

Damping Factor: All-Important or Utterly Meaningless?

by Eddie Vaughn

Chances are that if you're interested enough in great sound to be reading this, you're probably not much of a fan of loose, floppy, boomy, slow, tubby bass just for the sake of bass, the kind that rattles your fillings loose and vibrates stuff off the shelves, while giving you a splitting headache in the process. You're likely much more a fan of bass that realistically reproduces the lower registers of percussion instruments and pianos in a very natural sounding way. The kind of bass that is fast, tight, and dry, and rapidly decays after the note's sharp and incisive hammer-like initial attack.

Damping Factor: What It Is and What It Does

Damping factor (DF) is the function of an amplifier's output impedance and how it relates to controlling the loudspeaker, especially at low frequencies. It is expressed as a ratio, calculated by dividing the load impedance by the amplifier's output impedance (impedance is symbolized by the letter Z). For example, if an amplifier has an output Z of 2 ohms and the load is 8 ohms, that yields a DF of 4. This method can be used for estimating the DF, but is not highly accurate. In the real world, a speaker's impedance curve is not flat, therefore the actual DF is higher or lower at certain frequencies. In other words, the DF tracks the speaker's impedance curve. When calculating the DF, one must not only figure the output Z of the amplifier's output stage, but must also consider the resistances of the output transformer's secondary winding and the speaker cables as well.

So what does DF do and how does it apply in my system? In general, the higher the DF, the stronger the amplifier's "grip" on the woofer. The higher the DF, the more control the amplifier has over the woofer. A typical SET amplifier may have a DF of perhaps 4 or 5 at best. Some have a DF under 2. A vintage PP amplifier from the Golden Era of Hi-Fi (the 1950's and 1960's) may have a DF of 10 to 20 or so. Specs on paper meant everything, and besides a lot of power with very low distortion it had to have a high DF. Yet some Golden Era amps with high DF had very weak, tubby bass. How? An amplifier's damping factor has a lot to do with the quality of bass you'll get, doesn't it? Or does it? A low DF makes for soft, mushy bass with a loose, boomy decay of bass notes, doesn't it? Or was that just back then, on the popular speakers of that day? Does it apply nowadays? Has anything changed? Well, just like the tired old cliché says, "The more things change, the more they stay the same". Confused? We'll try to make sense of all this, using a classic tube amplifier as a demonstration.

The Dynaco ST-70, and the "Golden Era of Hi-Fi"

In this section, we'll begin exploring how amplifier output Z (and therefore DF) relates to the real world, instead of just some basically meaningless spec on paper. In today's lecture in Damping Factor 101, we'll be using the legendary Dynaco ST-70 as our "cadaver" for dissection. The ST-70 was the most popular tube amplifier in history, with about 300,000 sold. It was a true icon of the Golden Era of Hi-Fi, which ranged from around 1950 to the mid/late 1960's. The ST-70 is warm, mellow, smooth, and unobtrusive, the signature typical of the Golden Era. It does have one serious problem however, that is as famous as the ST-70 itself! That problem is it's poor bass performance. But wait a minute, the ST-70 has a DF of 15, much higher than many other tube amps that actually have better bass performance! So how can it have a relatively low output Z and still have soft and poorly extended bass? The reason is NOT the damping factor at all, it's because of a fatal design flaw within the amplifier itself...

The ST-70 uses about 30 dB of global negative feedback (NFB) to net it's very low distortion specs and high DF (for a tube amp). This copious use of NFB is typical of Golden Era amplifiers. Negative feedback is a sample of the signal taken from the output of an amplifier stage and re-injected into the front of that same stage (local NFB), or into an earlier stage (global NFB), where it is 180° out of phase with the signal present at the re-injection point. In other words, "feeding back." The circuitry contained between the two points is called the "feedback loop." Usually, the global feedback loop in a PP hi-fi amplifier will run from the speaker terminal back to the amp's input stage, thereby encompassing the entire amplifier circuit. NFB lowers an amplifier's distortion and increases it's DF by lowering the output Z. However, it also does some bad things. Because NFB is taken from the very rear of the amp and injected back into the front, there is a frequency-dependent time smearing effect that occurs, which blurs the focus. It also creates a "homogenization" of the sound, that leaves it lifeless and uninteresting. The ear is extremely sensitive to the negative effects of NFB.

NFB also reduces gain. The 7199 is the ST-70's preamp tube. It consists of a very high gain pentode to boost the input signal (high gain is required to recoup the gain lost to NFB) and a triode section that is used as a phase inverter to split the signal from the pentode section into the opposing-phase signals that drive the push pull output stage. The signal from the triode phase inverter travels through some too-small value coupling caps, which rolls off the bass. The bass-deficient signal

is ran through the rest of the amplifier, where the ST-70's global NFB loop runs from the speaker terminal back to the input stage at the cathode of the 7199's pentode section. Remember, NFB reduces gain. When you apply a given frequency of NFB, the gain at that frequency is reduced by the amount of NFB present, and boosted at other frequencies with respect to the feedback frequency. So, the ST-70's bass-deficient (high frequency heavy) NFB causes the highs to be cut and the bass to be boosted. The preamp tube is therefore overloaded with bass, which not only eats up all its headroom but causes intermodulation distortions at other frequencies. The bass-boosted signal is ran through the much too small value coupling caps, where the bass is rolled off and the vicious cycle starts all over again! This is why the ST-70's bass is anemic and tubby. It's relatively high DF of 15 means nothing in light of the inherit design flaws.

Again, DF is a function of output impedance, and as we see here a low output Z alone (which for a tube amp, the ST-70 has) does not guarantee good bass performance. An amplifier must be properly designed, with output transformers capable of good bass performance (which the ST-70's A-470 output transformers certainly were), and a power supply having fast transient response, sufficiently low impedance, and adequate regulation to do its job right at low bass frequencies (which the ST-70 certainly did NOT have!). The Golden Era amplifiers that possessed all these attributes had nice bass that was well controlled and extended, yet it was often also a little muddy due to the high NFB.

So is damping factor just a meaningless figure? No. Do we just ignore it? Again, no. But, as we've seen in our analysis of the Dynaco ST-70, it's relatively meaningless in that particular instance. I just wanted to convey the point that DF is not a "be all, end all" spec that will universally guarantee good bass performance or the lack thereof. Well, I guess I did say DF was "just some basically meaningless spec on paper" a few paragraphs back, didn't I? Actually, it's still meaningful in today's hi-fi world, just not in the same way it used to be (more on that later on).

The "Dark Ages" of Hi-Fi, The '70's and '80's

The transistor was invented at Bell Labs in December 1947, from a piece of germanium, some paper clips, and a razor blade or two. Once the mass manufacturing techniques for this new device were established, it quickly superseded the vacuum tube in commercial electronics. It was smaller and lighter than vacuum tubes, operated at much lower voltages, required no heater filament power supply, had a much longer life-

span, and could withstand vibration and high g-force impacts much better than tubes. But the biggest reason to manufacturers was economics. It was far cheaper and easier to manufacture and build circuits with, especially in light of new advances in mass production circuit board technology. The mass consumer electronics industry began replacing tubes with transistors as early as the 1950's, and by 1970 the transition had been fully completed.

Solid state held a firm stranglehold on the audio market, and had completely supplanted tubes as the "medium of choice" for all consumer level audio electronics (except some guitar amps). Solid state promised better sound, but delivered nothing but harsh, ear-drilling noise. Although it sounded awful, solid state yielded far better distortion specs than tubes, which was a huge selling point to the mass consumer market as well as the refined, pipe smoking audiophile.

Not only was the distortion of the new solid state gear much lower, so was its output Z. Solid state amplifiers had incredibly high damping factors that were unattainable with tube gear. A DF of a few hundred to over a thousand was (and still is) commonplace. It was suddenly a new era where all the rules had changed, where what was impossible or impractical with tube amplifiers was commonplace with solid state. Solid state power amplifiers sporting 5 times the power, 100 times higher DF, and 20 times lower distortion than the average tube amp were the everyday norm. Speaker manufacturers wasted no time in catering to the new solid state amplifiers that were all the rage. Overnight, the market was flooded with inefficient multi-way speakers with huge woofers and complex, power-robbing crossovers. The high wattage and DF of solid state made the use of cheaply made, poorly designed, power hungry 15 inch (and larger) subwoofers with huge magnets and voice coils possible, a feat that would have never been attempted with a tube amp just a decade earlier. Suddenly, sound quality was out and big bass was in. This newfound ability to cheaply and easily produce ridiculous amounts of thumping, booming bass at insane sound pressure levels created whole new genres of music, such as disco and teenybopper/dance pop. It looked as if tube amplifiers and high efficiency speakers were dead forever, replaced by solid state amps and monster subwoofers.

The SET Revolution

Fast forward to the early '90's. Throughout the '80's, the few tube amplifiers that had remained in production were produced by boutique manufacturers in very low quantities. Sadly, most were merely near-verbatim rehashes of Golden Era amplifiers wrapped in a fancy

chassis. Ridiculously expensive, they were "rich men's toys" that were available only to the privileged few.

It seemed that in Western nations, not only had tube audio gear faded into total obscurity, but the memory of it had as well. Many people didn't even know what a vacuum tube was, and far fewer had actually seen one. Yet half a world away, tube audio had not only survived in Japan but was a thriving subculture. Some of the more ambitious Japanese audiophiles had begun experimenting with zero negative feedback, single ended amplifier designs using directly heated triode (DHT) power tubes, some of which had been considered obsolete since before 1950. How contradictory it was that one of the most technologically advanced nations on Earth would revolutionize hi-end audio not by inventing some new, hi-tech amplifier technology, but by reverting back to the 1930's! They discovered that the long forgotten SET platform had a magical midrange characteristic all its own, that was very captivating and musical. It just didn't make sense, as SET amplifiers had terrible specs on paper, with very high harmonic and intermodulation distortions, and very low DF. But, there was no denying the open, free-spirited sound that flowed from them, that made music live and breathe like nothing else could. Throughout the history of hi-fi, every "advance" had come in the form of improved specifications on paper. In reality, most proved to be a step backward in sound quality, so it came as no surprise that what spec'ed out the worst on paper would inevitably sound the best to the ears!

Word of the "new" SET amplifier spread rapidly to the ends of the Earth, and became the rage in the world of hi-end audio. However, SETs soon began appearing on the used market just as quickly as they'd appeared on the new market, and many audio aficionados began searching in other directions. Why? Wasn't SET supposed to be the "Holy Grail" of amplifier topologies? Wasn't it's smooth, warm, open, grain-free presentation heralded as magical sounding by all those who heard it? Didn't it give you goosebumps like nothing else could? Yes, it did all these things, and did them well. So why would anyone sell their DH SET? Damping factor was one of the main reasons, besides poor amplifier design.

SET Amplifiers and Speaker Synergy

Directly heated triodes quickly gained a bad reputation for being slow and syrupy, and having soft, fluffy bass with poor dynamics. Pretty much all DHTs in general were lumped into this category, but the 300B was especially villainized. It's negative reputation was completely unfounded, as the real blame didn't lie with the

300B itself, but within the amplifier's design and also the speakers it was used with. Especially the speakers.

First, a little off-topic diversion as we examine the amplifier itself. Large DHTs are much more difficult to drive properly than power pentodes and beam power tetrodes such as the EL34, 6L6GC, and 6550. The 300B is certainly no exception. Without going into the lengthy technical details as to why, it's in fact perhaps the most difficult of all the common DHT types to drive properly. Many designers did not have a good handle on how to correctly drive these "strange, new" power triodes such as the 300B. Today, many still do not! Most apply the same techniques they use building vintage-type push pull amplifiers, and the result is a slow, syrupy sound with rounded-off attack and poor dynamics that undeservedly became synonymous with the 300B. Properly driven, the 300B is very dynamic and authoritative, provided it is powered by a stiff, fast, low impedance power supply and mated to a proper output transformer of high quality. The author prefers to drive the 300B with a single, high transconductance VHF/UHF small signal triode through a silver wound, Permalloy-core interstage transformer, a far cry from the 12AX7/12AT7 or 6SN7/6SL7 driver stage and resistive-capacitive coupling of classical PP amp design.

The other main root cause for poor SET bass performance is speaker incompatibility, which brings us back on topic. At the height of the DH SET craze, many an individual excitedly connected their new SET amp into their system, their hands trembling with anticipation at the promise of a magic they'd never heard before. Many had bought a SET to replace their high-NFB PP tube amp or solid state amplifier, and therefore they owned multi-way speakers with complex crossover networks, or other types that demanded a high DF and lots of power. A big, inefficient woofer with a high mass cone/highly compliant suspension and a wacky impedance curve, paired with a complex, power robbing crossover network is THE worst thing you could ever mate with a SET amp. The high mass cone and soft suspension over-rings on bass notes and creates tubby, loose bass. When your amplifier has a DF of 300, this is no problem. When it has a DF of 2, it's a BIG problem. A SET has no chance of adequately "manhandling" such woofers, and the roller coaster impedance curve makes the poor little guy puke his guts out trying to drive such a crazy load. Of course, the amp (or more often, the 300B) gets blamed for the mushy, tubby bass that results.

After listening to a few tracks, they were indeed spell-bound by the openness and air of the mids and highs, but were also completely let down by the slow, flabby bass. The great midrange tonality could only outweigh the syrupy slowness and lack of bass performance for

so long, and their new "miracle amps" ended up on the auction block. The truth is, they never really got to hear the amp first and what it was actually capable of. Had this scenario been just a little different, with it mated to the correct speakers, their old PP or solid state amplifier would be the one sitting in the garage collecting dust. When you take that same SET and mate it to some efficient 2-way speakers with a flat impedance curve and a minimalist crossover (read: one capacitor), the whole ballgame changes. If the woofers are designed to be friendly to a SET (low damping factor requirement), the bass performance can be quite good. In my opinion, fullrange single driver speakers are great with SETs. Their ultra low cone mass, stiff suspension, insanely high magnetic flux density, and whisper-thin voice coil gap all go together to make them among the most SET-friendly of speakers. They are naturally well damped/controlled themselves, and they excel with low-DF amplifiers. Because of the low cone mass and stiff suspension, there is little over-ring. The dynamic attack is very quick and incisive, and bass notes decay quickly without tubbiness or over-ring. If you've never heard a really fast SET amp driving the right pair of speakers, you'd be amazed at how quick, tight, and dry the bass is. The cutting edge dynamic attack is simply unreal, as are all the little microdynamics of instruments within the soundstage. Anything else sounds homogenized and "closed in" by comparison.

Here is where the tide turns. Thus far, we've discussed speakers that SETs can't drive, although it actually wasn't the SET's fault, it was the speaker. You gotta use the right tool for the job! When you take that high-NFB PP amp or solid state amp and put it on the fullrange single driver speakers, it sounds just as bad as the SET did on the monster woofers and complex crossover. The high-DF amplifier gets together with the lightning quick, well-damped characteristics of the fullrange single driver, and all you get is a compressed, lifeless, muddy, mucky sound. Here we see that an amplifier's DF can actually be too high for certain speakers, and prevent the free, unrestricted dynamics and nuances that give life to the sound. Is it because these amplifiers have flat dynamics? No, it's because they've been mated with the wrong speakers! Overdamping is just as bad as underdamping.

So Where Does That Leave Us?

As you can see, DH SETs have gotten a bad rap for something that wasn't their fault, or more specifically it wasn't the triode power tube's fault itself. Our multiple-choice question was, "Damping Factor: All-Important or Utterly Meaningless?" In summary, we can conclude that the truth lies somewhere in the middle. Along with efficiency and impedance, DF is a useful spec for de-

termining how synergistic a given speaker will be with a given amplifier, although the most important factor is still how a particular combination actually sounds. Speakers designed for high-DF amplifiers must be mated with high-DF amplifiers, and speakers designed for SETs must have SETs, or other low-DF amps such as one of the nice sounding, zero/low NFB solid state amps on the market, that run in very hot Class A operation (the SETs of solid state!).

This is one of the most basic and essential rudiments of putting together a good system, yet few are aware of it or understand it. It can be likened to tires on a car. You do not put racing slicks on a family car driven in a rainy climate. You don't put narrow, deep-treaded tires on a 3000 horsepower rail dragster or a Formula One car! Mud and snow tires don't belong on a sports car. For optimum performance, you must mate the correct tires to the automobile. If the combination of car and tires performs poorly, the fault lies within neither the car nor the tires, but the combination of the two. Neither is a poor performer on it's own, as each has it's proper place where it performs in an exemplary manner. But if operated outside it's intended medium, one can expect nothing less than sub-par performance as the result.

In closing, it bears worthy of repeating that the output transformer's secondary resistance and the resistance of your speaker cables are also part of your amplifier's output impedance. High DC resistance here can contribute to making the bass soft and mushy as well. Don't blame that power tube or speaker just yet!

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