NAD

A proposal to the audio industry

THE POWER ENVELOPE: A Better Way to Compare the Musically Useful Power Output of Amplifiers

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Introduction

The RMS continuous power rating of an amplifier, measured with a constant-level sine wave, has long been recognized as an inadequate means of specifying an amplifier's ability to reproduce musical waveforms. But early methods of specifying transient power output (EIA Peak Power and IHF Music Power) were subjected to such flagrant abuses that in the early 1970s the Federal Trade Commission stepped in and forced the audio industry to adopt full-bandwidth RMS continuous power as its primary rating standard. At the time this seemed a reasonable move. Whatever its limitations in absolute terms, it did provide a valid basis for comparing amplifiers.

Ironically, by the time the FTC power rule was adopted, technical evolution had already begun to make it obsolete. Before that time, most amplifiers employed fairly simple (and fairly similar) power-supply circuits, and consequently did not differ greatly in dynamic headroom. But during the early '70s two schools of amplifier design emerged. One camp favored a "stiff" power supply whose rail voltage remained the same regardless of the character of the signal, while the other camp favored power supplies having a higher quiescent voltage but "soft" regulation, producing less continuous power but greater short-term output for transients.

This trend was recognized by the adoption of the "dynamic headroom" specification as part of the Institute of High Fidelity's IHF A-202 amplifier test standard, which became EIA standard RS-490 when the IHF was absorbed into the Consumer Electronics Group of the EIA. The FTC continuous-power rating remains the primary standard, with the IHF dynamic headroom measurement suggested as a secondary standard for comparing amplifier performance.

Thanks to continued evolution in amplifier design--in particular, the development of signal-controlled "smart" power supplies--the IHF method of measuring dynamic headroom has also become inadequate to specify amplifier performance. This engineering trend benefits the consumer, by making the amplifier a more efficient reproducer of musical waveforms, with less manufacturing cost wasted on the irrelevant ability of the amplifier to heat a resistor. The audio industry should now adopt a standard means of quantifying this benefit.

We suggest the "power envelope" as a straightforward, easily understood, and musically appropriate way to assess the useful power output of amplifiers. This method of presenting an amplifier's performance was first introduced by NAD at the January 1985 Consumer Electronics Show. Since then it has been adopted by Carver Corp., by Proton Corp., and by Julian Hirsch of *Stereo Review* in two amplifier reviews.

The power envelope, as a diagram or as a set of power ratings, is the clearest method of illustrating--and validly comparing--the musically useful power output of amplifiers. It shows the rated maximum output that the amplifier can deliver, *as a function of time*. It includes the two measurements, continuous power and IHF dynamic power, that are already standardized and familiar to consumers. It extends the concept of dynamic power by measuring the amplifier's ability to deliver bursts of power lasting as long as a typical musical note--much longer than the 0.020 second "on" time of the IHF dynamic headroom test signal, and shorter than a constant full-power sine wave.

Measuring the power envelope

Conceptually, and in respect to measurement method, the power envelope is a logical extension of the IHF/EIA dynamic headroom measurement. The test signal employed in the headroom test is a tone-burst that is gated on for 20 milliseconds in each half-second. The signal is gated off (or reduced by 20 dB, to 1% power) for 480 milliseconds between bursts.

To measure the power envelope, the gating of the tone burst is slowed down, so that the duration of the burst becomes progressively longer.* For each tone-burst length, the signal level is raised until the amplifier begins to clip at the *trailing end* of the tone burst.

Interpreting the power envelope

Figure 1 shows the complete power envelope for a new amplifier (top) and for several conventional amplifiers (bottom), measured with load impedances of 8 and 4 ohms. The actual steady-state output of the tested amplifiers ranged from 75 to 500 watts/channel, but since we want to focus on the *shape* of the power envelope curve, the measurements for each amplifier have been scaled to the same steady-state clipping level. Three regions are identified in the power envelope:

1. The IHF dynamic power (20 mS burst), a measure of the amplifier's ability to reproduce the very brief attack transients in music, especially in percussive sounds.

2. The "burst" power that is available for reproducing musical notes and chords lasting several hundred milliseconds.

3. The steady-state power for continuous test tones.

It is noteworthy that the conventional amplifiers measured here (including models by Yamaha, Hafler, and NAD) do not differ greatly in their power-supply regulation: the power envelope curves are quite similar in shape, though they span a seven-to-one range in power output. In every case, including NAD's older amplifiers, the 20mS IHF dynamic headroom is between 1 and 2 dB when expressed relative to the steady-state clipping level, and the headroom for a burst length of 300mS is less than 1 dB.

* See Appendix.

Figure 1.

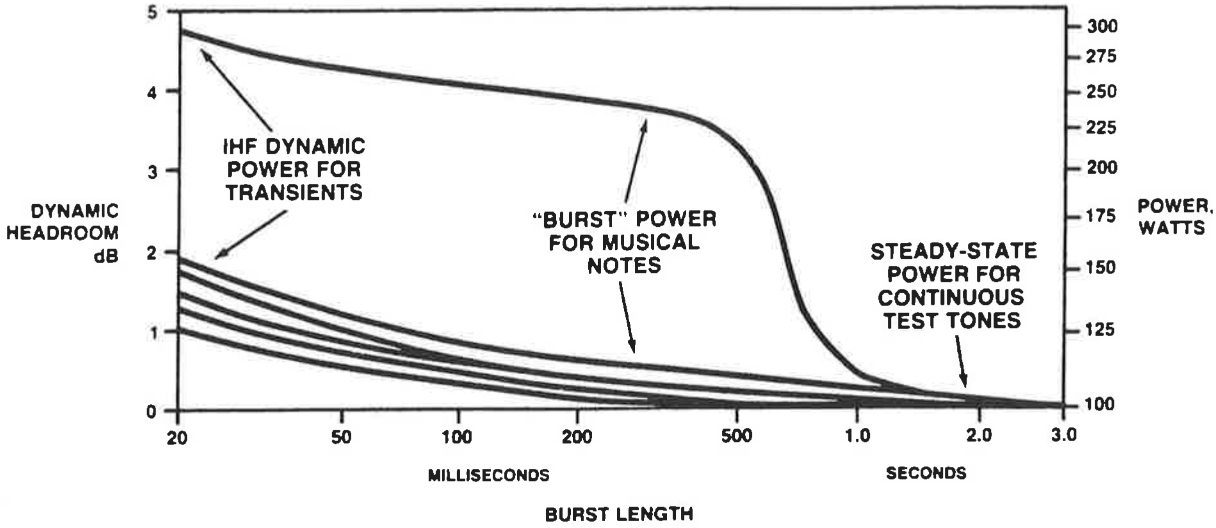

Figure 1. Complete Power Envelope, measured with load impedances of 8 and 4 ohms. New amplifier (top line) conventional amplifiers (bottom lines).

Figure 2.

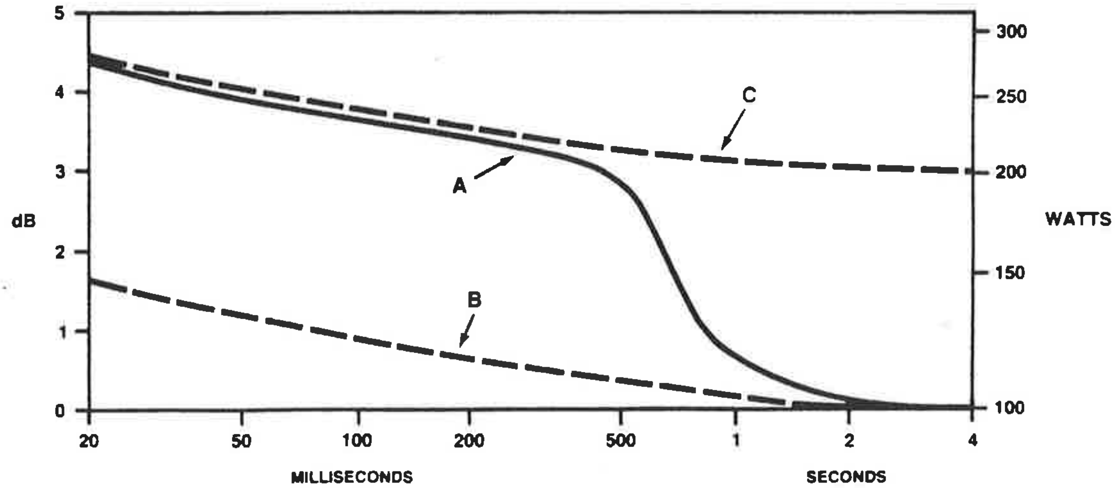

Figure 2. Power Envelope Curve of three amplifiers. Amplifier "A" is commutating design with a bi-level power supply. Amplifiers "B" & "C" each employ conventional single-stage power supplies.

But the new amplifier, with a bi-level power supply, has 4 dB more power for burst lengths up to 1/2 second.

If time and space don't permit the measurement and presentation of the complete power envelope curve as shown here, amplifiers could be compared by listing the power output for just three "on" times, for instance:

	Amplifier A	Amplifier B
20 mS (transient power)	300W (25 dBW)	160W (22 dBW)
300 mS (burst power)	250W (24 dBW)	125W (21 dBW)
continuous power	100W (20 dBW)	100W (20 dBW)

Inevitably, people will want to adopt just one number as an easily-remembered power rating. For the past fifteen years the FTC continuous power has been that number, even though it is appropriate only for comparing amplifiers that have tightly (and identically) regulated power supplies. With today's "smart" power supplies, steady-state power is rapidly becoming irrelevant as a rating method.

That leaves the two dynamic-power measurements, with short and long burst lengths. The ear tends not to notice clipping that lasts only for the brief duration of an attack transient. So the single number that most accurately describes an amplifier's useful power for music is the middle rating, measured with a tone burst of approximately the same duration as a musical note.

How does this measurement relate to amplifier design? Let us consider first the standard ratings, continuous power and IHF dynamic headroom, which represent the amplifier's performance for very long and very short signal "on" times.

The manufacturing cost of an amplifier is directly related to its steady-state power. High continuous power requires a power transformer with large iron cores and massive copper windings to pass several hundred watts without overheating or saturating; large and costly filter capacitors from which many amperes of filtered output current can be drawn; large output transistors (or several wired in parallel) through which high continuous power can be passed to the output terminals; and large heat sinks, possibly aided by thermostatic regulators and noisy ventilating fans, to dissipate the excess heat in the output stage. The continuous-power rating, especially with the FTC-mandated preconditioning (one hour of operation at one-third power), is basically a test of the amplifier's thermal capacity--its ability to pass a constantly high level of current through its power supply and output stage without overheating.

The IHF dynamic headroom test is just the opposite. Its 20-millisecond burst places virtually no strain on the power supply. And since the signal is off (or at a 1% power level) most of the time, the average power level is 1/25th of the measured dynamic power, producing very little heat. Therefore, the IHF 20mS headroom test is simply a measure of the available output voltage swing. In theory the amplifier designer could make this voltage arbitrarily large, constrained only by the breakdown-voltage ratings of the transistors. In practice, for amplifiers that employ a conventional power supply, the IHF dynamic headroom test is simply a measure of how loosely regulated the supply is--i.e. how high the supply voltage floats when it is not being pulled down by a heavy current drain.

Thanks to the development of "commutating" amplifiers, in which the effective rail voltage varies from moment to moment to meet the requirements of the signal, manufacturers are now able to tailor their products to efficiently match the dynamic power demands of music. This, in turn, is why the audio industry needs a more accurate way to rate the musically useful power output of amplifiers.

A commutating amplifier is one that has power supplies at two or more voltage levels, relying on the low-voltage supply most of the time (to minimize the heating of the output stage) and switching over to the high-voltage supply when greater output is needed to reproduce musical peaks without distortion. The historical development of this idea includes designs from Hitachi ("Class G"), Soundcraftsmen ("Class H"), Carver ("magnetic field"), Yamaha, Braun, NAD ("PowerTracker"), and Proton ("dynamic power on demand").

When successful, these approaches to amplifier design permit the amplifier to produce large bursts of power, to cope with the uncompressed dynamic range of digital recordings--without the high cost that would be incurred if the amplifier had to produce such high power continuously. The power envelope measurement, using an extended-length tone burst, provides a direct test of this benefit.

Figure 2 illustrates, for example, the power envelope curves of three amplifiers:

Amplifier A is a commutating design with a bi-level power supply.

Amplifier B employs a conventional single-stage power supply. It has the same steady-state power output (and costs nearly the same to manufacture) as Amplifier A, but produces much less short-term power.

Amplifier C also employs a conventional single-stage power supply. It has the same burst power for music as Amplifier A. But since it produces twice as much continuous power, it costs about twice as much to manufacture.

The power envelope of music

How long should a commutating amplifier be able to produce elevated power? How long are the power bursts in music?

To find out, we used an oscilloscope to monitor the dynamic power envelope of several types of music, using Compact Disc recordings as the source, and photographed dozens of high-level bursts. The music was played at a high (but not uncomfortable) volume level. Typical results are shown in Figures 3 to 11. All of the photographs have

DYNAMIC ENVELOPES OF VARIOUS MUSICAL SIGNALS.

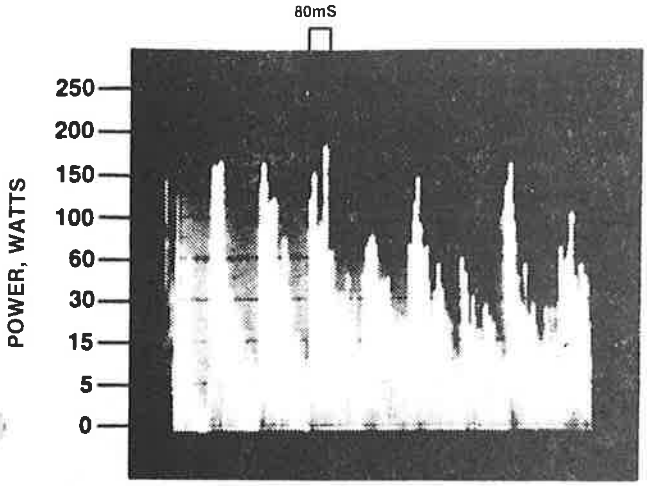

Figure 3. *Genesis, "No Reply At All."*

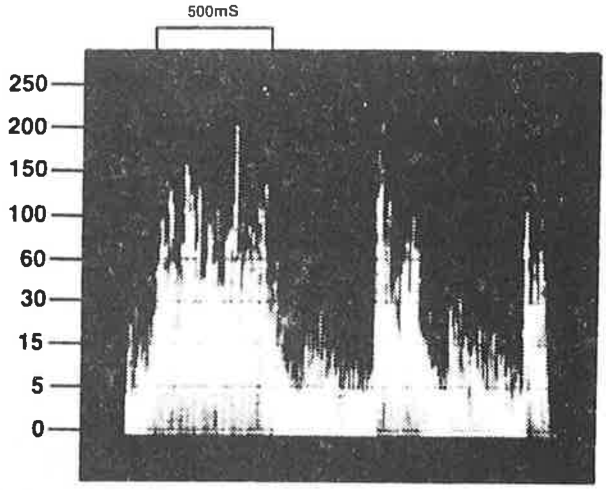

Figure 4. *Bee Gees, "Paradise."*

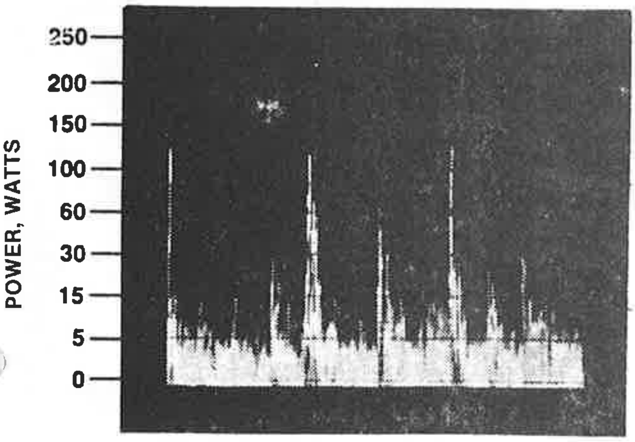

Figure 5. *Bee Gees, "Paradise."*

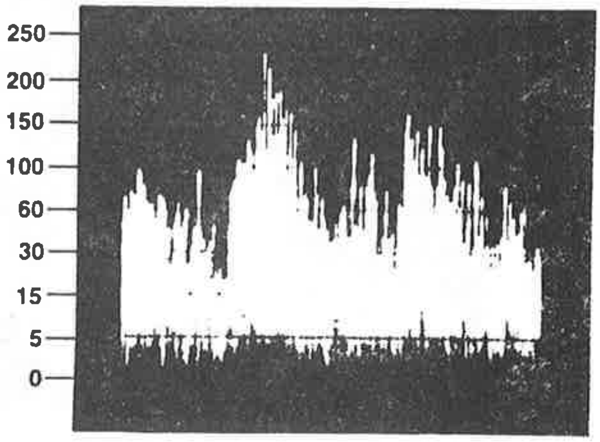

Figure 6. *Mahler, Symphony No. 2.*

DYNAMIC ENVELOPES OF VARIOUS MUSICAL SIGNALS.

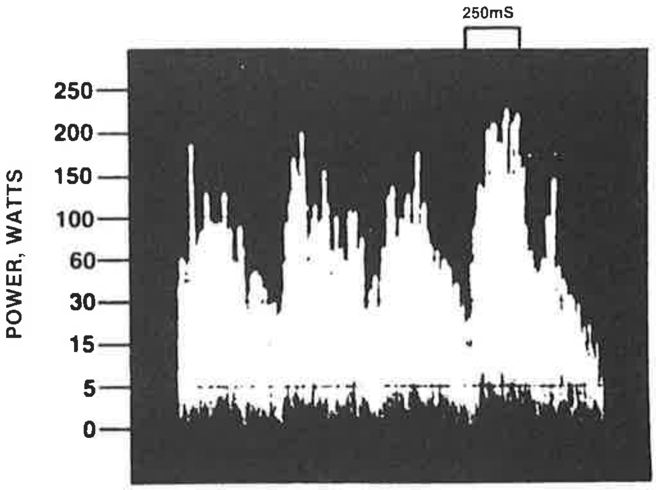

Figure 7. *Bruckner, Symphony No. 4*

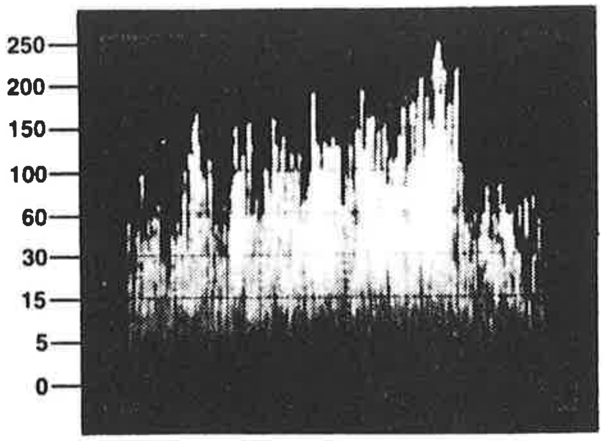

Figure 8. *R. Strauss, "Also Sprach Zarathustra."*

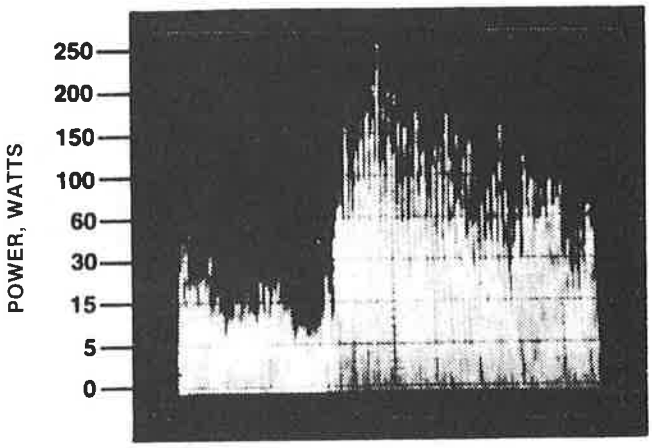

Figure 9. *Mussorgsky, "Pictures At An Exhibition."*

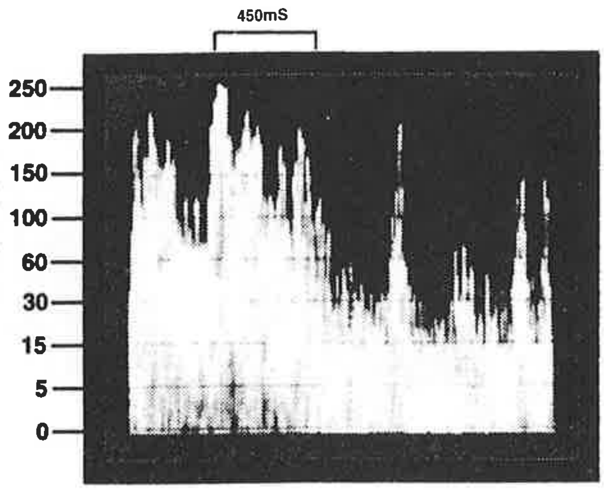

Figure 10. *Chopin, "Polonaise."*

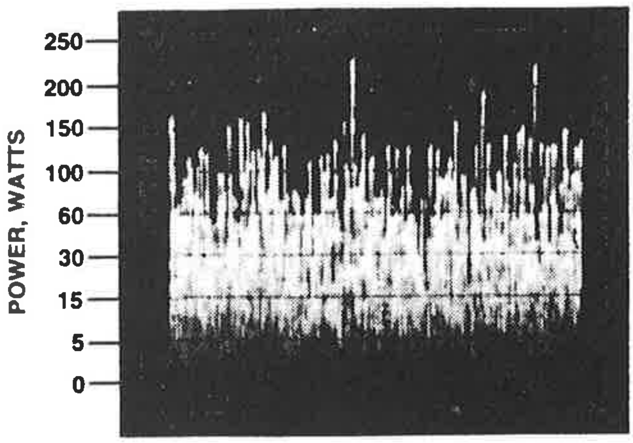

Figure 11. *Bach, Toccata.*

the same scaling: in each case a two-second segment of music is shown, and each horizontal division in the photograph is 200 milliseconds long.

Figures 3 to 5 are examples of popular music. Figure 3 (a segment of "No Reply at All" by Genesis) shows repeated bursts lasting 50 to 100 milliseconds; the power reaches 70 to 150 watts during each burst and falls to the 20 watt level between bursts. Figure 4 (a vocal passage from "Paradise" by the BeeGees) shows a 100W burst more than a half-second long, as well as shorter bursts and higher transient spikes. During the large burst there is a brief spike, less than 20 mS long, to the 200W level. Figure 5, an instrumental section of the same recording, shows very brief bursts not much different from the 20mS IHF dynamic headroom test signal, superimposed on an average power level of only a few watts.

It is often assumed that rock music has a much smaller ratio of peak-to-average power than classical music. That may be true after heavy processing of the signal by an FM station, but as these photographs show, CDs of rock music have considerable dynamic punch.

Turning to classical music, Figure 6 shows a two-second excerpt from the first movement of Mahler's Symphony No. 2, with a burst that remains above 100 watts for 300 milliseconds (plus brief spikes up to the 200-watt level). Figure 7, one of many passages for tympani and brass from Bruckner's Symphony No. 4, exhibits a series of 200mS bursts above 100 watts, repeating at half-second intervals. Figure 8, from "Also Sprach Zarathustra" by R. Strauss, shows a crescendo that stays above the 100-watt level for a full second, finally peaking over 200 watts. Figure 9, from Mussorgsky's "Pictures at an Exhibition" shows a low-level passage (under 15 watts) followed by a powerful chord that is above 100 watts for about 1/2 second.

Figure 10 shows a solo piano recording (a Chopin Polonaise); there are short transients, as expected, but also full chords longer than 200 milliseconds.

Figure 11 shows a portion of a long, sustained chord from a Bach Toccata played on the pipe organ, traditionally assumed to represent the best justification for a high "continuous" power rating. It does indeed show a sustained power level of about 70 to 100 watts, remaining nearly constant throughout the two-second duration of the photograph. Interestingly, though, there are also brief transients to the 200-watt level. Even in music that sounds as if its power level would be uniform, an amplifier benefits from dynamic headroom above its steady-state power level.

As these photographs show, what music needs (and, therefore, what an amplifier is called upon to deliver) is not a constantly high level of steady-state power but bursts of dynamic power that vary in duration from the brief 20mS transient of the IHF headroom test up to several hundred milliseconds. This should not be surprising; at a typical metronome setting of 75 beats per minute, the length of a quarter-note of music is 200 milliseconds.

Conclusion

For listeners, the value of an amplifier depends on the level at which it begins to distort musical sound, and the only reason to purchase a larger amplifier is its superior ability to reproduce the high-level peaks in music (especially the uncompressed peaks in Compact Discs) without audible distortion. With "smart" power supplies and commutating amplifiers becoming increasingly common (from several other manufacturers as well as NAD), there is no longer any correlation between the musically useful output of an amplifier and its steady-state power rating.

The audio industry must adopt a dynamic-power or burst-power measurement as its primary standard, in order to provide consumers with a rating system that relates to the real ability of amplifiers to reproduce music without distortion. The IHF/EIA dynamic headroom rating, using a 20 millisecond tone burst, is a step in the right direction. But the ear is relatively insensitive to distortion in sounds that last for only a few milliseconds. A measurement of dynamic power using an extended-length tone burst (with an "on" time of 200 to 300 milliseconds, corresponding to the typical duration of a musical note) is *the single most accurate way* to rate any amplifier's musically useful output.

Since most loudspeakers on the market have a true impedance that is less than 8 ohms in the frequency range where the highest power demands in music occur, this test should be done at both 8 and 4 ohms. If a single-number rating is desired, the 4-ohm burst power should be used. An even more useful (but more challenging) single-number rating would be obtained by measuring the burst power at 8, 4, and 2 ohms and averaging the three numbers.

We invite comment from reviewers and manufacturers.

Appendix: The Duty Cycle

When the "on" time of the tone burst is lengthened, should the "off" time between bursts be increased in the same proportion? Since our goal is to define a test that authentically measures the musically useful power output of amplifiers, the duty cycle of the test signal should be chosen to reflect the demands that real musical signals make on an amplifier's power supply and thermal dissipation.

Studies have shown that the ratio of long-term average power to short-term peak power in music ranges from less than 5% to nearly 14%. Even in the worst-case situation (rock music compressed for broadcast), the ratio of average to peak power is around 15%.

The IHF test signal (20 mS on, 480 mS off) has a duty cycle of only four percent, superimposed on a constant signal at one percent power. This resembles very impulsive music (see Figure 7, for instance). Simply scaling it up in time by a factor of ten yields a tone burst that is on for 200 milliseconds and off (or at 1% power) for 4.8 seconds. With such a long time for the amplifier to cool between bursts, this may be too easy a test.

Another proposal, however--that the duty cycle be increased to 50%, with the "off" time between bursts equalling the "on" time--is unreasonably severe and does not represent any realistic music situation. With this signal the long-term average power level would be equal to 50% of the short-term burst power, which never occurs in music. (If it did, most loudspeakers would quickly burn out.)

If a 4% duty cycle is too easy a test and a 50% duty cycle is unrealistically severe, a 20% duty cycle may be a sensible compromise (i.e. 100mS bursts repeating at 500mS intervals, 200mS bursts at 1-second intervals, 500mS bursts at 2.5-second intervals, and so on). This allows filter capacitors to re-charge between bursts of maximum power (as real music does), while producing a dissipation requirement that is just slightly more demanding than worst-case musical signals.

Alternatively, the standard IHF test signal could be made more challenging (and more accurately representative of loud passages in music) by raising the signal level between bursts to -10 dB. Thus the signal would be at full power 4% of the time and at 10% power during the remaining 96% of the time, producing a dissipation requirement similar to the worst-case situations found in music.

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NAD

Technical Bulletin--The Power Envelope

A New Generation of NAD Amplifiers

For several years NAD has led the industry in producing affordable stereo amplifiers that deliver unexpectedly large amounts of real speaker-driving power for the reproduction of music. NAD amplifiers have always employed massive power supplies and large transistors with high current capacity (to drive the low and complex impedances of loudspeakers), with an extra margin of dynamic headroom for musical transients. Now, as other manufacturers have begun to follow NAD's lead in these areas, NAD is launching a new generation of amplifiers that establish completely new standards for musically useful dynamic power.

The key to these new amplifiers, as with all NAD products, is that they go beyond conventional specifications and laboratory tests to provide optimum performance under the real conditions of everyday use. NAD amplifiers are designed, first and foremost, to reproduce the dynamically varying waveforms of music--not just sine-wave test tones.

The Dynamic Envelope of Music

All amplifiers have a "continuous" or RMS power rating, measured with a constant-level test tone. But music is not a constant tone: it changes with each surging chord and pulsing beat. Music has a high "peak to average" ratio, meaning that in virtually every musical sound there are short-term peaks whose intensity is several decibels greater than the average level.

This can be seen in tape recorders: the flickering LEDs of a "peak-reading" display often register momentary bursts of sound that are several dB higher than the averaged level shown on a VU meter. This characteristic is obvious in the accompanying photographs, each showing the intensity of musical sound over a period of two seconds. For example in Figure 1, a two-second excerpt of a popular song played at high volume, bursts of high intensity (during each note and syllable) alternate with the brief near-silences between notes when only the reverberation of the previous note is heard. The

DYNAMIC ENVELOPES OF VARIOUS MUSICAL SIGNALS.

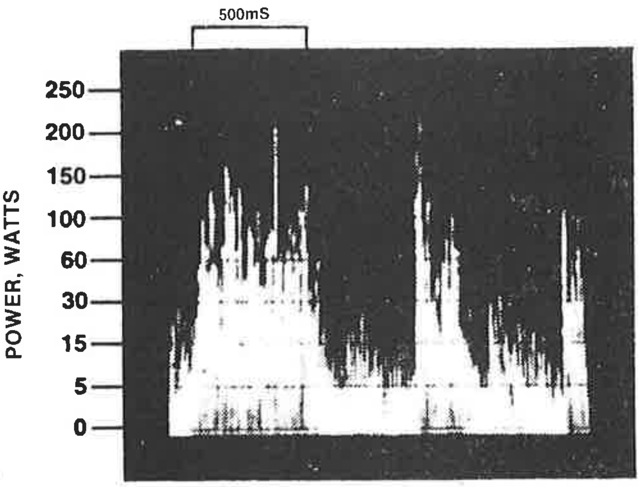


Figure 1. *Bee Gees, "Paradise."*

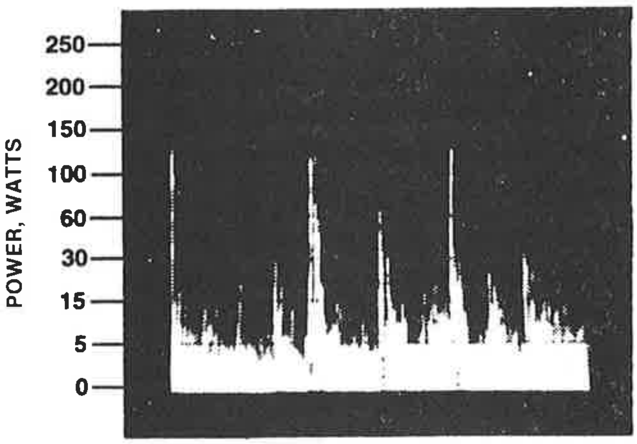
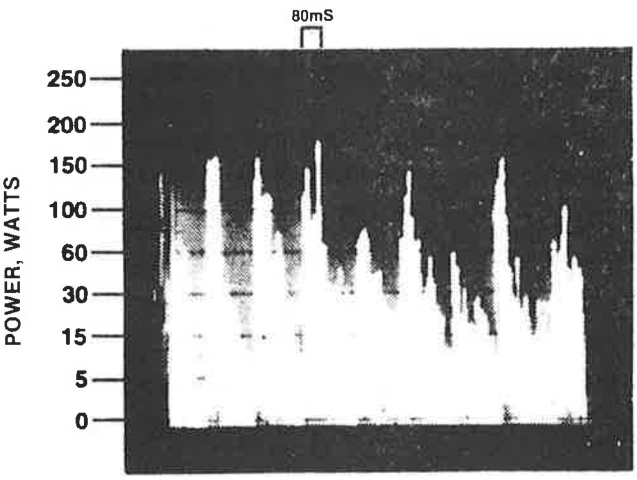


Figure 2. *Bee Gees, "Paradise."*



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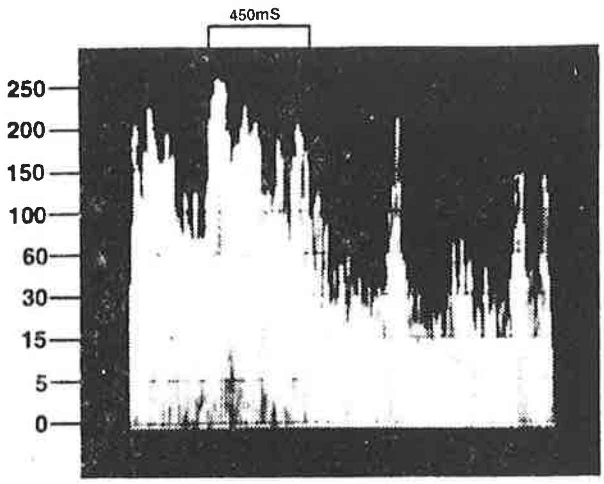

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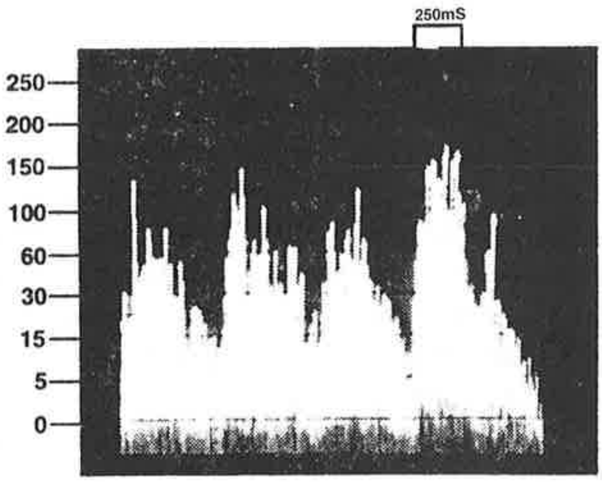

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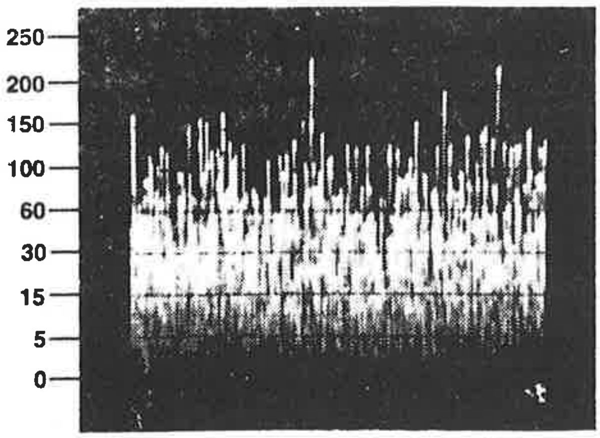


Figure 6. *Bach, Toccata.*

average power may be no higher than 30 watts, but it consists of 100-watt bursts paired with intervals in which the power drops to 5 watts.

Similar patterns are seen in the other two-second samples of music shown here: an instrumental portion of the same song (Fig. 2), some loud rock music with a driving beat (Fig. 3), a solo piano (Fig. 4), and a symphony orchestra (Fig. 5). Even in Fig. 6 (a massive full chord played on a pipe organ), the signal level is not constant; the highest power levels occur in brief transients that last for only a few hundredths of a second.

Recognizing this fact, modern amplifiers are designed to deliver higher power for brief transients than for continuous tones. This is measured by the IHF "dynamic headroom" test, in which a tone is switched on for only 0.02 second (20 milliseconds). In specifications and test reports, the "continuous" RMS power represents the amplifier's ability to play constant test tones, while the "dynamic headroom" tells you how much extra power the amp can deliver in a short burst.

The very brief tone-bursts in the IHF headroom test are similar to the musical impulses seen in Fig. 2. What, then, is the amplifier's ability to deliver extra power not only for transients lasting a few thousandths of a second, but for the longer bursts seen in these examples--for 100, 200, or 300 milliseconds, the duration of the notes in music? That is measured by the "dynamic power envelope", which shows an amplifier's maximum undistorted power *as a function of time*.

The Power Envelope

Figure 7 shows the power envelope curves for several fine amplifiers. The height of each curve at the left-hand edge of the graph is the amplifier's dynamic headroom as measured in the standard IHF test, with a 20-millisecond tone burst. At the right-hand edge of the graph all of the curves approach the 0 dB reference level, which is the amplifier's maximum undistorted power for continuous test tones.

As the graph shows, in good amplifiers of conventional design the IHF dynamic headroom, as measured with a tone-burst only 20 milliseconds long, is typically about 1.5 dB (i.e. about 40 percent) higher than the maximum steady-state power. With a tone-burst that lasts for 200 or 300 milliseconds, the duration of a typical note of music, the dynamic headroom of a normal amplifier is no more than 0.5 dB, or 12 percent above the maximum steady-state power.

Figure 7.

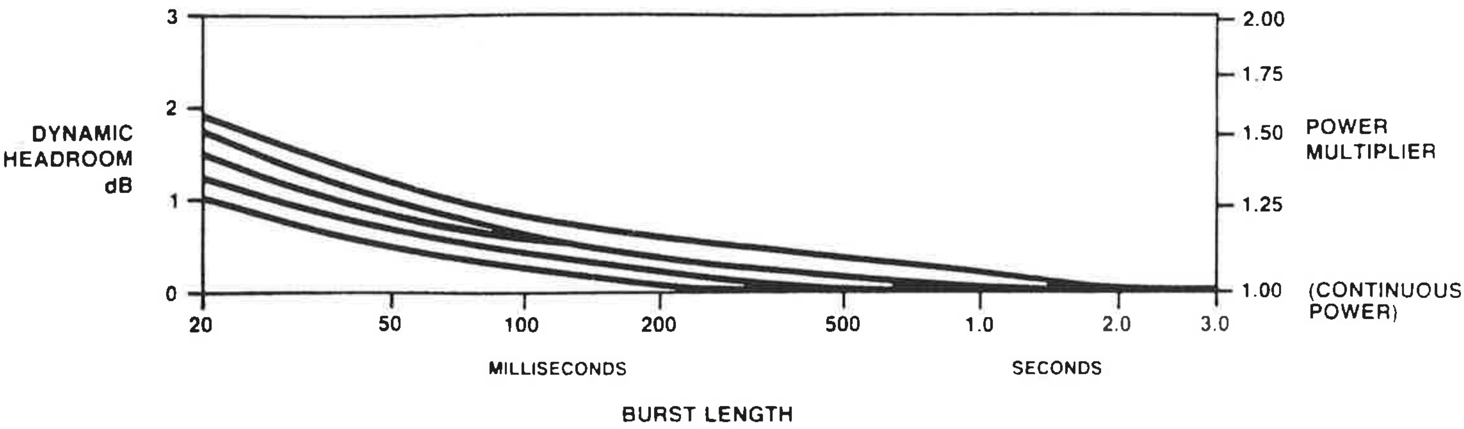
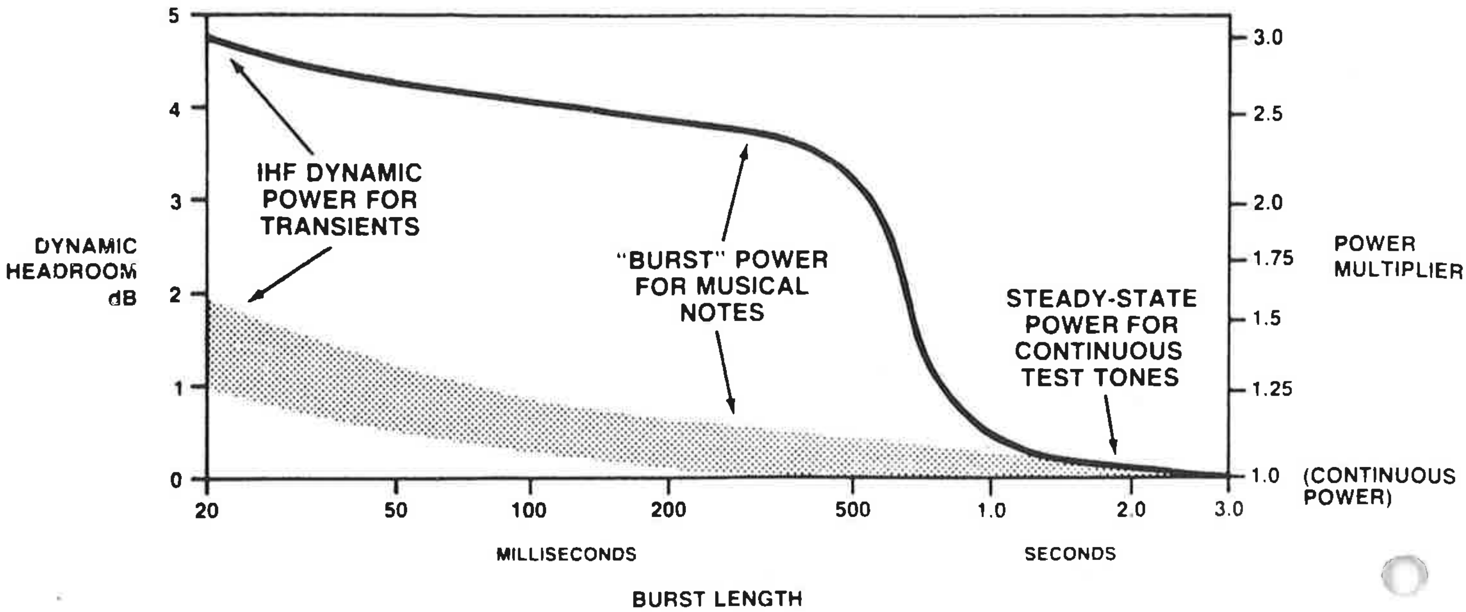


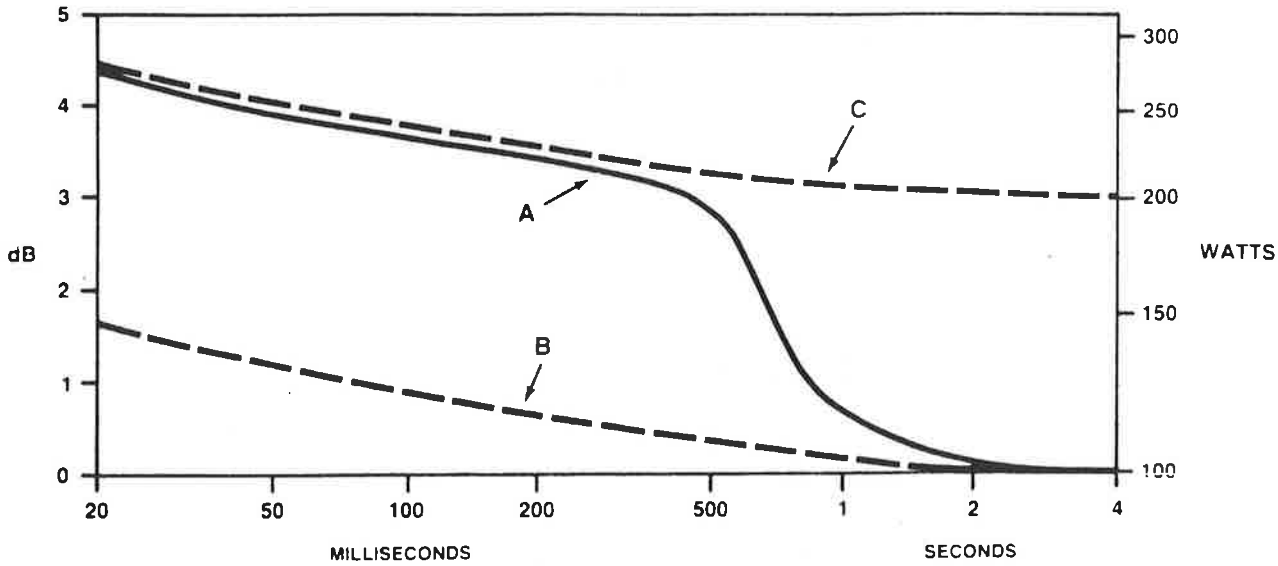
Figure 8.



Compare that to Figure 8, the power envelope of a new NAD amplifier. The headroom for short 20-millisecond bursts is not just 40 percent but a full 200 percent higher than the continuous power. For the 300-millisecond duration of a long musical note, the headroom is not just 12 percent but 250 percent greater than the steady-state level!

The practical consequence of Power Envelope design is seen in Figure 9, which compares the power envelopes of a new NAD amplifier (A) and two competing amplifiers of conventional design. Amplifier B has the same continuous power output, and therefore costs about the same to manufacture, as the NAD amplifier; but it has only half as much useful power for music. Amplifier C has the same musically useful power as the NAD amp. But in order to achieve that output, Amplifier C had to be designed with a high level of continuous power for test tones--expensive power that heats the amplifier, and raises its cost, but is never used for music. (With any amplifier, you will normally set your volume control so that the loudest musical bursts remain undistorted, and in all types of music the long-term average power is several dB lower than those peak levels.)

Figure 9.



It may fairly be said that the new NAD Power Envelope family of stereo amplifiers and receivers is the first complete line of audio electronics designed to play music rather than test tones.

How it works: the PowerTracker

Any power amplifier consists of two parts: a power supply and an audio circuit. The audio circuit functions as an electronic valve, opening and closing to feed current from the power supply to the loudspeaker in accordance with the demands of the audio signal. Since power is the product of voltage and current, the amplifier's maximum output is determined by the voltage of the power supply and by the current-carrying capacity of the circuit. A genuinely powerful amplifier is one that operates at high voltage and can deliver high current.

If the amplifier were built for *continuous* operation at these high voltages and currents, it would require an enormous power transformer, special filter capacitors, plus an elaborate system of heat sink fins and ventilation to dissipate the resulting waste heat. The manufacturing cost of the amplifier would be doubled or tripled, for no purpose. But music is dynamic, requiring maximum power only in bursts--not continuously.

A NAD "Power Envelope" amplifier meets the dynamic needs of music by employing two power supplies: a lower-voltage supply that operates up to the amplifier's rated continuous power level (with normally modest heating and modest cost), plus a high-voltage supply that is used only when high power is needed. The key to its operation is the NAD PowerTracker control circuit (patent pending), whose operation is illustrated in Fig. 10. At normal signal levels the lower-voltage supply provides all current to the output. When the audio signal rises above the amplifier's rated RMS power level, the PowerTracker's "gate" turns on, allowing maximum current to flow from the high-voltage supply.

Figure 10.

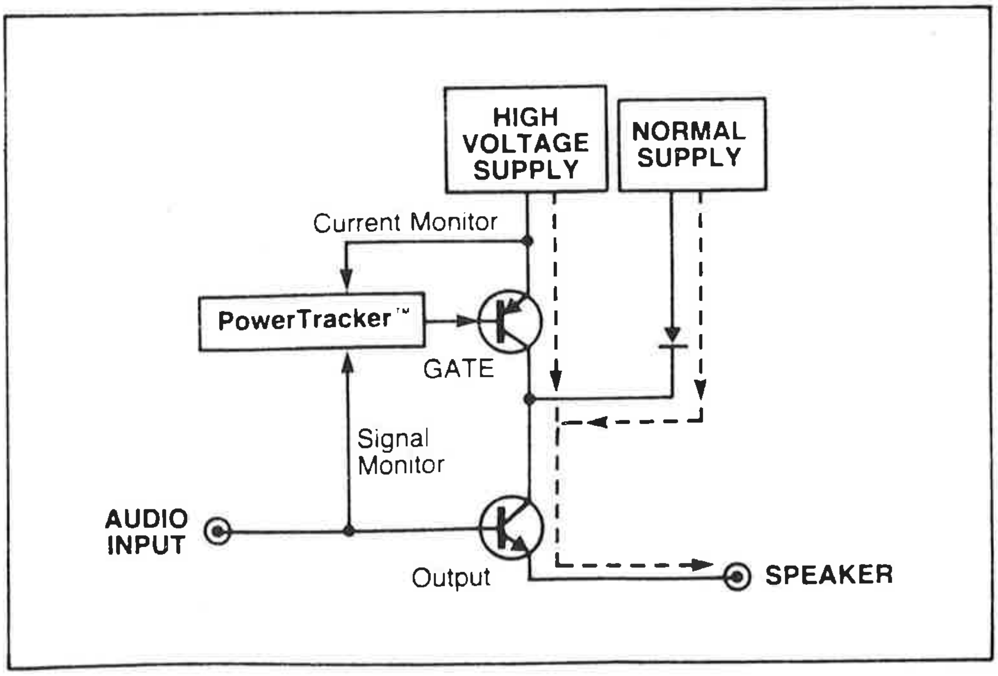


Figure 10. The PowerTracker

The high-voltage supply contains a solid-state memory device that functions as an elegantly simple analog computer, monitoring both the heating of the power supply and the flow of current. If the output has been fluctuating up and down (i.e. playing music), then the average current is modest, and the high-voltage supply remains available to provide maximum current on demand. But if the average goes up, reflecting constantly high output for more than a few seconds, then the high-voltage supply shuts down and the amplifier reverts to the lower-voltage supply.

Thus, as long as the amplifier is playing normally dynamic music signals, it can provide the high voltage and high current of a very powerful amplifier. But if it is fed a continuous high-level test tone (or is constantly overdriven by a careless user), the amplifier automatically closes down to its rated power level to protect itself and avoid overheating.

Getting the details right

In some amplifiers with switched power supplies, the switching transients can introduce distortion. The design of the PowerTracker circuit provides double insurance against this. First, no switching ever occurs at low signal levels, where even a small amount of distortion might be obtrusive. The lower-voltage supply produces all output up to, and including, the amplifier's rated continuous power level. The high-voltage supply is used only to produce bursts of power above the rated RMS output, in the top 6 dB of the music's dynamic range. Relative to this high level, a switching transient would introduce an inaudibly small percentage of distortion.

Second, there is no abrupt switching between supplies. The output stage is permanently connected to the lower-voltage supply, and an electronic gate opens to allow current to flow from the high-voltage supply when needed. It opens quickly enough to provide full power for high-level bursts of music, but smoothly enough that no false transients are added to the signal.

As a further bonus, the PowerTracker circuit is simple, elegant, foolproof, and adds very little to the amplifier's cost. Most important, these new "Power Envelope" amplifiers retain all of the sonic virtues and price/performance value that have made NAD a world-wide favorite.

Close-tracking Soft Clipping™. NAD premiered the use of Soft Clipping™ in solid-state amplifiers, gently rounding off waveform corners to prevent harsh distortion when the demands of the musical signal exceed the amplifier's limit. The newly improved circuit accurately tracks the available peak power, regardless of speaker impedance, keeping the amplifier's sound clean and transparent right up to the maximum output level. So even if you manage to overdrive the amplifier at high volume levels, it will continue to sound musical.

High-current design. Current flowing through the voice-coil is what causes a speaker to produce sound, and NAD was the first manufacturer to emphasize the importance of high output current capacity, unrestricted by so-called protection circuits, to cope with the complex and reactive impedance that many speakers present. Even the smallest NAD amplifier can deliver peak currents in excess of 15 amperes, and larger models produce up to 50 amperes to drive any loudspeaker without distortion or limiting.

Ultra-low noise. Lifelike reproduction of musical sound requires delicacy to handle very small signals as well as power for the big moments. Every NAD amplifier is designed with low-impedance circuits so that no low-level hiss or hum can intrude on the quiet background of the music. A stereo system based on NAD electronics is a clear, transparent window through which the widest-range analog and digital recordings can be enjoyed.

NAD

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