is.
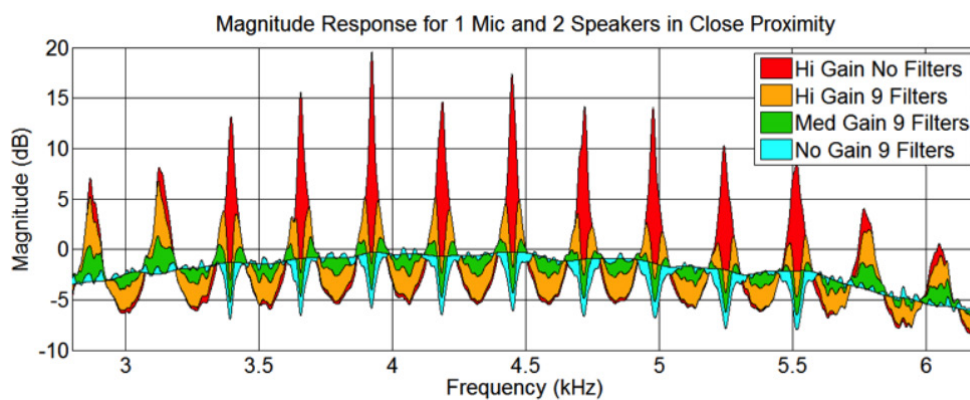

Figure 9 – AFS Filters with Various Feedback Loop Gains

Myth 2:

Humans Can Do Better Feedback Suppression with Their Ears and a Graphic EQ –
The best kind of feedback is the kind that never happens. That requires preventative measures which this paper has addressed, and many of which are best solved by humans. As far as reactive feedback suppression, though (after feedback has started), feedback suppressors are usually better.

While humans are still better than a computer at distinguishing between feedback and music, they are not likely to be better at estimating the precise frequency of the feedback tone. dbx's latest AFS algorithm can estimate the feedback frequency with an error of 0.2 Hz, which is far more accurate than what a human can do. Once it knows the feedback frequency, it can set a very narrow notch filter on the offending tone much quicker than a human can with a graphic or parametric equalizer. It can also use a much narrower filter than a GEQ because of how accurately it can place the notch on the exact feedback frequency.

The best kind of feedback is the kind that never happens.

AFS's notch filters are often so narrow that they are completely inaudible. Figure 10 compares the AFS filter width to a competitor's notch filter and a GEQ filter. Be aware that notch filters set at lower frequencies are more likely to be audible, even if they are the same bandwidth as their inaudible high-frequency counterparts. This is due to the nonlinear perception of human hearing. We would make them narrower, but then they wouldn't be wide enough to properly kill feedback (see the next topic).
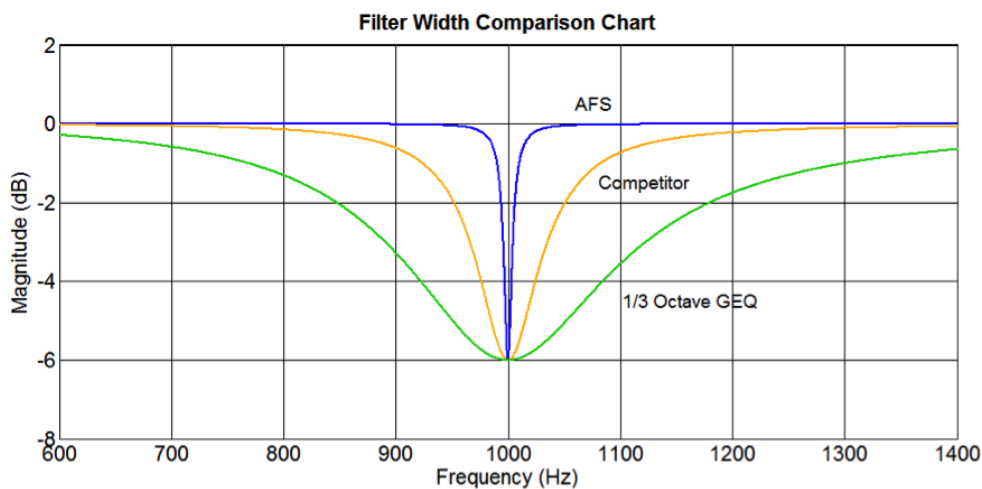
Filter Width Comparison Chart

Figure 10 – Filter Width Comparison Chart

Myth 3:

Narrower Filters are Always Better – Sometimes true, but not always. With longer round-trip feedback delays, the feedback regions will be very narrow and that's when you can really take advantage of AFS's narrowest filters. At other times, you really do need a wider filter to properly address the problem. Figure 11 shows an example of the natural feedback region being wider than the notch filter placed on it. If the feedback loop gain is increased, it is possible that one or both of the two side lobes will be strong enough to feed back. This is why AFS filters are allowed to automatically widen if a nearby problem is detected, allowing them to more accurately match the width of each problem region.
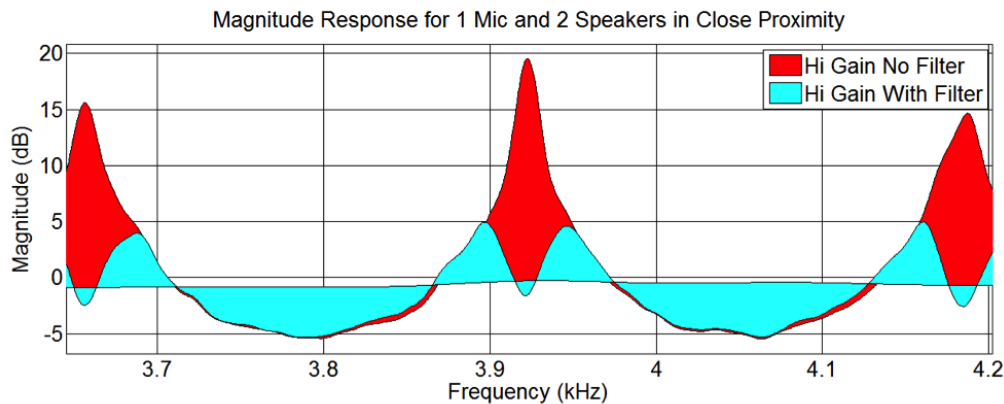
AFS filters are allowed to automatically widen if a nearby problem is detected, allowing them to more accurately match the width of each problem region.

Figure 11 – AFS Filter Narrower Than the Feedback Region

6. Summary

Here are the main tips to take away from this paper. If you do these things, you will be well on your way to a feedback-free performance.

- Feedback is most likely to occur where broader EQ issues are prevalent.
- High feedback loop gains adversely affect your tone. Unless you really need to, avoid performing at near-feedback levels.
- Achieving maximum gain-before-feedback means getting a totally flat response at your inputs, which may conflict with your tonality goals.
- Always implement passive feedback reduction techniques, then EQ, then AFS.

- **Passive Feedback Reduction Techniques**
    - Treat your venue with some "Natural EQ" when possible by adding bass traps, diffusers, etc. This is a more permanent fix to the general EQ issues.
    - Less is more. Fewer speakers and mics results in fewer feedback paths and possibly a higher gain-before-feedback.
    - Take microphone and speaker directionality into account. Study the polar patterns of your microphones and investigate the ideal angles to place them at in reference to your speakers. If using omni-directional mics, try switching to a directional type.
    - Keep your mics and speakers as far away from one another as possible. This will reduce the level of the feedback coming into the mic.
    - Watch out for strong reflections that may also cause feedback.

Less is more. Fewer speakers and mics results in fewer feedback paths and possibly a higher gain-before-feedback.

- **EQ Tips**
  - For maximum gain-before-feedback, EQ for a flat response coming from the mics. If the mics have a natural boost at certain frequencies, you'll have to compensate for that as well.
  - A room full of people has a different response than an empty room. The AutoEQ in the DriveRack PA2 is non-invasive enough to run through even as the crowd arrives, in many cases.
  - Watch out for speaker delay misalignment and polarity issues. These can have a big effect on your tone.

- **AFS (Advanced Feedback Suppression)**
  - If you're worried about tone, use the narrowest filters to eliminate any problematic feedback areas and then reduce your levels as much as possible.
  - If your main concern is preventing feedback, wider filters can potentially treat multiple feedback problems at once and serve as an emergency replacement for proper system EQ.
  - AFS Fixed Mode - Ring out your system with the performers present when possible. The feedback paths can be very different on an empty stage compared to a full one. As you proceed, have the performers move close to the mics and speakers to reveal any hidden feedback paths that might spring up later during the performance.
  - AFS Live Mode – Comfort and safety usually take precedence over tonality during the performance. For the safest setup, switch to wider AFS filters to ensure that you eliminate feedback as quickly as possible.
  - If you hear filters moving around on low-frequency feedback but never properly eliminating it, you're probably in the scenario where the feedback region is wider than the filter is allowed to go (see Figure 11). Switch to wider filters in this case to prevent the problem from recurring.

> If you're worried about tone, use the narrowest filters to eliminate any problematic feedback areas and then reduce your levels as much as possible.

Appendix: Audio Equipment Used

Microphone: AKG D88 S Dynamic Supercardioid Microphone

Speakers: JBL LSR4328P Powered Studio Monitors

Sound Card: Lexicon I-O 42

Feedback Suppressor: AFS on the dbx DriveRack PA2

Delay Processor: dbx DriveRack PA2