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LOUDSPEAKER CABLE DIFFERENCES

CASE PROVEN

New measurements allow meaningful differences between speaker cables to be displayed like day and night.

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Introduction

About 20 years ago, a few perceptive people involved in sound reproduction, noticed differences in the depth of bass, or resolution of vocal detail, etc, when different cables were substituted for the 'bell wire' and 0.75mm^2 PVC or rubber mains cables that were then the norm for speaker wiring in homes and recording studios respectively. Having discovered 'wire matters', an early approach was to use much thicker wire, as an aid to damping. This reduced inductance, enough to make a marginally stable, badly designed amplifier 'go RF' and expire. The ensuing panic and apparent lack of dialogue between cable experimenters and amplifier designers explains the appearance of 'spaced-eight' (ie. o-o) speaker cables, where low capacitance is a knee-jerk feature.

Over the past decade, the ideas of some original thinkers as to how loudspeaker (as distinct from line) cables should best be made to transfer audio accurately, have converged in the opposing direction. In a 1991 AES paper on cables [1], down-to-earth US audio consultant Fred Davis attacked the ideas of some cable makers that factors explicit at RF (notably characteristic impedance) were of any relevance over the length of any practical speaker cable runs. By modeling the speaker's energy storage (alias reactance), he demonstrated that even cable resistance was not the most critical parameter. Instead - and surprisingly even for bass frequencies - the cable's series inductance was the keynote. Moreover, he argued that shunt capacitance across the cable had no influence and that contrary to popular opinion, very high values would not cause HF loss. The same conclusions were arrived at independently by Tommy Jenving, a specialist cable maker based in Sweden who proceeded to make the idea reality (see Appendix 1).

It was in an open session at a previous *Reproduced Sound* conference (in 1990 [2]) that Dr.Keith Holland and Phillip Newell used a custom subtractor amplifier to make cable losses and errors audible to a professional audience - possibly for the first time.

Test Procedure

The tests outlined here, arose out of a challenge - to 'objectively' validate the claims made by Jenving (see Appendix 1). Leading up to this, MicroCAP IV (PC-based) simulation of loudspeaker/amplifier interfaces had already been used to demonstrate energy 'tails' when a stimulus stopped. Taking this into 'realspace', the Dual Domain version of the *Audio Precision* test set has a DSP-based FFT-test routine which allows sinewaves to be graphed over time. It's analogous to using a storage scope or performing transient analysis with a simulator. Fig.2 shows a pair of 1kHz sine tonebursts, in a 6ms window, offset vertically for clarity. In the measurements that follow, these tonebursts will be the stimulus at the driving end, and signal received at the destination end, of the Cable Under Test (C.U.T.).

Figure 2 shows the test set-up. The signal is read at both ends of the CUT. This poses at least one awkward question: what cable to use for these sense connections ? On the one hand, they are each about

1.9m, and their own reactance hence energy storage characteristics would be expected to affect the results. On the other hand, as sense cables, they are not passing any appreciable current. This explains why the 'obvious' course of using the CUT for sensing too, wasn't adopted - since according to Jenving and others, the optimum cable characteristic for the sensing or line level condition is the opposite . Fig.3 shows how the sense cabling was partly isolated with standoff resistors. Their value is governed by the need to:
(i) maintain a reasonably low source impedance in the sense cabling;
(ii) not increase the AP analyser's noisefloor unduly; and
(iii) not unduly degrade the analyser's CMR.

To keep CMR > -80dB, 10 year aged (hence stable) *Holco* metal-film resistors in each pair were matched to better than +/-0.006% at the room temperature with a *Datron* 6.5 digit DMM. For all the tests, the sense cables were identical lengths (within +/-2%) of identically coloured Musiflex cabling, taken off the same reel [3].

Optimum cable placement in a crowded lab required some lateral thought. First, the CUT needed to have both ends relatively near one another so that the sense cables could be the same length without coiling or folding. But the tested cable couldn't be tied back on itself as this would cancel some inductance, and wouldn't represent a real condition of use. Second, a quick method was needed to make the positioning easy to replicate, without gaffering down. Third, the CUT had to be kept away from other parallel cables, EMI sources (any one of three PCs & VDUs) and any substantial areas of ferro-metal (such as steel test equipment casings) to avoid warping the CUTs' immediate electromagnetic environment. Repeat positioning is then less critical.

The solution was to hang the cable from a wooden roof beam. The cable's '∏' shaped length (2.2m up, 1.1m across and 2.2m down) was then well spaced off from bad influences, as well as being mainly orthogonal to them.

The loudspeaker chosen for testing was a modern, full-range 15" dual concentric. The load included the associated, high quality 2 way passive crossover, developed to 'high end' standards. Inductors are all air-cores, and capacitors specially chosen and modified polypropylene types. The 0.9v rms test signal used for the LF and mid frequency testing, while enough to develop $100dB_{SPL}$ @ 1kHz @ 0.4m, represents only $^1/_8$th watt into the nominal 8Ω. The higher excitation required by the majority of less efficient monitors - as well as by the majority of more 'SPL hungry' monitoring users - would seem likely to increase any differences.

The rising impedance *vs.* frequency of the modest 150w/8Ω/ch. lab test amplifier (which has a conventional 2 pair MOSFET output stage followed by a small, $\cong 1\mu$H air-core output inductor) and the speaker/crossover combination, are considered typical of their genre, and were invariant. Variations in contact resistance *are* of concern, so reputable (European and US makes of) XLR connectors were soldered to both ends of most of the tested cables. All visibly tarnished pins were cleaned with alcohol. Connections were made with the test signal muted, to avoid degradation by arcing. Some cables had cores that were too thick for solid termination. Others arrived with high quality 4mm bunch-pin plugs ready fitted. These were plugged into short (6"/150mm) 4mm-to-XLR conversion tails, made with the same heavy PTFE wire as the Y-splits.

Results

For anyone who has doubted that loudspeaker cables can affect music reproduction, figs.4 to 29 offer some easy-to-grasp pictures of what's going on. The cables involved are described in Figure 1. Each graph is a magnification of the point immediately after the sine wave burst stops - as arrowed in fig.3 . Ideally, there would just be a resumption of a straight, central, horizontal line. But cables, passive crossovers and speakers are all energy storage devices - ranked in order of their ascending energy storage. The most immediate analogy is room reverb decay. In theory, the stored energy should be clamped right down on and got over with quickly, by virtue of the high NFB used in most professional power amplifiers - the test amp included.

Passive System Tests

The first test is with a 1kHz burst (figs.4 to 11). In each graph, one response is almost flat. This is always the more tightly controlled response at the amplifier output. Deviations here indicate deficiencies with the amplifier's NFB control. The other, wilder or more wavy response is the imperfect damping at the speaker end. The different sizes directly show the ability of the cables to aid the action of the amplifier's NFB. The ranking (based on the distance between the first negative impulse and subsequent positive peak, in grid units and rounded to 2 significant figures) is:

Supra Ply	0.7
Connectronics	0.8
Sonic Link blue	1.0
Sonic Link mains	1.3
Twisted 1mm^2	1.3
Monster	1.5
Bellwire	1.6
Twisted solid 0.5mm^2	3.6

In the above and all subsequent tables, the top of the list indicates best performance. Notice that even at this midrange frequency, the damping-in-time varies. For example, the purpose made top two cables have clearly damped to a low level after the first three half cycles, whereas with some of the others, a distinct gap remains well after the third half-cycle. Also, the negative peak excursion is considerably smaller than the positive in some (bellwire and solid core), whereas the difference between successive half cycles of damping is less pronounced for the Connectronics and Supra Ply. As these two apparently present the smallest or else shortest 'damping demand' on the amplifier, the difference may be accounted for by the NFB needing to act less. A curious feature - considering their physical differences - is the peaking similarity between the Monster Cable and bellwire.

HF testing was carried out at 15kHz (figs.12-19). In all cases, the signal shows quite large, but well enough damped, ringing at the driven end. This is a common enough power amplifier imperfection. Notice how much the peak amplitude of the larger of the two plots - which is always the signal at the speaker end - varies. Again, ranking is based on the difference in grid units between the first and second half cycles. Surprisingly at such a high frequency, some of the fat, low resistance cables are damping best - if not in the order one would predict from their CSA:

Supra Ply	5.7
Sonic Link blue	5.8
Connectronics	5.8
Twisted 1mm^2	6.0
Sonic Link mains	6.1
Monster	6.2
Bellwire	6.2
Twisted solid 0.5mm^2	7.0

As the ranking method is ad-hoc, what happens if it is changed ? Below, the ranking is the difference between the send and receive waveforms, with the cable having the least overall difference first.

Again the difference is in grid units:

Supra Ply	1.0
Connectronics	1.3
Sonic Link blue	1.6
Sonic Link mains	1.7
Bellwire	1.8
Monster	2.0
Twisted $1mm^2$	2.0
Twisted solid $0.5mm^2$	2.1

Testing next at 125Hz (figs. 20-27), the spread is similar and no less interesting. The best damped ranking, again based on the vertical grid units between the first two half cycles is:

Supra Ply	0.4
Connectronics	0.6
Sonic Link blue	0.8
Sonic Link mains	1.4
Twisted $1mm^2$	1.4
Monster	1.7
Bellwire	1.8
Twisted solid $0.5mm^2$	4.8

Notice that at the point where the sinewave starts again, the destination signals in the bell-wire and 0.5mm solid core cables have not wholly re-converged on the drive signal (look for the tiny gap), demonstrating not just poorer damping, but also excess dispersion or sluggish settling - and likely differently at other frequencies.

Controls and Active Tests

A natural follow-on question is "How much are these results down to the cable's own characteristics, as opposed to the speaker's ?". In figures 28 and 29, the worst and best performing cables were connected to an 8 ohm, 1kW-rated lab test load that is almost purely resistive. Now the differences are smaller - but still clearly discernible on this scale. So we may conclude that cables *do* exhibit measurable energy storage, but that a speaker's own energy storage usually swamps this.

A control was run, the best performing cable was reconnected the next day and replotted. Repeatability was very close. Small differences are due to the finite certainty of the FFT and screen pixels, and variations in contact resistance in both the XLR connections and the *Audio Precision*'s relays.

One more test was carried out, to demonstrate that the differences hold in an active system - where the speaker cable connects (almost) directly to a drive unit. Rather than radically change the test conditions, the test speaker was retained, but its internal passive crossover was bypassed and the LF section of the dual concentric was directly driven. The existing two internal runs of lightly twisted 32/0.2 PVC-insulated wiring was replaced by one run of the same 0.6m length of a similar wire. Testing was at 125Hz and 1kHz. As direct connection to bass drivers usually relates to high power systems, the thinner cables were not retested. Instead, chunky $4mm^2$ 2 core mains flex as widely used in PA and installations was added. The AP plots are omitted as they are so similar to those shown already:

At 1kHz the numeric ranking is as follows again based on difference between the initial positive peak at the speaker and amplifier end:

Supra Ply	0.5
Sonic Link Blue	0.55
Twisted 1mm^2	0.7
4mm^2 2 core mains	1.25
Monster Cable	2.1

At 125Hz, the difference between the first positive and 2nd negative peak at the speaker end is expressed in grid units. Notice how some of the differences are numerically reduced without the crossover's energy storage to battle against:

Supra Ply	1.0
Sonic Link Blue	1.1
Twisted 1mm^2	1.3
4mm^2 2 core mains	1.7
Monster Cable	2.2

Summary

Large differences between different cables connecting a loudspeaker driven with a discontinuous signal (that represents the back-end of a music transient) has been demonstrated clearly for the first time, using industry-standard test equipment and without recourse to exotic techniques. At 45mV relative to 1.3v peak drive, alias minus 29dB down - or just 1 part in 28 - the size of the largest perturbations is surprising - even though they had been predicted 9 years before [4]. With the best performing cables, perturbations are reduced to about 1/10th of this, or -50dB down. Hence the measurements show how *cables expressly designed for audio, and in particular for speakers, can improve damping perturbations by at least 20dB*. Settling time is also shortened with the better cables. The results clearly demonstrate the limitations (at least with a full range speaker) of the conventional, simplistic approach of using the fattest wire, as well as the futility of using a thin solid core [5], on the grounds of damping. The results also illustrate the logic of making special cables for mains - considering that mains current into any DC power supply is a repetitive burst waveform, much as simulated here.

It is clear from the tests that Supra Ply is indeed a star performer, as claimed. Against a wider range of audiograde cables, it would be unsurprising if some other low inductance types were strong competitors. But the point of this article is simply to show that cables do differ measurably in ways that relate to music. The measurements provide a way of short-listing serious contenders and eliminating spaced-eight cables from serious consideration, after which users and system designers must make their own decisions based on cost and relative sonics in the context of their system(s).

Appendix 1

Development History

Tommy Jenving has been making special cables for audio in Sweden since 1976. The first improved speaker cable was *Supra 2.5*. The idea of Supra *Ply* came more recently, and laterally through developing and patenting a shielded mains cable called Supra *Safe*. The idea was to protect both studio equipment and humans from 50Hz (or 60Hz) E-M fields. While researching into reducing power line radiation, it was found that low inductance was the key, and that high cable capacitance was unimportant. Realising that the pulsating, high peak current flow conditions in speaker cables are similar to mains wiring into DC power supplies, Jenving was able to ask 'why are exotic speaker cables made with low capacitance as a main feature, and consequent high inductance ?' The answer seemed to be that such wares are fundamentally of wrong design, even if some 2nd and 3rd order details are attended to.

Unlike almost any other cable maker, Jenving has no trouble clearly outlining the logical design philosophy of Supra 2.0 in plain English. A number of other cable makers in the USA have converged on broadly the same minimum inductance approach, but use more exotic, ultra costly materials (such as notionally 99.9999% pure silver), and they are oddly unable to explain their approaches so coherently. Jenving divides relevant parameters into the 'dynamic' - those that vary with frequency - and 'static' - those that don't. The latter comprises firstly, resistance. Cable resistance that is very low relative to speaker voice coil resistance, is essential for good damping, but as the test results show, it is only the beginning of the story. Characteristic impedance is also frequency invariant - but its relevance in the audio range is truly negligible, even at ultrasonic frequencies and over the lengths used for PA systems.

Turning to the 'dynamic' parameters, namely capacitance and inductance, Jenving's work reminds us that the two work in opposition; minimise one and the other will rear-up. The frustrations of cable design are hidden until Skin Effect (including the related Proximity Effect) is recognised. Both work like extra inductance, ie. *an added,* rising resistance with frequency. Skin effect occurs because with increasing frequency, locally circulating 'eddy' currents in conductors cause increasing resistance below the conductor's surface. So the skin of the conductor appears to have the least resistance to current flow. The counter-intuitive outcome is that fat, low resistance conductors develop an unexpectedly high resistance both at high audio frequencies (above 2kHz) *and to transients.*

Some cable makers try to overcome this by paralleling thin and fat wires. Jenving's approach has been to use zoned tin plating to progressively increase the resistance of the conductor towards the outside. The *higher* resistivity of tin largely defeats the skin effect — so that a high CSA, stranded conductor can be used without transient and hf losses and errors. Meanwhile, tin's relative inertness prevents oxidation of the (almost) oxygen-free copper conductors. The cable is completed with a covering of special PVC having low emission of corrosive chloride ions. Although many 'audiograde' cables use notionally superior insulators and conductors such as PTFE and Silver, such niceties seem irrelevant until basic details are mastered. Previous extensive testing by Colloms [6] certainly shows that cable sonics has had little corroboration with the mere excellence of the materials.

Appendix 2

Commercial Reality

For professionals, recommendation or purchase of 'audiograde' cable for installations would be less worrying if there was evidence of some kind of progressive, price-linked merit. Instead, as almost anything you do different with cables changes some aspect of sonic quality in any system having sufficient resolution, there is an almost random diversity in audiograde cable constructions, and little (if anything at all) in the way of coherent, solid justifications for the different approaches. It is salutory to learn that long term listening tests [7] can have a low price speaker cable ranking second against highly expensive types. A number of makers (particularly in the USA) hide their ignorance about what they are making, behind the misuse of impressive-sounding but almost meaningless phrases like 'time compensated' (instead of *delay*-compensated) and 'phase noise' and 'phase coherence' [8]. Many makers (and they're not even oriental) evidently just copy. No doubt such products can sound better in particular ways and in particular instances. But the real innovators seem few, and those who 'have a real handle' on what they are doing, even fewer.

Appendix 3

Caveats

In the real world, the 'best' speaker cable for a given situation is a complex issue - even without advertising overstatement and misinformation. If the power amplifier turns into an RF oscillator because it cannot handle high or even modest capacitance (and some otherwise reputable designs can easily do this), the listener would likely find the sonics better with a less well damped (but less capacitative) cable. So if RF is not checked for, using suitable equipment, entirely wrong sonic decisions can be made. Another possible pitfall is with valve (tube) amplifiers, and also esoteric transistor amplifiers with zero or low overall negative feedback. Their damping can be so poor (*far* worse than the situation seen in figs 12-19) that the cable's damping differences documented here may be swamped, again leading to a different optimum.

Appendix 4

Audio Precision - System One

Test settings

Sample rate:	192kHz
Steps:	377
Trigger:	free running.

1kHz & 125Hz test conditions:

Test level:	+1.63dBu/0.93v *
1kHz MSR:	2 on, 4 off
125Hz MSR:	2 on, 6 off

15kHz test condition:

Test level:	-3.4dBu/524mv *
15kHz MSR:	2 on, 4 off

* as applied at the loudspeaker end of the C.U.T.

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Abbreviations

C.U.T. (CUT): Cable Under Test *(after DUT)*

MSR: Mark/Space ratio, the on/off periods of a burst waveform.

NFB: Negative FeedBack, ie. error correction.

OFC: Oxygen Free Copper. Raw copper contains oxygen and has random crystallinity. Successive annealing and related processes remove impurities, including oxygen. When oxygen levels are below say 1ppm (part per million), the copper is considered free of oxygen, hence OFC. In reality, the surface at least, will eventually re-oxidise. Yet it is reported (at least with silver) that tarnishability ceases when purity exceeds 99.99999%.

PVC: Poly Vinyl Chloride. Nobody makes capacitors from PVC because its dielectric losses are so high, ie. it steals energy. Yet all cables are in part elongated capacitors. PVC (like most plastics) initially emits chemically reactive substances (eg. plasticisers and chloride ions), that can oxidise conductor skins, making them semiconducting and diodic.

Sheath: The outer, secondary insulation over the conductors, which turns *n* wires into cable.

TPI: Twists (or Turns) per Inch, also called lay.

Figures

Figure 1 — Table

The Test Group

The variety of cables tested alongside the Supra Ply (D) includes examples of generic types that are universally used or accessible (A,B,C), or easily made up (E,F). Other purpose-made audiograde cables (G-X) were needed to contrast against. They had to be practical and immediately wireable - many audiophile cables are not. In A-Z order:

A: 'Bellwire' is $0.5mm^2$ comprising sixteen 0.2mm (16/0.2) strands of plain copper in an oval sheath, alias '2192Y'. It's commonly used for table lamps as well as low-budget speakers.

B: '*Connectronics*' is this maker's plain, $2.5mm^2$ 2 core in a heavy, circular PVC sheath, with about 30 strands. Made for speakers, rugged enough for touring, it is like a 20 Ampere mains flex.

C: '*Monster Cable*' is the LF section of the budget bi-wire speaker cable, sold by Harman UK for install, in 1991. The measured conductors comprise at least 100 thin strands of OFC totaling about 2.5mm^2, cased in transparent and soft circular PVC, with a black, rippable, circular PVC sheath. The unused HF conductors are thin solid core, not unlike like cable 5. They are inside the sheath but were wholly unconnected during tests.

D: Jenving's *Supra Ply* 2.0 comprises 240 tin plated strands totaling 2.0mm^2 that are above 99.9% OFC, in a rectangular, maximum capacitance profile. The quite thin, 'Ice Blue' PVC insulation is specially stabilised, ie. emission of chloride ions is low. The overall transparent sheath is ordinary PVC.

E: Twisted 0.5mm^2 solid core wire. PVC insulated with no sheath, and twisted about 1 TPI. The diameter follows a theoretical optimum for low dispersion audio transmission developed by Dr.Malcolm Hawksford, as originally published in Hi-Fi News [4].

F: Twisted 1mm^2 wire, comprising 32 strands of plain 0.2mm, PVC insulated and loosely twisted about half TPI, with no sheath.

G. *Sonic Link*, AST-150. Made in UK by Nalty. Comprises 30 strands of 0.25mm tinned copper, insulated and sheathed in silicone rubber. Sample was blue. Similar physical characteristics to an Arctic-grade 2 core, 1.5mm^2 mains flex, ie. dressability is superior to common PVC.

H: *Sonic Link*, 3 core 'audiograde' mains cable. The 3rd core was not connected at all. A 2 core version is usually available. Each core comprises 19 thick strands of 0.25mm silver plated copper, with PTFE insulation -including a thin but extremely rugged sheath.

LOUDSPEAKER CABLE DIFFERENCES

Captions for figures on following pages:

Fig.2: The test set-up uses standard DSP-aided test equipment from *Audio Precision.*

Fig.3: Two test tonebursts. ***In figs.4-28, the arrowed area is magnified about twenty five times.***

Fig.4: Bellwire @ 1kHz

Fig.5: *Monster cable,*

LF section of @ 1kHz

Fig.6: *Connectronics* @ 1kHz

Fig.7: *Supraply* @ 1kHz

Fig.8: Twisted $1mm^2$ @ 1kHz

Fig.9: Twisted $0.5mm^2$ @ 1kHz

Fig.10: *Sonic Link* mains @ 1kHz

Fig.11: *Sonic Link* blue @ 1kHz

12–19 all 15kHz:

Fig.12: Bellwire @ HF

Fig.13: *Connectronics* @ HF

Fig.14: *Monster cable,* LF @ HF

Fig.15: *Supraply* @ HF

Fig.16: Twisted $1mm^2$ @ HF

Fig.17: Twisted $0.5mm^2$ @ HF

Fig.18: *Sonic Link* blue @ HF

Fig.19: *Sonic Link* mains @ HF

20–27 all 125Hz: –

Fig.20: Bellwire @ LF

Fig.21: *Connectronics* @ LF

Fig.22: *Monster cable,* LF section @ LF

Fig.23: *Supraply* @ LF

Fig.24: Twisted $1mm^2$ @ LF

Fig.25: Twisted $0.5mm^2$ @ LF

Fig.26: *Sonic Link* blue @ LF

Fig.27: *Sonic Link* mains @ LF

Fig.28: Twisted $0.5mm^2$ into an 8 ohm resistor.

Fig.29: *Supraply* into an 8Ω resistor.

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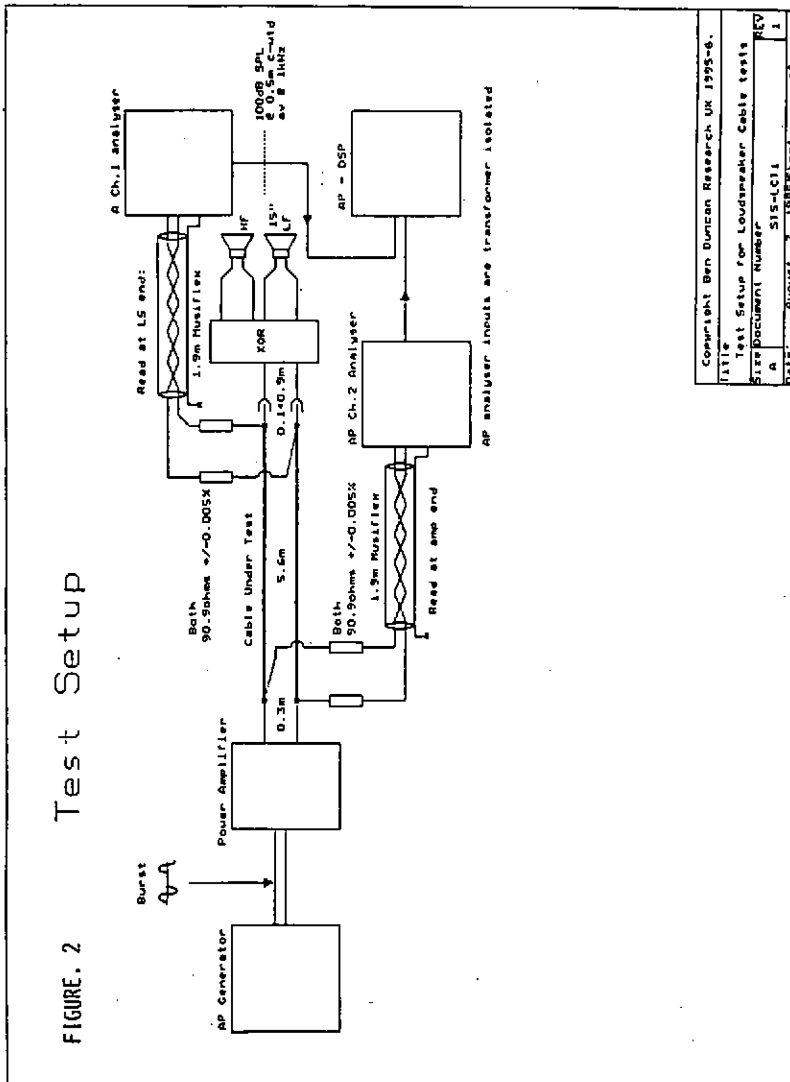
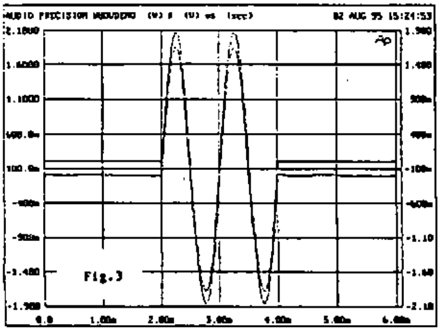


FIGURE. 2 Test Setup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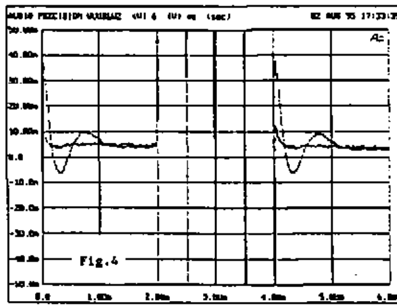
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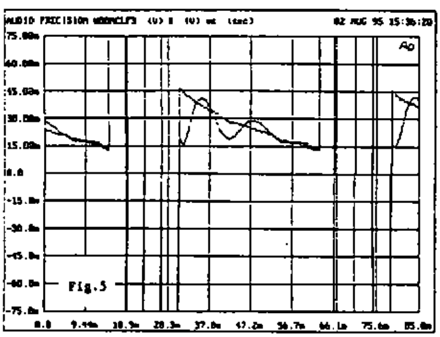
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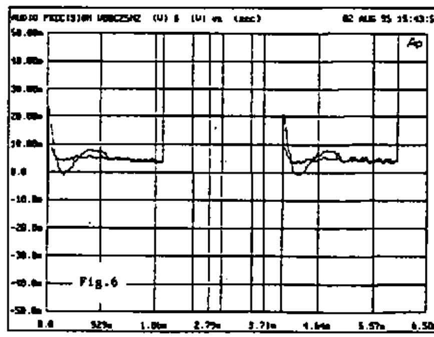
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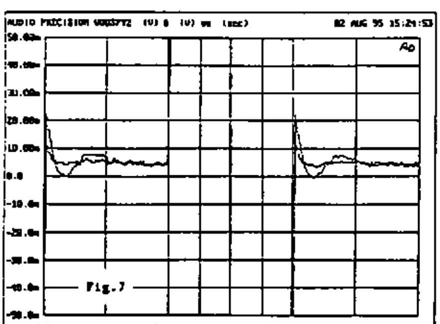
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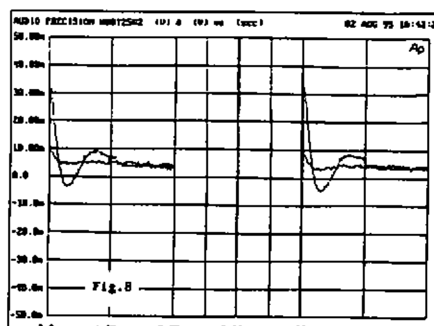
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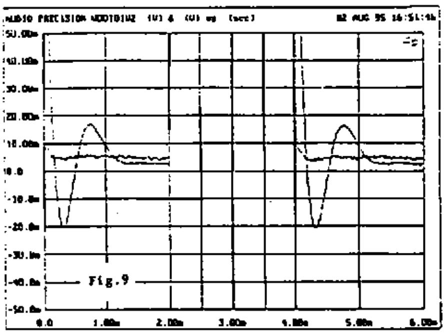


Fig.9

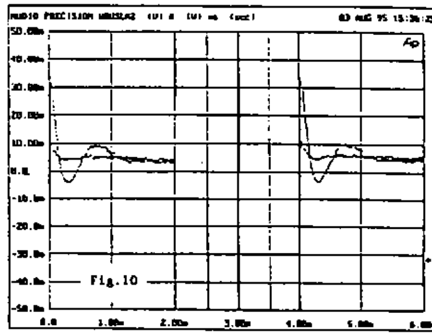


Fig.10

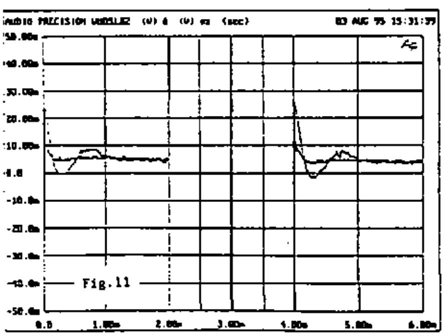


Fig.11

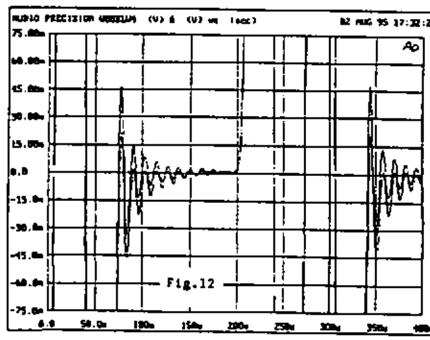


Fig.12

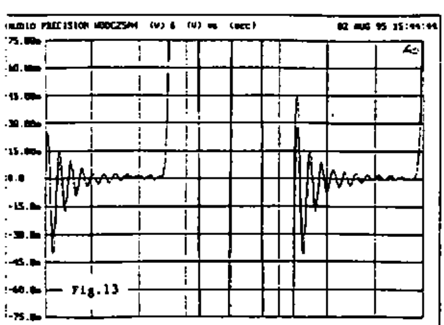


Fig.13

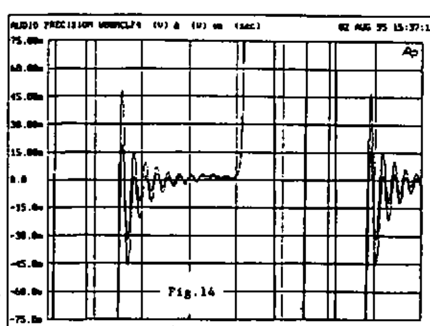


Fig.14

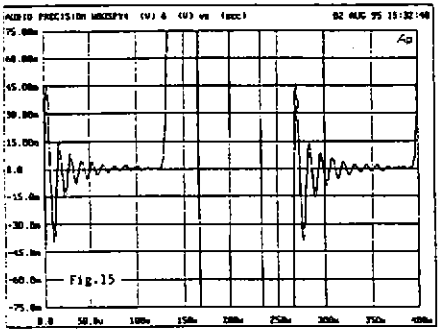
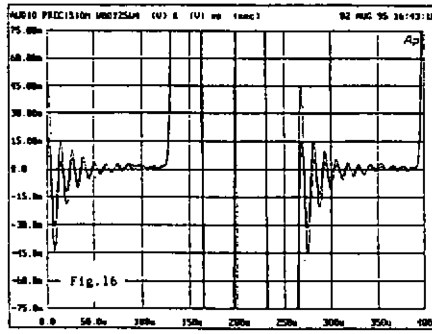


Fig.15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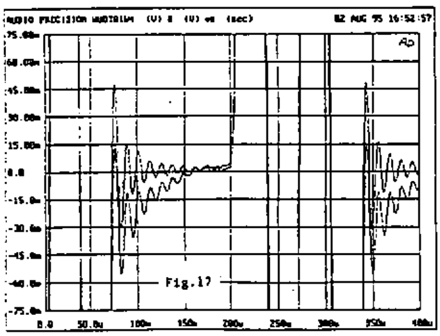
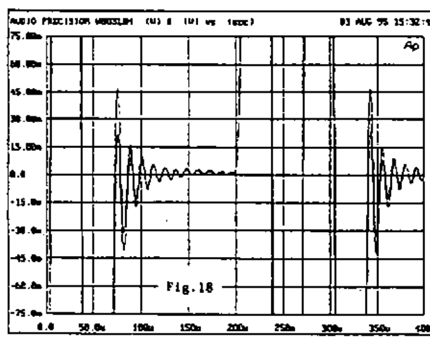


Fig.17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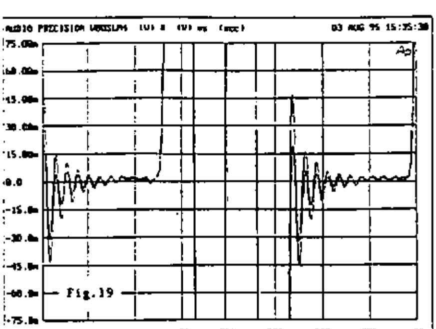
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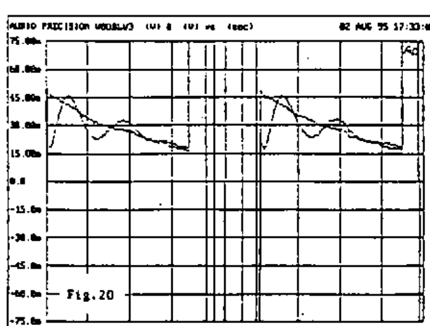
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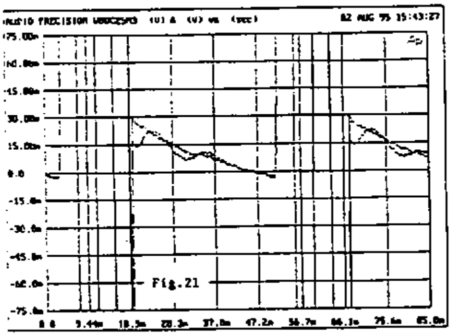

Fig.21

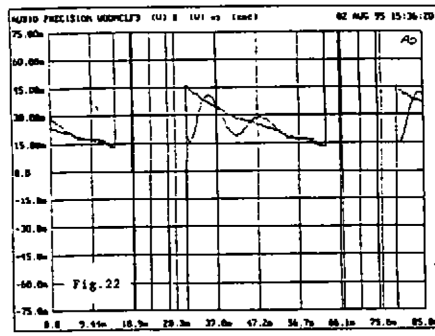

Fig.22

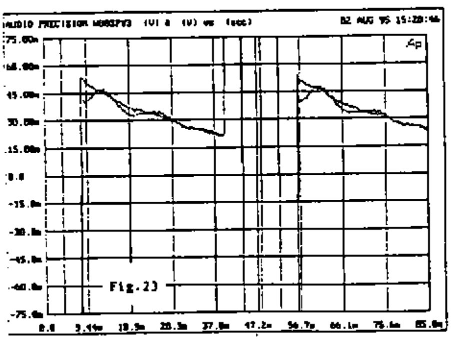

Fig.23

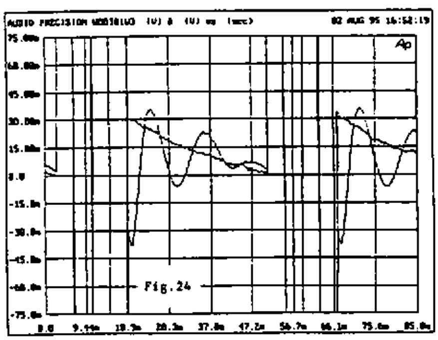

Fig.24

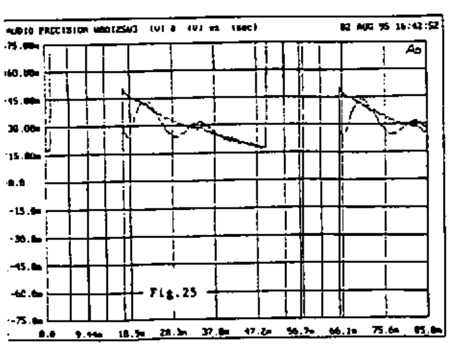

Fig.25

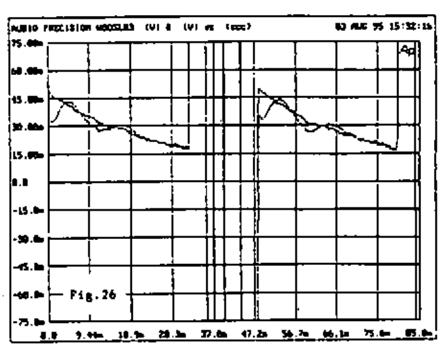

Fig.26

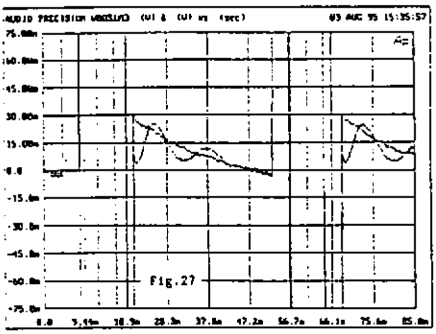
Fig.27

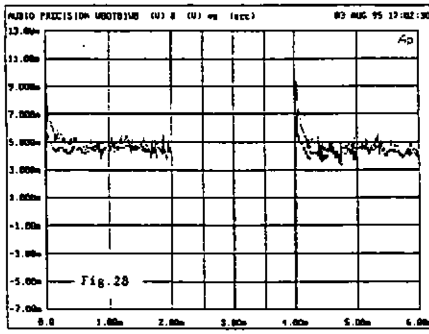
Fig.28

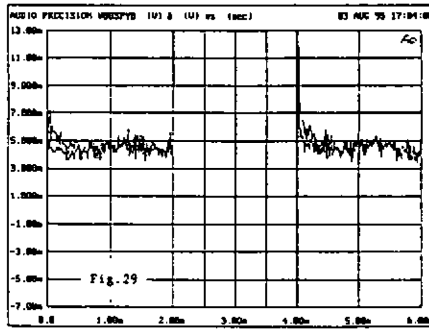
Fig.29