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REALISTIC AMPLIFIER TESTING:

PROCEDURES FOR PROFESSIONAL TOURING MUSIC PA

RATPRO-5

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Introduction

For too long, most testing and technical reporting of professional audio power amplifiers has been overly concentrated on a limited set of measurement results. There has been little or no published 'real world' testing. Most testing is ad-hoc.

Possibly for the first time, some tests to be described, which have been developed for 'real world' testing of 20 professional power amplifiers in *Live !* magazine earlier this year, form the nucleus of a standard, all-round test procedure, one that's useful for users and specifiers, as well as manufacturers. Part of the test procedure is to develop a formal procedure for comparison irrespective of different makes, types, topologies, power & impedance ratings. In these tests, pass and fail criteria are not the main objective; users can make (and justify) their own decisions. Instead, the tests have revealed performance aspects that are normally hidden and that it pays to know about, *and* provide a uniform and tough basis for comparison and discussion - with caveats identified. The procedure goes on to employ conventional measurements and listening tests. Finally, some realistic abuse tests are carried out. Not all of today's amplifiers survive all of the tests.

The test procedure begins with switching on the AUT (with no signal), for at least 30 minutes before testing. This allows the normal standby temperature to develop.

THERMAL CONDITIONING & COLD/HOT POWER RATIO

The amplifier is then driven in tandem ('stereo') mode, essential to *fully* prove the thermal capacity. Each channel is connected to identical loads, below 8 ohms, but not below the minimum rated. In the ***Live !*** tests, 5 ohms was an arbitrary, available value suiting all models.

Hot air from the loads is vented away from the AUT's vicinity. The AUT is normally bench mounted, and is assumed to have a free flow of air around it. Unless the test space is cavernous or very draughty, ambient temperature will increase several °C during the testing. An increase up to about 30 °C over the warm up period is beneficial as it simulates more realistic conditions.

Next, channel gains are set at max. Gain differences between channels may be noted at this juncture, particulary if above 0.5dB. The higher channel is then backed off to match as close as possible, and the mains is set to a given voltage. In the ***Live !*** tests, 320v DC (full wave rectified mains - see fig.1) was adopted [3] , referred to −1 dB below visible clipping.

The amplifier's *cold* power output (Po) & %THD are plotted *Vs.* input drive (in dBu), for each channel. At this point the AUT heatsink may seem 'warm' to humans but is relatively cold.

The AUT is then driven with APN having a 10dB ±1dB PMR (crest factor, voltage - see fig.2) and a level set to peak just below visible clipping, to simulate *arduous* use with *worst case* program, for one hour. *Hot* Po & %THD *Vs.* drive are then replotted, at the original mains voltage.

Note 1: If shutdown has occurred, replotting will need to take place after a period of cooling and reheating. The amount of reheating will require experimentation and careful timing, so thermal shutdown does not recur during the test sweeps, but so temperatures are close to the maximum sustainable just before thermal shutdown - noting that fan cooled amplifiers cool down quickly, once power output ceases.

The test establishes at least four performance aspects:

(i) Relative Thermal Capacity
The APN (which is pre-clipped, audio-bandwidth-filtered, and as set in the preceeding paragraph) drives most (not all) amplifiers through their least efficient zone where most heat is generated, namely about -3 to -4dB below clip. The ***Live !*** tests established that today's touring amplifiers 'last' between a few minutes and over 1 hour .

Comparison is complicated (or requires demarcation) by differing minimum impedances (mainly 2 ohm drive capability in some units) Vs. real PA enclosure impedances and operational standards. Regarding power differences I wrote in [4]: "In the more likely event that a 'more watts per ohm' amp will be used up to its voltage swing capability (having paid for it) into the same impedance box [PA speaker enclosure], then there's a valid basis for comparison." As to minimum rated impedance differences, I continued "Comparisons ... are valid on the basis that you cannot just change the impedance of a PA box by flicking a switch, and that wiring cabs ... to make full use of 2 ohm capabilities may not be acoustically or operationally acceptable. In other words, a 2 ohm rating is an impedance headroom bonus which you [the systematic professional user] cannot necessarily plunder." Comparisons is also complicated by some AUTs having class G & H (rail switching) topologies, which are efficiency relations increasingly at variance with ordinary Class A-B amplifiers - with each dB below clip.

Despite some caveats, the keynote remains: some of AUTs will run cooler than others, under a given condition, and may be expected to require fewer power transistor replacements their life.

(ii) Hot Power Delivery
By re-measuring the power delivery (for 0.1% THD) after 1 hour has

elapsed, with the same DC (peak) mains voltage, power referred to 0.1% THD may be found to have decreased, due to cumulative increased resistance &/or losses in output devices (if MOS-FETs) &/or transformers and fuses. In a few cases %THD+N changes, making the %THD referred output power appear to change. Such false power changes are usually visible however from radical changes in graph shape from cold to hot. A hot power rating which 'increases' above 100% (of the cold rating) is another giveaway.

Cold/hot power ratio may be considered, eg. an AUT with a ratio of 0.75 would be giving only a three quarters (75%) of the rated power after the 1 hour test. In practice, true power droops below 80% (0.8x cold power or -2dB output voltage loss) did not occur and wouldn't be very acceptable in professional standard AUTs. Some of the total 'power' droop may be lost voltage gain (eg. caused by thermally drifty VCAs), separate from losses in the power loop.

(iii) Hot Working Distortion

Amplifiers that have been solidly at work for an hour get hot *all over*, even if their workload is light. Measuring %THD in this condition shows it more like it really is, compared to swept bench tests where only the output device junctions are appreciably heated. Changes in %THD will certainly be of interest. More than a doubling in %THD may be of concern. In practice, the %THD of most MOSFET output stages fell slightly, and most Bipolar ones saw a slight rise, neither large enough at under ± 10%, to be of concern. That the change is so small is one of the oft forgotten benefits of high negative feedback. Wilder changes in %THD would be expected with those esoteric (mainly domestic) amplifiers having low or zero feedback.

(iv) Thermal Data & Efficiency

By measuring and comparing the temperature difference between inlet and outlet air, efficiency may be compared. After rating this in °C rise per output watt power output , differences can be allowed for. The constant drive, -*X* dB below clip partially simplifies the

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comparison. Still, the comparison can be misleading and is most applicable when there are single, compact or at least equivalent air inlet and outlet locations of similar sizes, whether per ch. or per AUT, and also similar airflow. This latter could be quantified by timing the filling of a plastic dustbin liner.
These aside, then based on the hot output wattage (Po), the °.C rise per watt output (Wo) can be calculated, eg:

61 °C & 1400w = 0.043 °C/Wo

More efficient amplifiers should yield lower °.C/Wo figures, but again there are caveats and so differential temperature measurements were not pursued in the tests.

ACOUSTIC POWER CAPABILITY

This (or some equivalent) test is performed immediately after thermal conditioning. It was intended to reveal discrepancies between measured power into resistive loads, and real work into speakers. Measured SPL may be less than expectations where any kind of current limiting or V-I sensing or other protective circuitry acts.

The amplifier is first driven with APN with no load, set to a given level. It takes time to trim APN to an exact voltage-level. If the test speakers were connected during this procedure they might heat up excessively. Worse, the amount of heating could vary with each set-up.

Note 2: Instead of *no* load, the usual resistive load might be used. This would help remove damping factor from the SPL equation; see below.

In the ***Live !*** tests, 45.0v rms ±0.25v was arbitrarily chosen to be within the drive units' rated capability, while calculated to trigger overzealous amplifier protection. A test speaker system (with adequate power handling) is then connected and the 'c' weighted,

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'slow' (average or rms) dB_{SPL} at 1m is promptly recorded (by plotting smoothed-out amplitude Vs.time) at least 3 times, before the voice coil begins significantly to heat up its surroundings. The test speaker is disconmnected straight after the test.

The chosen speaker system should be reasonably 'hard to drive', ie. impedance dipping below 4 ohms. Ideally it should include a passive crossover & two LF/MF (12" or larger) nominally 8 ohm drive-units ideally mounted in a ported cab &/or bass bin. Together the drive units should dip to about 2.5 ohms at some spot frequencies, preceded by a zone of worst case, capacitative phase angle.

Note 3: Consideration may be given to using a switchable array of drive units, so that solely 2 ohm rated or all amplifiers, are additionally tested with a nominally 2 ohm array (two or four paralleled boxes containing a total of 4 x 12" or 15" 8 ohm drivers, etc). This will dip to a minima of about 1.3 ohms.

With suitable test equipment settings, plotting time, hence voice coil heating for both channels of the AUT can be limited to under 1 minute. The drive units are allowed to cool for at least 60 minutes before another test is carried out.

Anomalies

In a previous test by Manuel Huber [2], a fairly gross variation of 8dB was noted between different amplifier models, after allowing for their different power ratings. However each amplifier was driven at its rated power (or a given X dB below this). As the rated power deliveries of the amplifiers being tested varied by 2 fold (power) or 3dB (voltage), different, undocumented degrees of thermal compression in the drive unit were included in the dB shortfall.

The present test's 'fixed voltage' procedure coupled with the need for a fairly high rms level of 45v (with peaks up to nearly 11dB higher) to involve realistic SPLs does mean most amplifiers (excepting the few capable of 95v rms or above) are clipping - by varying degrees. This causes rms dB-SPL to be highest in the reverse, counter-intuitive order, ie the most clipped amplifiers giving more rms output SPL

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than any higher powered peers suffering less clipping. As the mains peak voltage is set at a nominal level, the amount of clip and increase in power density is computable. With the APN signal likely to be clipped *by most AUTs* tweeters in the test speakers should be disconnected - as they will not survive.

Naturally, such test results are most valid when the amplifiers under test have similar power rating. Still, even with power ratings varying as much as +/-50% (eg. 250w to 750w, as several did in the ***Live !*** tests) the dB difference in stress is less different than it appears.

In practice, results in ***Live!*** proved interesting but inconclusive; the test requires development. In an earlier iteration, mains voltage was adjusted to make all amplifiers clip at the same voltage/power level. But then the output stages are not being tested commensurate with their V&I capabilities - a case of tightening up on errors and loosing the whole purpose of the test in the process. The same applies in some measure to any large reduction in the drive voltage from 45v. A substantial reduction in output level (but also V/I test stress) down to 15v (-10dB or a third of. 45v) would be needed so all AUTs were driven under, rather than most over, clip.

Baxandall's V-I tester [5] is an alternative approach. However, typical V-I linit test patterns are too complex for straightforward assessment.

CONVENTIONAL TESTS

Although sophisticated in the details they reveal, compared to that revealed in traditional spot frequency or crude graphical measurements, the following tests are variations, derivatives or expansions of standard, classic measurements. Mostly they have been covered in previous reviews and papers. They include:

Bandwidth with 5 ohm load, 1dB < clip, swept from 10Hz to 200kHz. Reverse sweep (200kHz to 10Hz) was found to be needed for AUTs having subsonic (VLF) protection which mutes the drive.

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Noise spectra. Typically magnetic spectra at 50, 150, 300Hz; Ripple at 100, 200Hz; and VDU susceptibility at 16, 32kHz were observed. The VDU was the AP test set's computer monitor, was standard VGA, and its scan coils were about 30" from the centre of each AUT.

%THD Vs. Freq. @ -1dB < clip, at least 80kHz BW with 10Hz to 50kHz sweep, with a 20Hz-20kHz bandwidth sub-sweep nested for comparison.

Others include:

- CMR +N *vs.* frequency.
- CMV withstand at inputs
- Maximum survivable and minimum operable mains supply.
- AC power draw for a given (high) output level.

In all cases, both channels are driven, and both are loaded with a 'medium to low' impedance (typically 3 to 5 ohms)

LISTENING

With due caveats, *skilled* listening supersedes most measurements in speed of problem revelation. Certainly with music, skilled listening can reveal subtleties (or even blatant) changes, distortions or omissions that routine (and even advanced) measurements are stone deaf to.

Methodology is open, but a great deal can be learnt by referring to the many hundreds of reviews by Martin Colloms in ***Hi-Fi News*** ;and other *omnijectivist* (listening *and* measuring) reviewers in ***Stereophile*** (USA). If A-B-C'ing, ensure level matching is performed using APN, so each AUT matches the other, broadband. Experienced listeners learn to ignore small and inevitable tonal differences. With single presentation, a wide range of SPLs are to be used.

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Blind listening seems ideal but it has its own problems and should not be neccessary with professionals. The ***Live*** ! listening tests were not blind yet amplifiers the listeners may have been prejudiced about (Fords amidst Daimlers) were nevertheless rated amongst the best sounding.

During listening, a ≥ 100MHz 'scope should be used to monitor both outputs of each AUT. Use of plaited cables (eg. *Kimber* cable, as specified by one of the UK 'box makers' inside their premier PA/studio enclosures) will help uncover latent stability problems that are not normally observed with ordinary twisted or parallel conductor cables - but might be triggered by the 'wrong' length or other chance circumstances.

ABUSE TESTING

Real world testing must include an evaluation of professional amplifiers' protective features. Tests are grouped in the order thought most likely to cause damage, so the most information will be gleaned from a single pass.

Hanging an open circuit cable off the AUT's input, and reading wideband (>500kHz) voltage indicates likelihood of damage to speakers, due to RF instability, usually at the *input* if a PA's multicore input is left unterminated (*ie*. unplugged from the crossover and left dangling). Stability with a long, loaded and open circuit speaker cable connected can be observed in adjacent procedures.

Salesmen frequently demonstrate amplifier short circuit protection by placing a 6 inch nail across the output terminals. This is dramatic, but not exactly the kind of short that often happens in practice. More likely scenarios include:

i) XLR speaker plug brutally inserted at an angle, so pin 2 is briefly shorted to chassis.

ii) Jack plug into a metal bodied socket on a speaker cabinet, briefly shorts when inserted/withdrawn.[XLR and especially jack connectors may be bad practice for high power output connections these days, but they are often used by *The impoverished* or *The expedient*].

iv) A long speaker cable is squashed by a scaffold pole or rubs against jagged metal, or if PVC, melts against a rigger's lamp, until the conductors are both bared and shorting.

v) A crowbar protective circuit inside a speaker cab operates - again at the end of a cable.

Controlled testing can be carried out with a number of shorting devices. A manually operated switch has the problem of non-uniformity of the contact's closure rate. A crowbar (using a triac) corrects this, but the rate of shorting (typically about 1μs) is far quicker than most real world shorts. Testing for proof against such fast shorts is only necessary if the speaker system in use employs crowbar protection. Relays have a relatively uniform, medium closing time - typically 10mS for a power relay. A minimum test set-up (fig.3) comprises a heavy duty relay, usually with 12v DC coil, a monostable timer with adjustable period (5 to 15 secs say), a start push-button, a timeout indicator and power supply. Signs of RF instability or oscillation caused by the long output cabling may be observed before triggering the shorting action. Attenuation and distortion are accepted while the 'short' is active.

An alternative worst case loading is offered by a 6.8μF (non polar) capacitor placed across the output (in tandem with a speaker load used earlier). This situation can occur when an HF driver has 'crowbar' DC protection or when the internal passive crossover has been miswired or shorted internally. With both dead- and capacitative- shorts, satisfactory AUTs will carry on working afterwards. They may be either shut down until the abuse is removed, or continue. Reset need not be automatic (though it's preferred by most) and shouldn't involve de-racking the amp, or soldering in new parts.

Occasionally power amplifiers overheat. Why ? Inadequate system

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headroom and driving into too low impedances at too high levels are two common reasons. Otherwise, fans expire or can get stuck by dirt. Outdoors, plastic coverings can be blown about and sucked into inlet louvres. Indoors, when it gets hot, low profile racks are easily blocked by carelessly dumped stage cloth or crew clothing.

To test, all air inlets were taped up, with APN drive just below clip, both channels loaded with 5 ohms, for 30 minutes - or until shutdown. Amplifiers may shut down at some point, indicates over-temperature, with maximum fan cooling followed by auto reset when cool enough. With some units, an unsatisfactory manual reset was required. Others made repeated shutdowns in the 30 minutes. Some failures caught fire or expired. Two makes bizarrely shut down their cooling fans or thermal 'I am too hot' indicators *until they had cooled down !* Satisfactory AUTs will auto-reset after the blockage is removed. No intervention should be needed other than removing the cause of the overheating.

Finally, AUTs should be able to handle incoming signal voltages at least as high as their own maximum output. Both the overdriven input and output stage should survive. APN allows survivability to be quickly tested across a representative range of frequencies and levels. Most of the amplifiers tested continued normal operation afterwards and their %THD characteristic was unchanged. Else more than about 10% permanent increase in %THD would raise eyebrows.

CONCLUDING REMARKS

The *proving* of a finely tuned valid test is that not all units pass nor fail. If some test procedures appear tougher than worst case, that is intentionally because less rigorous proving might not discriminate at all. Also, to be of value and apposite to users and makers alike, this and any other realistic test procedure needs to evolve over time, in time with the equipment. It should not be *moulded* but subject to continued evolutionary adjustment, improvement, additions and subtractions.

REFERENCES & FURTHER INFORMATION

[1] Cliff Hendricksen, Engineering justifications for selected portions of the AES recommended practice for specification of loudspeaker components, *J.AES*, Oct '84.

[2] Manuel Huber, Important Aspects of Power Amplifiers, *Studio Sound*, Nov '85.

[3] Ben Duncan, Live Power, *Studio Sound*, Nov '93.

[4] Ben Duncan, 'Power Factors' [20 Pro-PA Amplifiers tested], *Live !*, May '94. Back issues available from Live !, 35 High St., Sandridge, St.Albans, Herts AL4. Tel. (01727) 843995. Bound copies of (i) the Audio Precision test results (400+ graphs) and (ii) the complete test procedure booklet & wallchart are available from the author.

[5] Peter Baxandall, Testing power amplifier V-I limits, 82nd AES, London, Mar '87.

Acknowledgements

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APPENDIX

Abbreviations

AP = Audio Precision, *System One* test set.
APA = AP analyser
APG = AP generator
APN = AES standard pre-clipped filtered Pink Noise [1]
AUT = Amplifier Under Test.
[1] = reference

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Conventions & Equipment*

All mains supply voltages are DC (peak) values. For explanation see [3].

An adequately rated variac is required to maintain a consistent or minimum mains voltage during testing - depending on the test.

Input drive (from APG or APN) is usually balanced but may be unbalanced. XLR pin 1 is always connected ('GND') through.

Output sensing is always balanced. XLR pin 1 at APA is to shield only; there is no through connection to AUT output.

Both AUT Ch.1 & 2 outputs are separately monitored at all times with a ≥ 35MHz scope, using 10:1 probes. Mains earth connection should be lifted.

APA input and processed 'Reading' are monitored at all times with a ≥ 10MHz scope.

A 2 channel test load is required. To be adequate, it will likely need to be rated >1kW/channel (re. 4 ohms/ch). It must be adequately cooled, not only to avoid damage, but to ensure the ohmic value remains with a few % during tests. The loads must also be sufficiently non-inductive for their impedance to remain within 10% of the 1kHz value at 100kHz.

ENDs.

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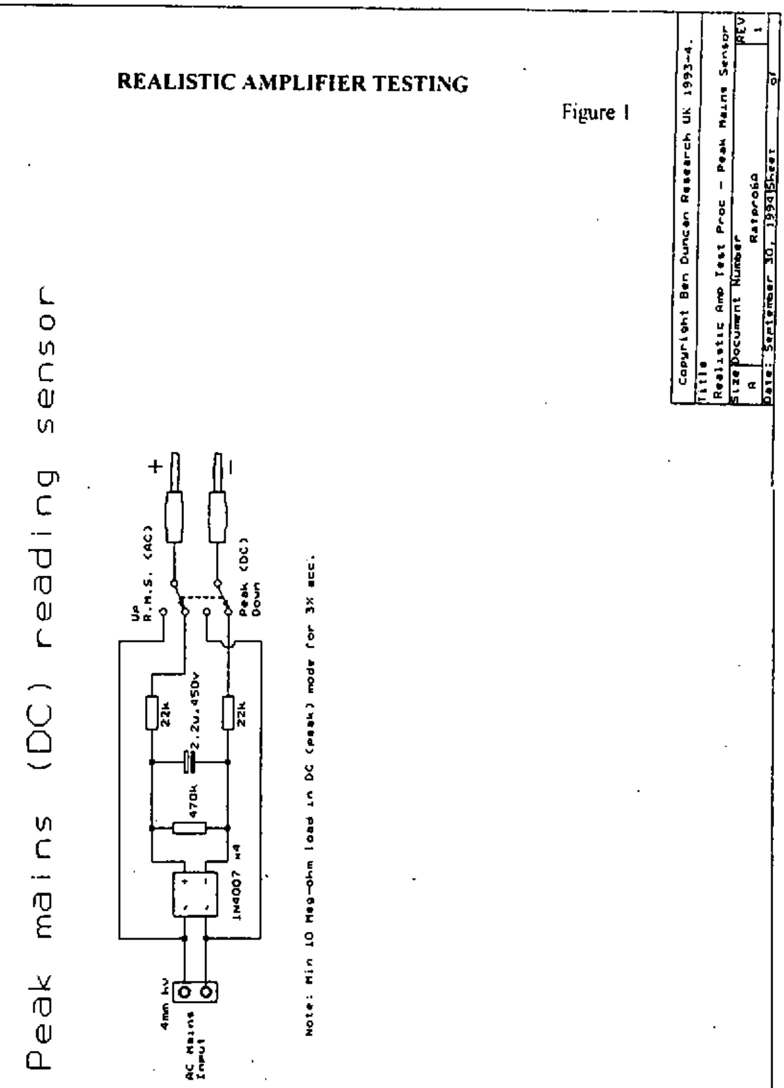

Figure 1

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Figure 2

APN (AES/EIA Pink Noise) Test source signal

BDR variant (having greater LF bandwidth than AES/EIA) used for tests. Shows peak (upper) to rms (lower) ratio varying from at least 8dB (at LF) up to 11dB (at HF) across audio band. Multiple plots used to average.

[Note for expediency, the **Audio Precision** test set has not fully smoothed the spikier peak levels below 400Hz on all of these; for more smoothing, a settling time >2 seconds per point would be needed - whereupon each graph would take several minutes to plot.]

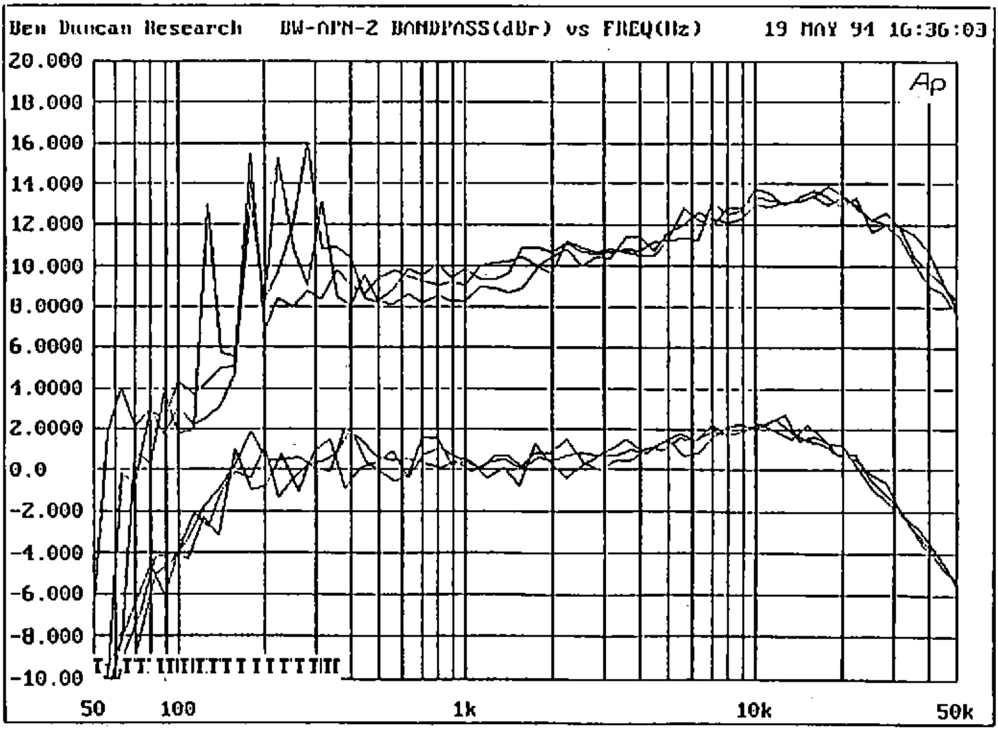

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Figure 3