THE EFFECTS OF VARIOUS TYPES OF CABLES ON THE PERFORMANCE OF HIGH FREQUENCY LOUDSPEAKERS

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1. INTRODUCTION

It is now around 30 years since the subject of the audibility of the effect of different loudspeaker cables became a vogue topic. Nevertheless, despite the specialist loudspeaker cable industry now having achieved a considerable size, world-wide, the controvertiality of the subject has still not been resolved. We read from John Watkinson, a well-known commentator on the subject "I have never detected a difference in sound whatever way the cable is facing." "I always fit arrowed cables backwards, and wait for someone to point out my error."[1] At the other end of the scale we read from Ben Duncan that, in effect, many of the hard-line objectivists, instead of doing their detective work, seem to prefer to deny that a crime ever existed. In other words, rather than finding out why cables can make a difference, they imply that if there is no measurable difference, then there is no difference to be heard.

Three of the authors of this paper, as well as having decades of experience in acoustics and electro-acoustics, have all also had many years of experience as recording engineers. All are also convinced that they have heard differences between different loudspeaker cables to the extent that one could be deemed to be sonically superior to the other, although the effects have usually been subtle. However, as this work has usually been carried out on nominally professional equipment, rather than esoteric hi-fi equipment, perhaps the more generally robust engineering has led to less obvious degrees of difference than are often discussed in the hi-fi media. The following series of tests was therefore undertaken in order to try to establish some definitive and repeatable experiments, to show whether significant, noticeable differences do exist, and if so, precisely where the effects are taking place which lead to those differences.

2. PHILOSOPHICAL BASIS FOR THE WORK

The impetus to make the tests described in this report came from the work involved in the commissioning of a large studio, whose owner was an 'audiophile' in his spare time, and a highly successful record producer by profession. He was also generally reputed to have a good pair of ears. After the commissioning of the studio, and during the period of settling-in, the owner was questioning whether the high frequency roll-offs on the monitor system were correctly chosen.
Several attempts were made to pacify him by means of minor adjustments to the passive networks ahead of the high frequency power amplifiers, but nothing seemed to satisfy him. The owner then asked about changing the cables to the high frequency drivers, which were fed via good quality 4 mm^2 cables of just over two metres in length, specifically sold as loudspeaker cable and using oxygen-free copper. Somewhat perplexed by all this, the system designer (P.N.) recalled reading a reference to the use of standard video coaxial cable for high frequency drivers[2], so thought that it might be worth a try. In the event, the high frequency drivers (used above 1 kHz) were re-wired with

RG59 standard coaxial copper cable, neither oxygen-free nor linear crystal. The length of the new cables was just less than three metres. In the year subsequent to this change taking place, no further complaint was heard from the audiophile studio owner. Since then, two existing studios have been retrofitted with the same arrangement, and a further studio has been newly constructed, and all the personnel of the studios have expressed their great satisfaction with the extra transparency of the high frequencies.

In no case could any change in the measured responses in the rooms be detected, yet the opinion that the RG59 yielded better results was unanimous. From an engineering point of view, this situation is rather unsatisfying, but it must be understood that the ultimate pass or fail rating of any studio design will be made in relation to the subjective comments of its users, so these opinions (which is all that they are) cannot be taken lightly by a studio designer.

3. BACKGROUND TO THE TESTS

The fact that cable-related sonic differences can be highly system-specific is well known, as is the need to keep resistance and inductance low if well-damped low-frequency responses are to be maintained. However, very little work seems to have been done on the specific needs for high frequency cabling in multi-amplified loudspeaker systems. It was therefore decided to investigate the effects of cables on the system which had actually been heard to exhibit differences under controlled conditions. The case under discussion, here, seems to be significantly bucking a trend inasmuch as the preferred cable was of relatively high resistance (compared to normal loudspeaker cable) and made of standard copper, albeit with a low inductance construction. However, the inductance of the cable which it replaced could barely be considered to be damagingly high. The relative parameters of the cables in question are given in Table 1 below:

Table 1

	5m OFC	**5m RG59**
Capacitance	69 pF/m	75 pF/m
Resistance	0.06 ohms	0.72 ohms
Dielectric rigidity	760 M ohms	4000 M ohms
Inductance		

There would appear to be four ways in which the cable could be affecting the response:

1. Linear distortion in the frequency domain due to inductance, capacitance and resistance.

2. Linear distortion due to time domain effects, as could be caused by reflexions in the line.

3. Non-linear distortion due to radio frequency pick-up, and its subsequent injection into the audio circuitry.

4. Non-linear distortion due to the changes in coupling between the amplifier and loudspeaker.

Test rigs were set up in order to look at each of these possibilities in turn. In cases 1, 2 and 3, cables of 5 metres and 50 metres were used. In case 4, cables of 20 feet (6 metres) were tested, (in the USA).

4. LINEAR DISTORTION DUE TO L, C AND R

Measurements at the amplifier output and the loudspeaker input were recorded on DAT. The amplifier/loudspeaker system used was exactly the same as the system in the studios previously referred to, comprising an electronic crossover channel with a frequency range from 1 kHz to 50 kHz, a Neva Audio Studio II power amplifier of 50 watts class A output, and a TAD TD2001 compression driver on a Reflexion Arts AX2 horn. Figure 1 shows the response of the two channels of the DAT recorder, which confirms that there was no significant difference between the channels recording the two ends of the cables under test.

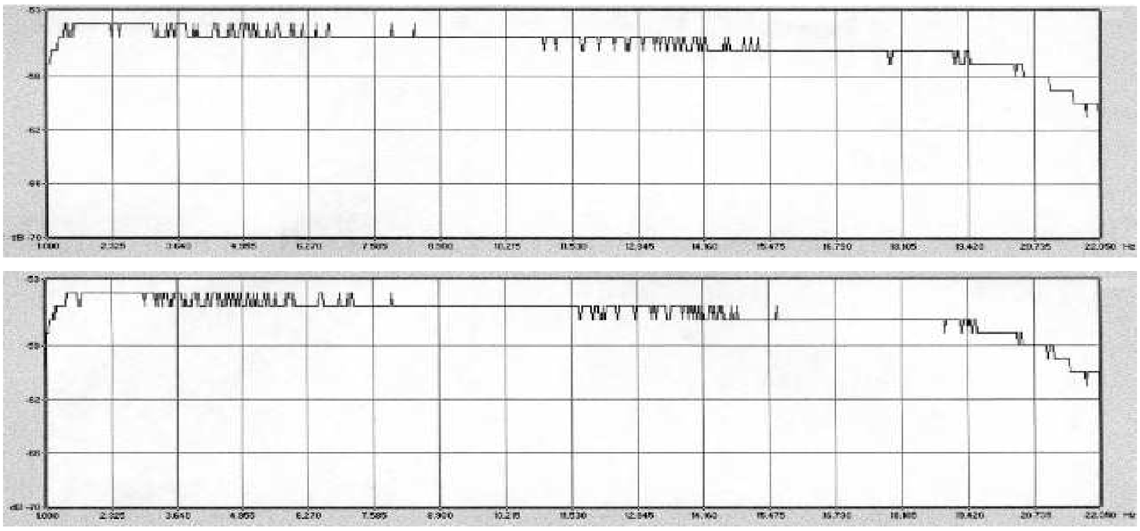


Figure 1
Comparison of the DAT channels used to record the tests. These traces are of the amplifier output, unloaded, and are the basis of reference for the following figure.

Figure 2 shows the responses at the loudspeaker ends of the cables, when 50 metres of each of the two types of cable were tested. If the cables were 'perfect lossless conductors' the plots should be the same as those in Figure 1. It can be seen that the OFC loudspeaker cable shows very low loss at lower frequencies, but a noticeable low-pass filter effect can be seen from the gradually falling response as the frequency rises. Conversely, the RG59 coaxial cable shows much greater overall loss, due to its resistance, but no frequency-dependent loss is evident. Obviously, at low frequencies, with mass controlled drivers, this degree of cable resistance would seriously compromise the damping factor, but at high frequencies (over 1 kHz) and with lightweight moving masses, the damping factor is hardly relevant. What is more, when connected to a passive crossover filter with an irregular impedance with frequency, the series resistance could upset the frequency response, but the driver impedance curve, in this case, was relatively benign. and, in studio use, the cables would normally be too short for the resistance to become a significant problem. The 50 m cables being tested here were simply intended to highlight differences, and would not be recommended for use in studios, although in sound reinforcement systems such lengths do get used.

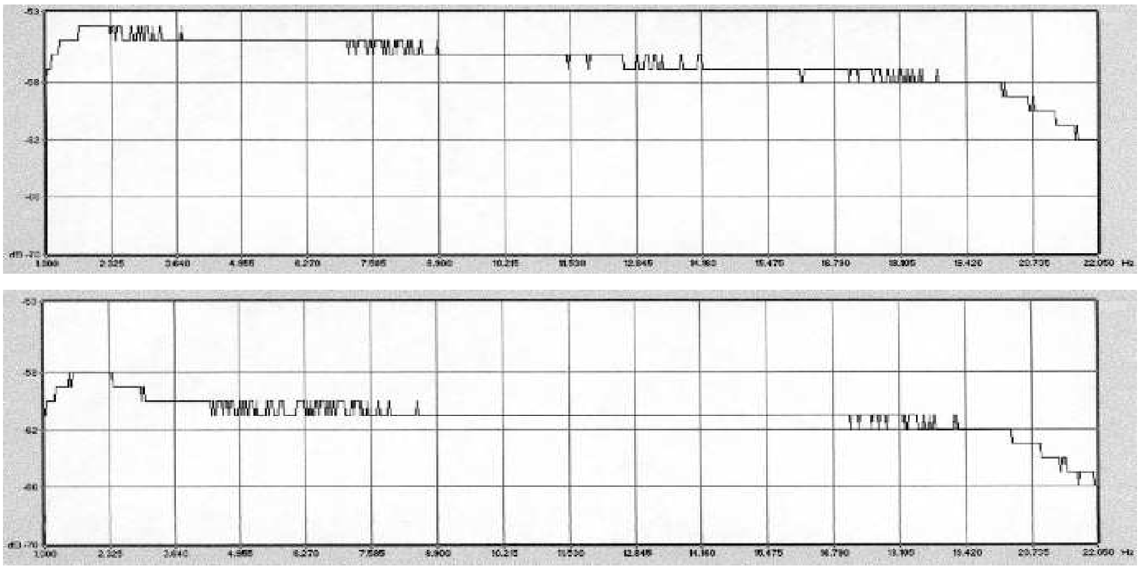


Figure 2
50 metres of cable. Upper trace is the OFC cable, lower trace is the coaxial.

Figure 3 shows the response of the OFC cable with a more realistic 5 metre length. The upper trace is the amplifier end of the cable, and the lower trace is the driver end. No significant difference is evident between the two plots, suggesting that no low-pass filter effect would be evident in a typical studio application. Figure 3 also compares well with Figure 1.

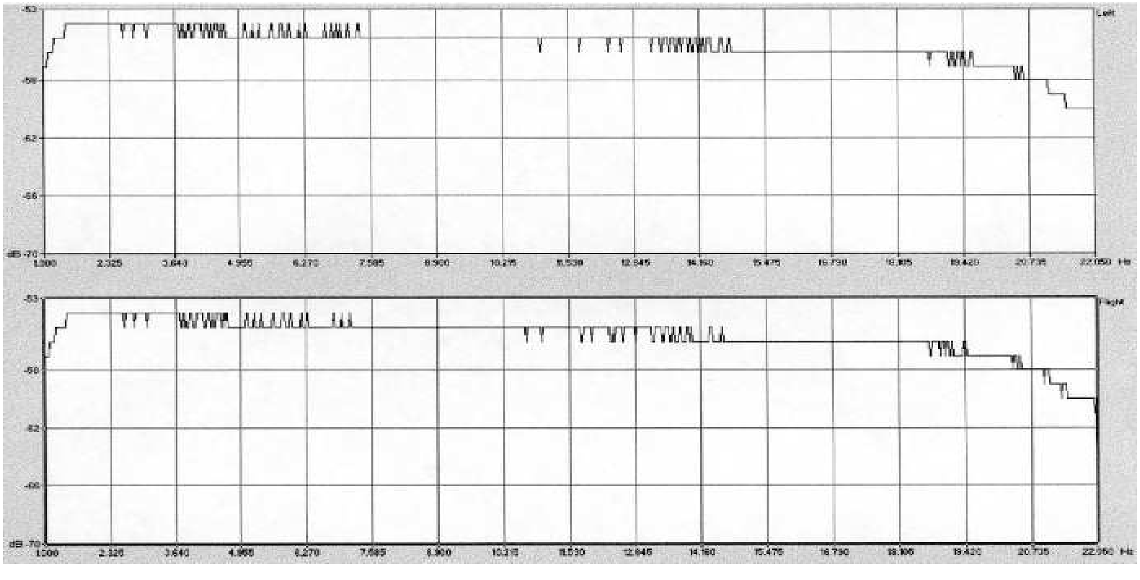


Figure 3
5 metres of OFC cable. Upper trace – amplifier end. Lower trace – driver end. No obvious difference is evident.

Somewhat strangely, Figure 4 shows the response with 5 metres of the RG59 coaxial cable, in which there does seem to be a slight high-frequency loss, as well as about 1 dB of overall loss due to the extra loop resistance, but the roll-off could be a measurement artefact due to the 1 dB steps used in this type of measurement display.

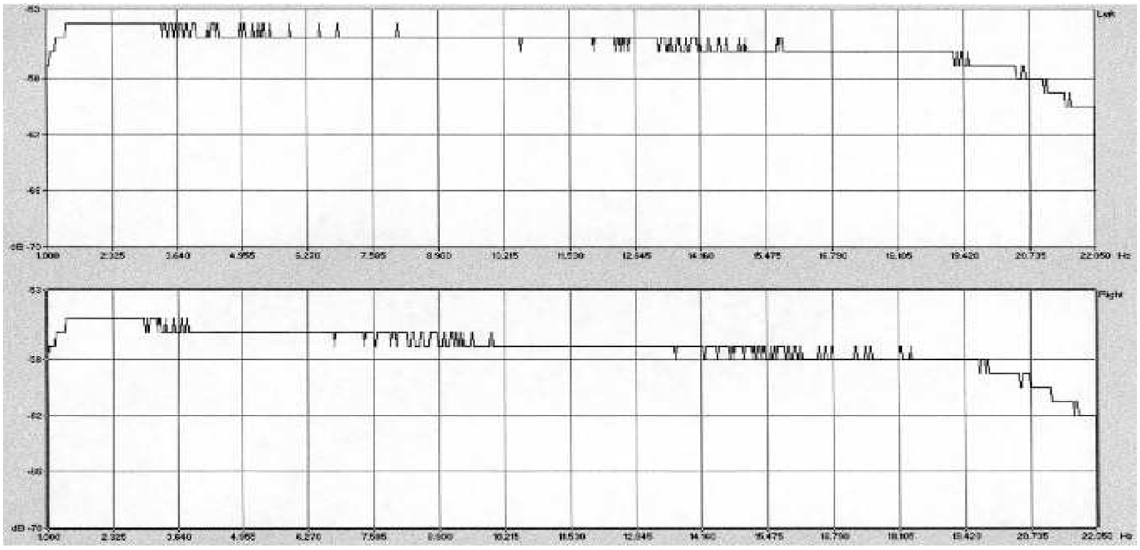


Figure 4
5 metres of RG59 cable. Upper trace – amplifier end. Lower trace – driver end.

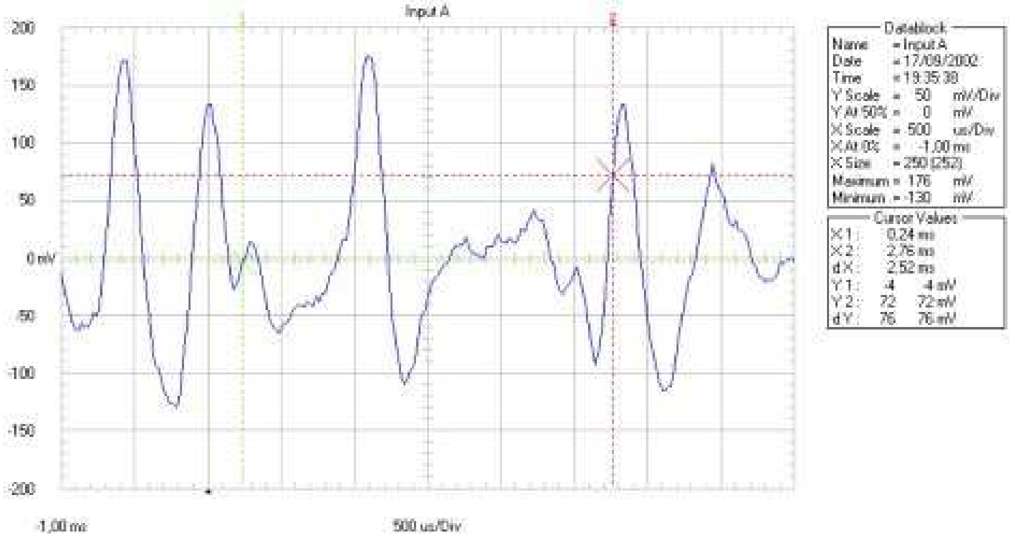
The preceding tests would seem to confirm that with lengths of only 3 metres, in studios, the losses due to resistance, capacitance and inductance are negligible. The previous filter adjustments carried out in the studio, as mentioned in Section 2, introduced much greater level and high-frequency roll-off variations, yet without being able to compensate for the preference for the RG59 cable.

5. LINEAR DISTORTIONS DUE TO SIGNAL REFLEXION

Work carried out at the Engineering School of Geneva (Switzerland)[3] has suggested that reflexions due to the mis-termination of impedances can build up in cables, with the resulting effect of distorting the wavefronts of the signals by means of the linear superposition of the direct and reflected signals. However, these measurements were carried out with 10 kHz pulses over 100 metre lengths of cable. In our tests, no trace of any such effect could be found on 5 metre lengths of loudspeaker cable.

6. NON-LINEAR DISTORTIONS DUE TO ELECTROMAGNETIC INTERFERENCE

During the tests reported in Section 4, it had been noticed that the background noise levels on the waveforms, when monitored by oscilloscope, appeared to be different for each cable type and length. In order to investigate this further, 50 metres of each cable was connected between the amplifier and the compression horn. The cable was laid out, and folded back on itself, three times, in order to avoid any loops. A waveform analyser was connected to the amplifier end of 50 metres of the OFC cable, and the output was observed whilst listening to a recording of solo trumpet at a comfortable listening level. The resulting waveform is shown in Figure 5.



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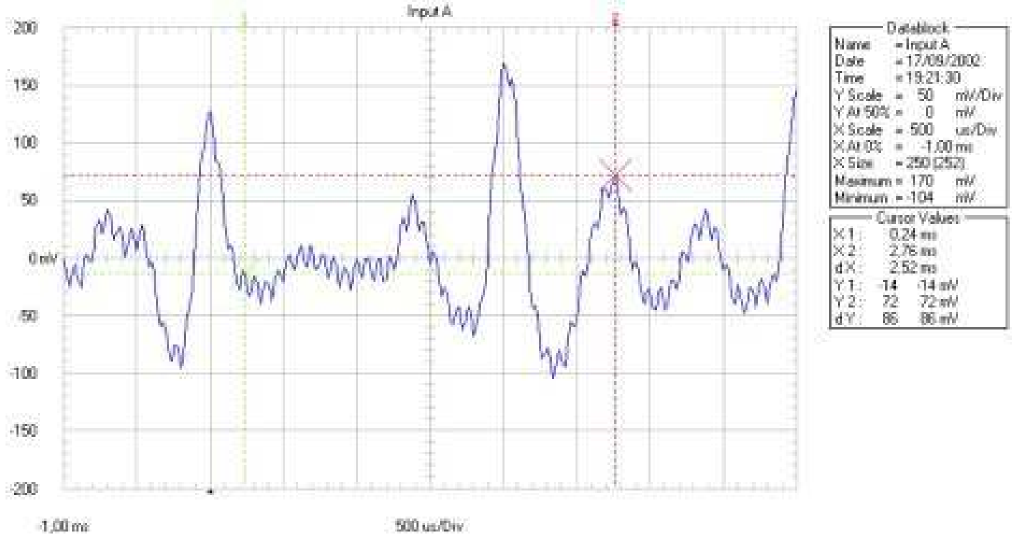
Datablock
Name      = Input A
Date      = 17/09/2002
Time      = 19:35:30
Y Scale   =   50     mV/Div
Y At 50%  =    0     mV
X Scale   =  500     us/Div
X At 0%   =  -1,00 ms
X Size    = 250 (252)
Maximum   =  176     mV
Minimum   = -130     mV
Cursor Values
X 1 :    0,24 ms
X 2 :    2,76 ms
d X :    2,52 ms
Y 1 :   -4     -4 mV
Y 2 :   72     72 mV
d Y :   76     76 mV
```

Figure 5
The waveform of a solo trumpet, as measured at the amplifier output terminals.

The waveform analyser was then connected at the loudspeaker end of the cable. Figure 6 shows the result, with a serious amount of interference.



```
Datablock
Name      = Input A
Date      = 17/09/2002
Time      = 19:21:30
Y Scale   =   50     mV/Div
Y At 50%  =    0     mV
X Scale   =  500     us/Div
X At 0%   =  -1,00 ms
X Size    = 250 (252)
Maximum   =  170     mV
Minimum   = -104     mV
Cursor Values
X 1 :    0,24 ms
X 2 :    2,76 ms
d X :    2,52 ms
Y 1 :  -14    -14 mV
Y 2 :   72     72 mV
d Y :   86     86 mV
```

Figure 6
The waveform of a solo trumpet, measured at the compression driver, connected via 50 metres of OFC loudspeaker cable.

The test was then repeated with 50 metres of RG59 cable, at first conventionally connected, and then with the screen connected to the red output terminal of the amplifier, and the inner core to the black (grounded) terminal. The results are shown in Figures 7 and 8, respectively.

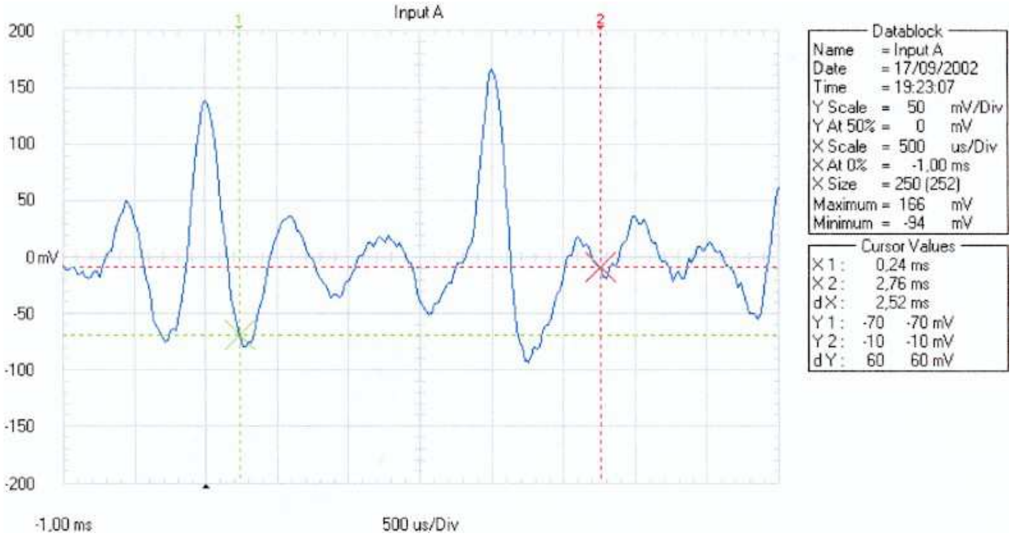


Figure 7
The waveform of a solo trumpet, measured at the compression driver, connected via 50 metres of RG59 coaxial cable.

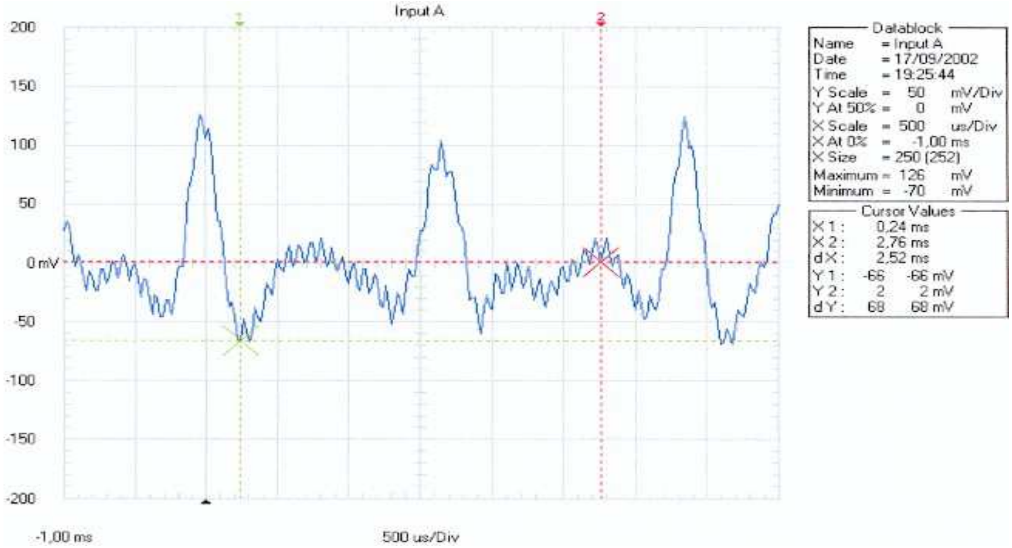
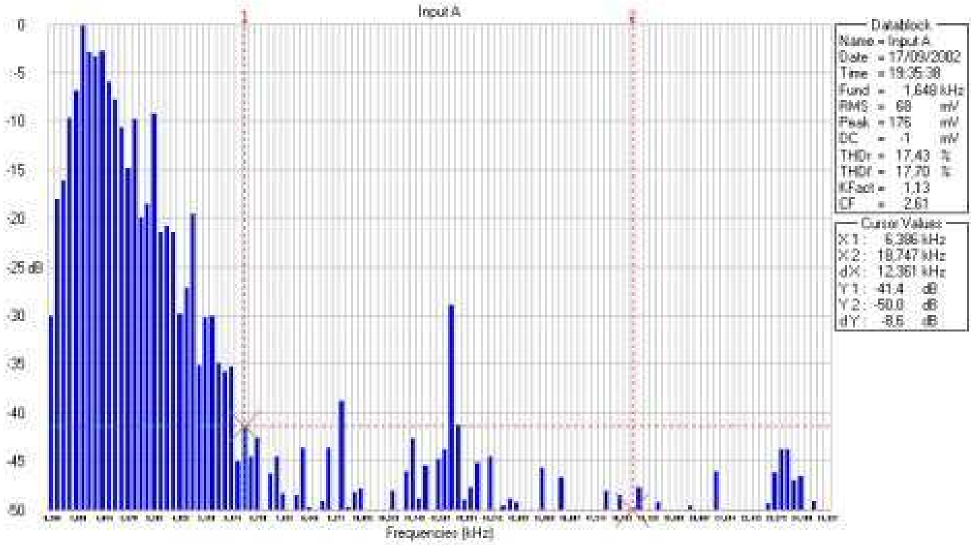


Figure 8
The waveform of a solo trumpet, measured at the compression driver, connected via 50 metres of RG59 cable, but with the core grounded, and the screen used as the live connector.

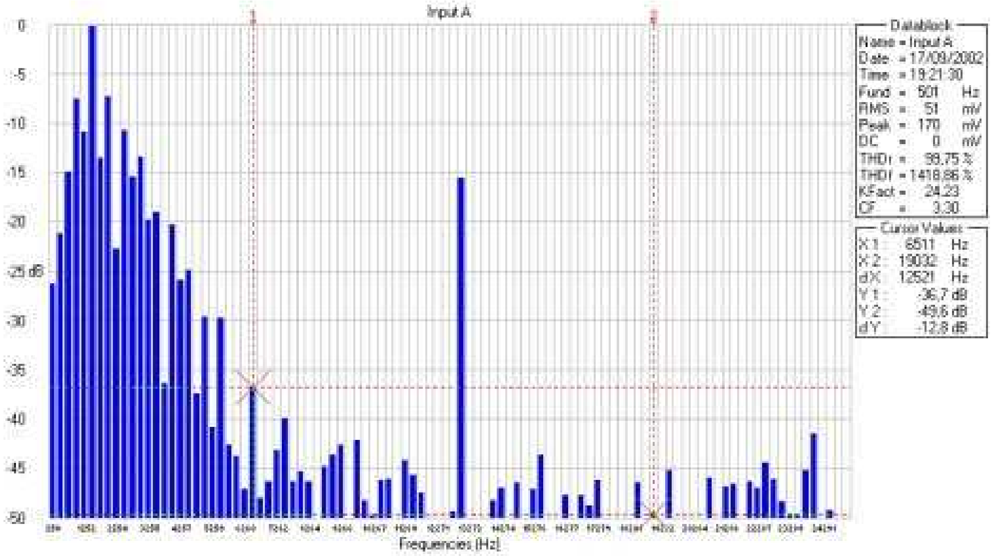
The better waveform purity of the conventionally connected coaxial cable is plainly evident. Although the voltage levels of the musical signals are low, the TAD 2001/AX2 combination has a sensitivity of almost 110 dB for 1 watt @ 1 metre, therefore even one milliwatt of input signal could produce around 80 dB SPL at one metre distance, so these voltage levels are not unrepresentatively low. In order to analyse the interference in more detail, a spectrum analysis was made for each of the measurements shown in Figures 5 to 8. These are shown in Figures 9 to 12 respectively.



Datablock
Name = Input A
Date = 17/09/2002
Time = 19:35:38
Fund = 1,648 kHz
RMS = 68 mV
Peak = 176 mV
DC = -1 mV
THDr = 17,43 %
THDf = 17,70 %
KFact = 1,13
CF = 2,61

Cursor Values
X 1 : 6,386 kHz
X 2 : 18,747 kHz
dX : 12,361 kHz
Y 1 : -41,4 dB
Y 2 : -50,0 dB
dY : -8,6 dB

Figure 9
The spectral response of Figure 5.



Datablock
Name = Input A
Date = 17/09/2002
Time = 19:21:30
Fund = 501 Hz
RMS = 51 mV
Peak = 170 mV
DC = 0 mV
THDr = 99,75 %
THDf = 1418,86 %
KFact = 24,23
CF = 3,30

Cursor Values
X 1 : 6511 Hz
X 2 : 19032 Hz
dX : 12521 Hz
Y 1 : -36,7 dB
Y 2 : -49,6 dB
dY : -12,8 dB

Figure 10
The spectral response of Figure 6.

These tests were all carried out in the city of Vigo, Spain, which is a major sea port with a mixture of heavy industry and general commerce. It is thus typical of the electromagnetic environment in which many studios are situated. The spectral plots show a predominating interference at around 13 kHz which, in the case of Figure 12, is only about 13 dB below the signal in the 1 kHz region. Compared to Figure 9, Figures 10 to 12 show much more clutter in the range above 6 kHz, which continues to ultrasonic frequencies. However the 13kHz component in the response of the conventionally connected RG59 cable is very considerably less than that of the OFC, or the inverse connected RG59.

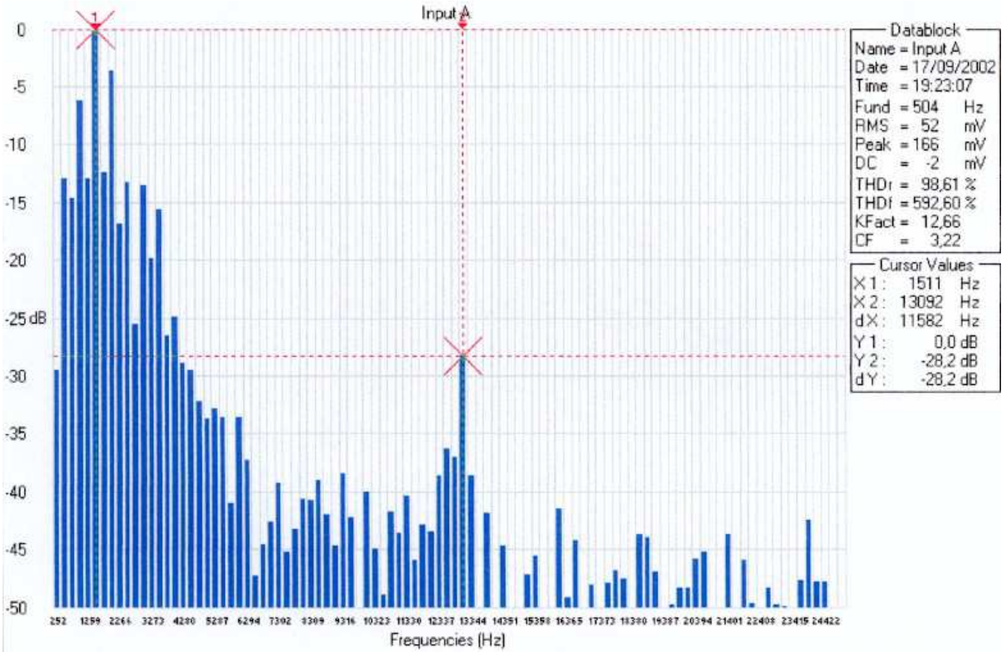


Figure 11
The spectral response of Figure 7.

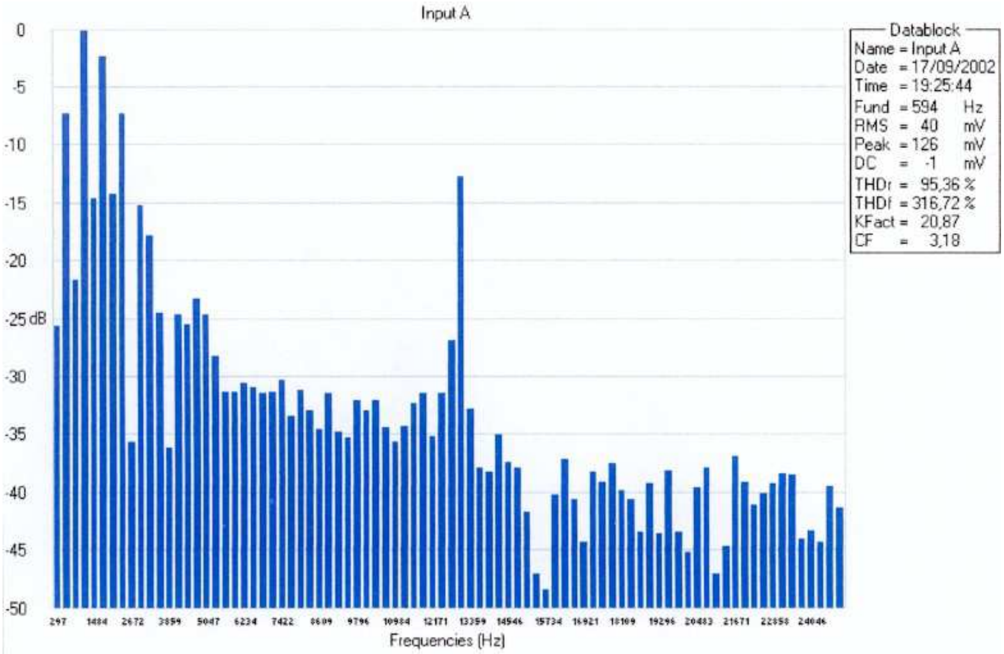


Figure 12
The spectral response of Figure 8.

Figure 13 shows the response at the driver end of the OFC cable, with the music stopped. Note that the peak level "0 dB" is 16 mV. Figure 14 shows the same measurement but with the RG59 cable, conventionally connected. Although the overall background clutter looks to be higher, it should be noted that the signal peak is only 4 mV, therefore the general background noise is raised by 12 dB relative to the levels shown in Figure 12. For side-by-side comparison, one should therefore refer the 0 dB level of Figure 14 to the –12 dB level of Figure 13. When thus considered, not only is the general background noise level lower by about 8 dB in the case of the RG59 cable, but also the 13 kHz signal does not have the same spectral clutter surrounding it. Are we seeing intermodulation effects, here?

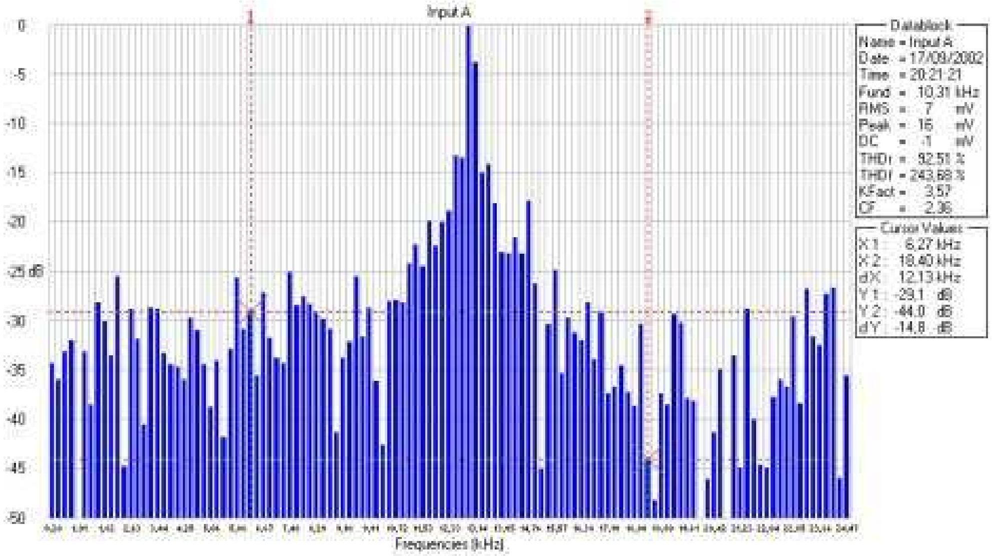


Figure 13
Response of the compression driver with the music stopped – connected via 50 metres of OFC cable.

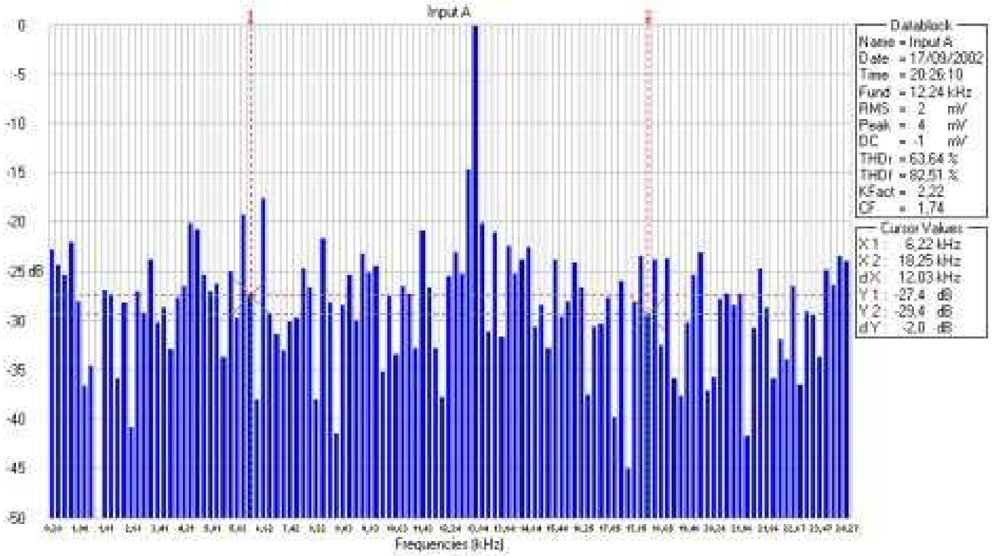


Figure 14
As Figure 13, but connected with 50 metres of RG59 coaxial cable.

In order to eliminate the measurement system from these responses, Figure 15 shows the response of the measurement system alone, disconnected from the cables but with its test leads open circuit and dangling freely. Note that the peak level in this case shows only 2000 microvolts (2 mV).

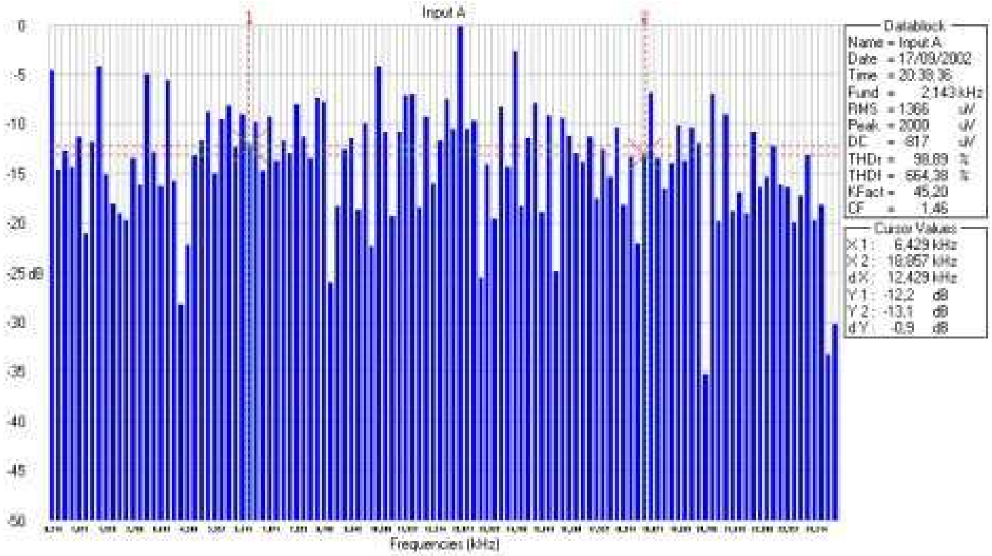


Figure 15

Response of the test system, disconnected from the loudspeaker cables, with its leads open circuit.

Clearly it can be seen that the signal at the loudspeaker terminals (and hence, it would follow, at the acoustic output of the loudspeaker) is quite different for each loudspeaker cable used. Although it would appear that the amplifier's effectively zero output impedance is sinking most of the interference, the design of the amplifier could be an issue here. Suspicions exist about the effect being different for different amplifier topologies, but this needs further tests in order to show any such dependency.

7. NON-LINEAR DISTORTIONS DUE TO THE ALTERED AMPLIFIER/LOUDSPEAKER INTERFACE[4]

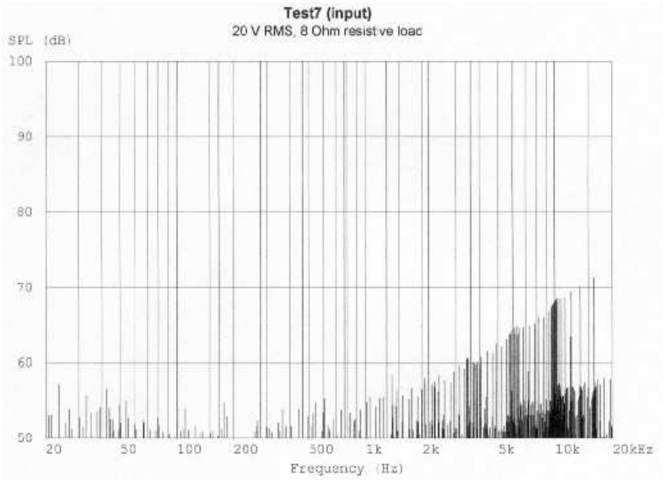
In order to test for any such effect, three 20 foot (6 metre) lengths of different types of loudspeaker cables were compared, using a multi-tone measurement system. This system was chosen because of its ability to show up the many intermodulation produces of a non-linear system when driven by a complex signal. The tests were carried out with a full frequency range, at first into a specially made, almost purely resistive, high-power load of 8 ohms. The three cables used were:

1. An audiophile loudspeaker cable – (Phoenix Gold, multi-strand)

2. A low cost loudspeaker cable – (Isoteric Audio).

3. A standard electrical cable of similar resistance – (Romex)

No discernible significant difference was noticed between any of the measurements when driving the 8ohm load. The results are shown in Figure 16. The tests were then repeated using two different loudspeakers with passive crossovers. This time, a different set of results emerged. The distortion patterns were noticeably different, not only between the different cables, but also between the input and output ends of each cable. The results are shown in Figures 17 to 18, for the AIG and SW loudspeakers, respectively.



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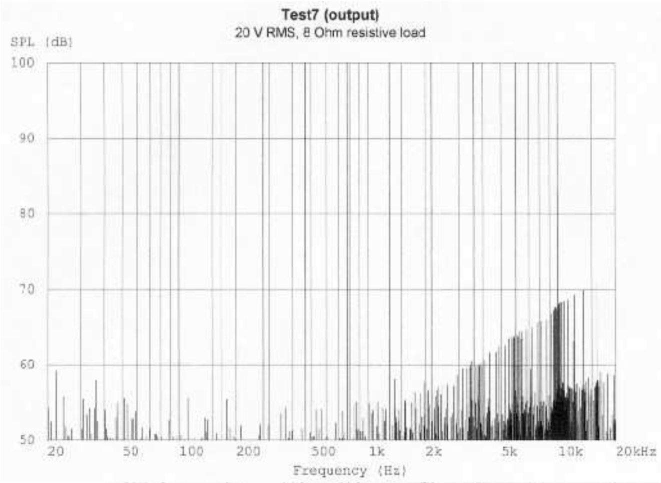

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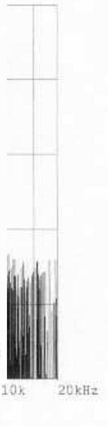

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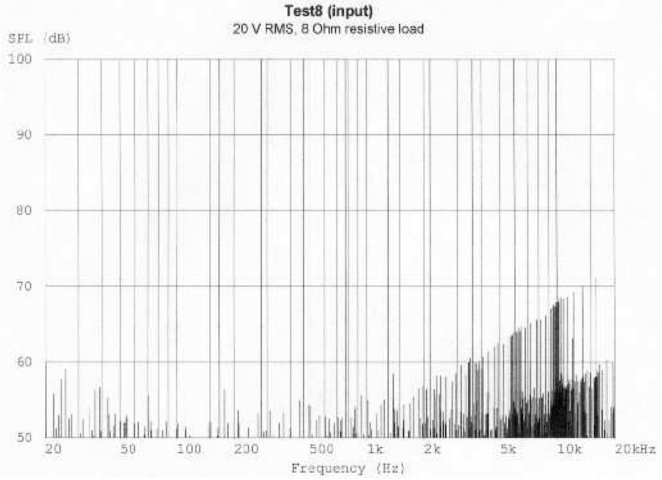

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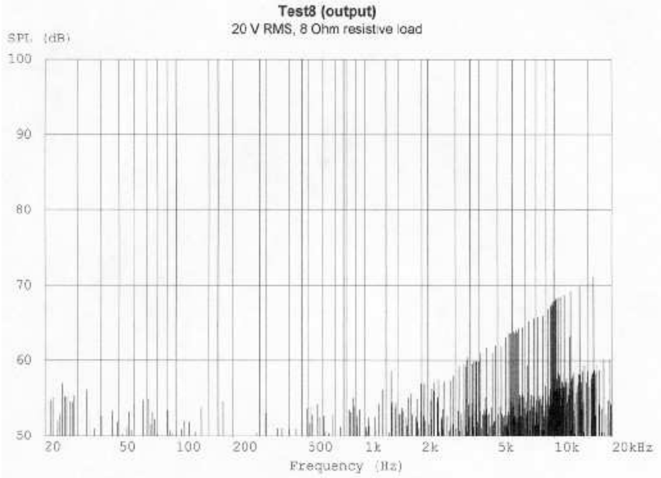

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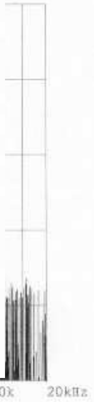

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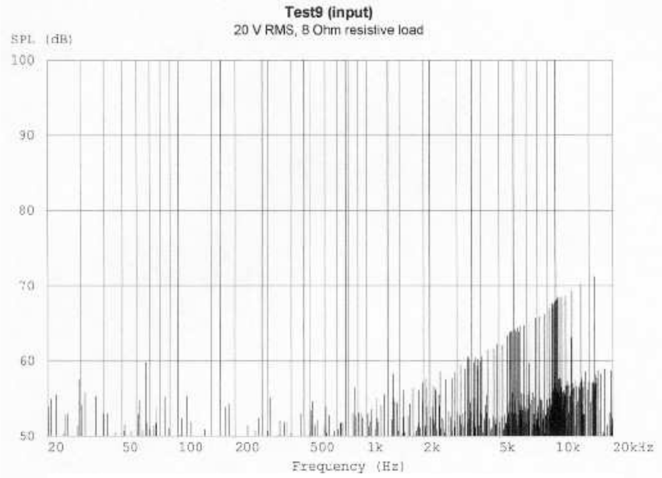

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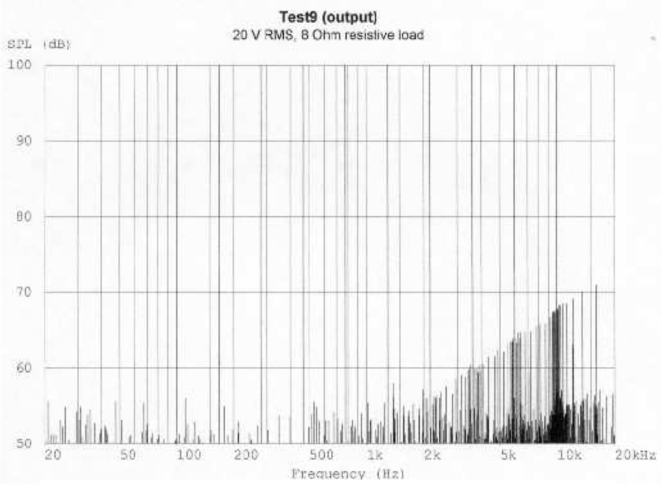

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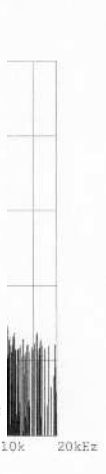
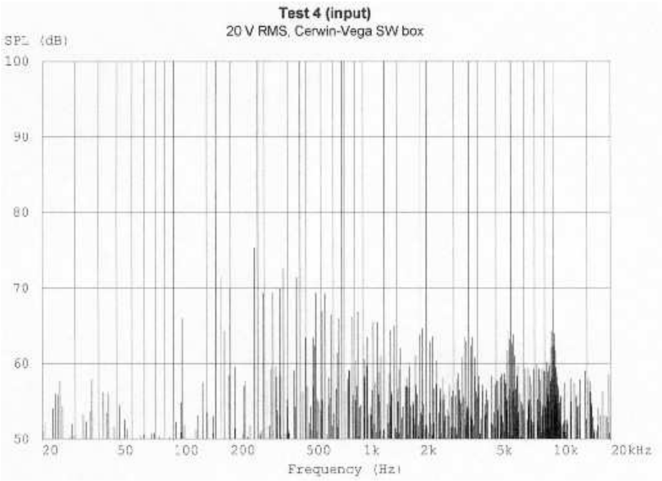


Figure 16

Location: Cerwinski Laboratories Inc.

Figure 17



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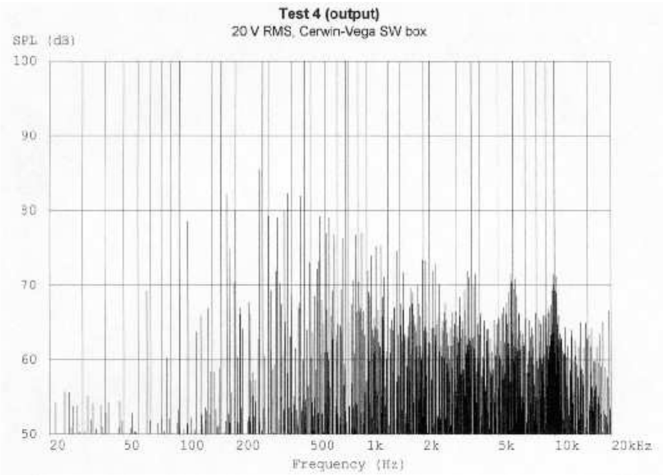

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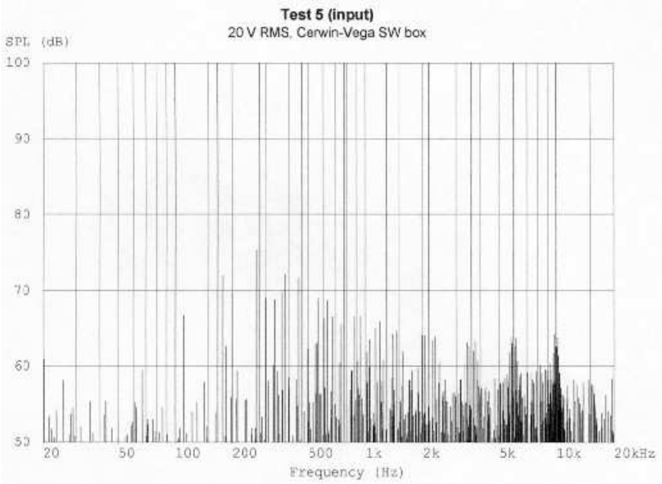

Object: Input signal (cable Isoteric Audio USA)
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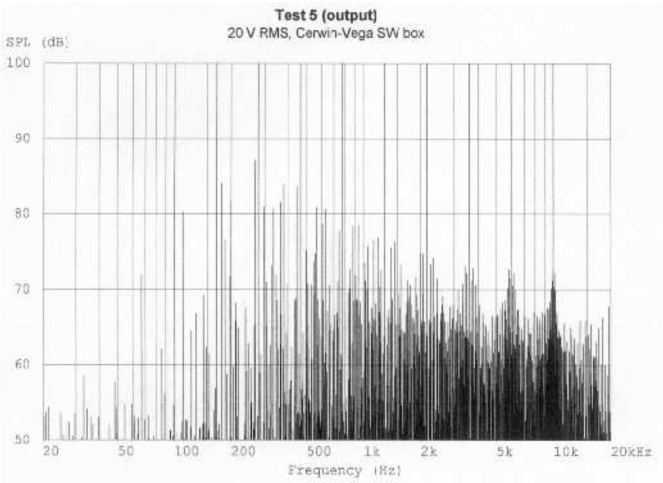

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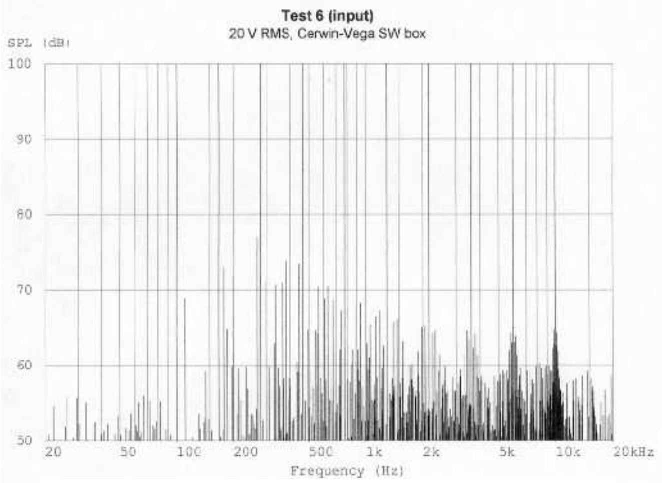

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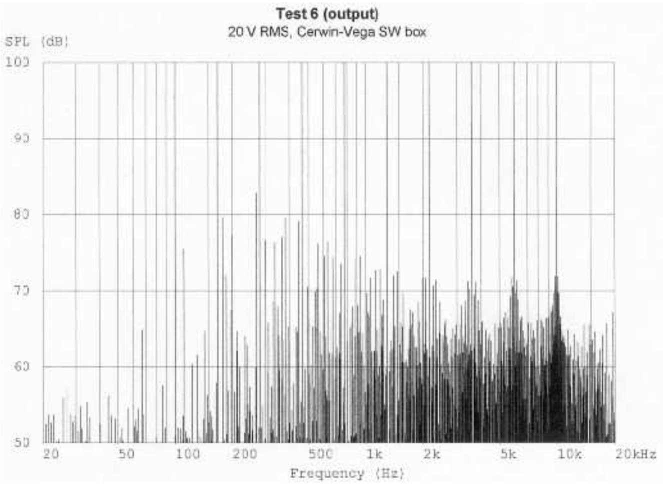

Object: Signal after cable Romex
User:
Location: Cerwinski Laboratories Inc.

Figure 18

The implication, here, seems to be that the different cables change the way that the complex load is 'seen' by the amplifier. The reasons why this should be so are the subject of further research, but it has been shown here that there is a measurable non-linear distortion difference when an amplifier is used with different cables and a reactive load.

In fact, Ben Duncan seems to have measured directionality in loudspeaker cables, in work carried out for Jenving Technology AB, of Sweden[5]. He claims that the diode-like contacts caused during the extrusion process can make the cable more sensitive to external radiation pick-ups (electromagnetic interference), depending upon which end of the diodes is facing the low impedance of the amplifier output, and which end is terminated with the relatively much higher impedance of the loudspeaker. However, it can be seen from his Figures 19(a) and 19(b), that the different harmonics are not necessarily equally preferentially treated with respect to direction. In Figure 19(a) the second and third harmonics respond differently to the cable direction, whereas in Figure 19(b) one direction shows an improvement for both second and third harmonics. In each case, multiple measurements were made, but the results always coincided. They were not one-off measurements; they were very repeatable.

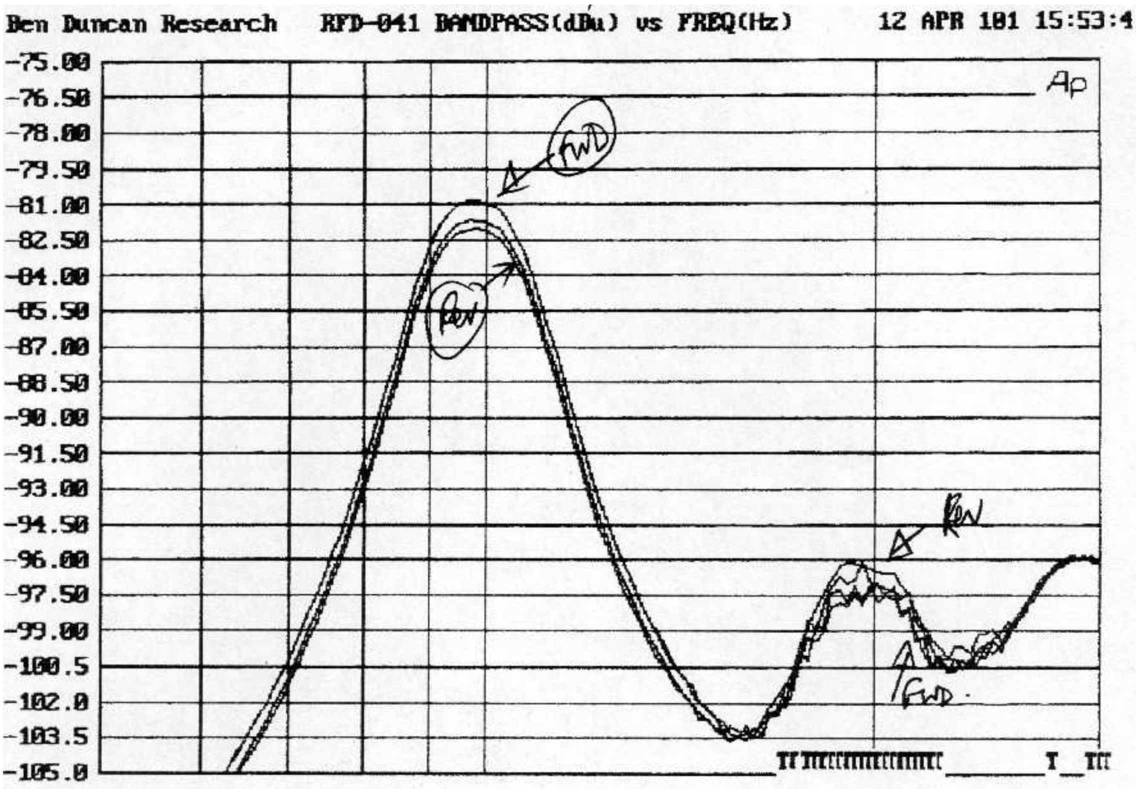

Figure 19 a

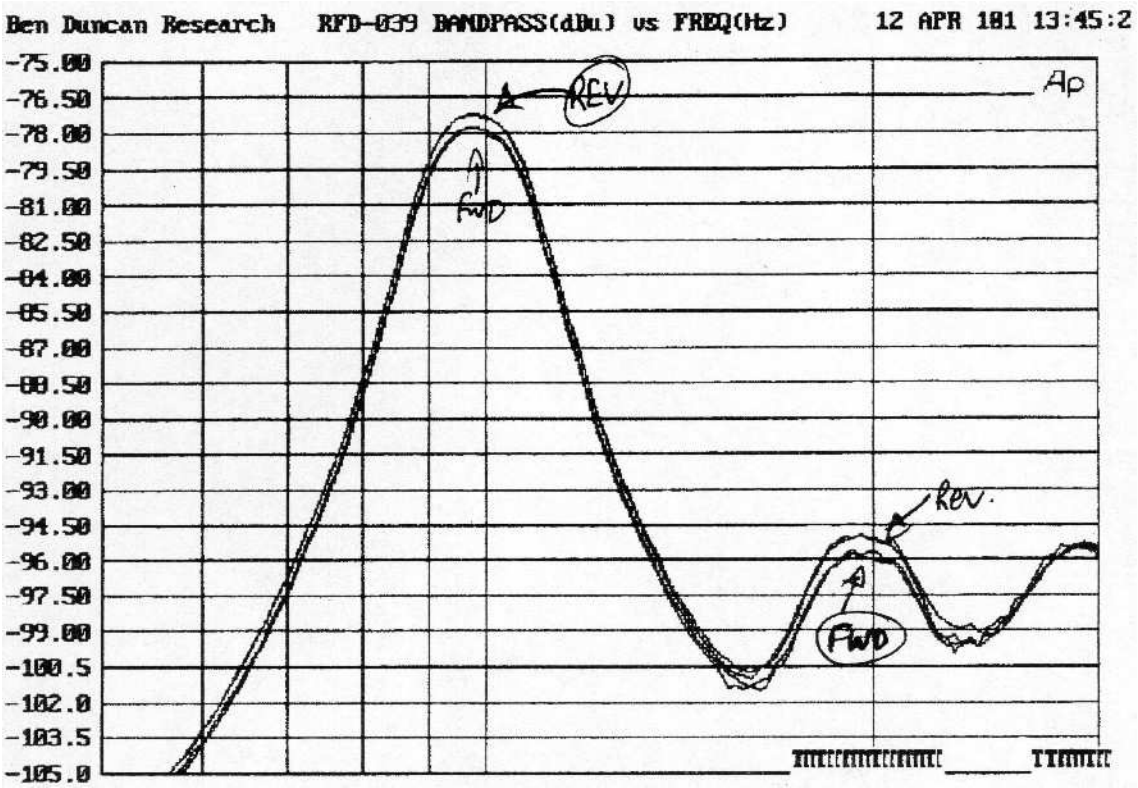

Figure 19b

8. CONCLUSION

The findings presented in this report all appear to support three of the ‘golden rules’ of high quality studio monitor system design in that:

1. Loudspeaker cables should be kept as short as possible.
2. Passive components should be avoided in the loudspeaker circuits.
3. Narrower, separately amplified frequency bands are less prone to disturbances than are full-range, passively crossed-over systems; therefore it is best to use multiple amplification.

Nevertheless, the tests reported here were triggered by an audible improvement being heard, (after the loudspeaker cables were changed) in the sonic transparency of a system which already obeyed the above rules. The most appropriate conclusion to be drawn from the results of the reported tests is that sonic transparency, which is itself hard to define, can be marred by low-level noise signals below the wanted signal, and that cables can, directly or indirectly, induce such noises.

The ‘noise’ signals apparent in Figures 5 to 13 would appear to be static, yet it is surprising that no obvious difference could be heard in the background noise of the amplifier when the cables were changed. However, the level difference due to the cable resistance differences could have masked any effect. It is also still not known to what degree the sonic performance of different amplifiers could be affected by these extraneous signals contaminating their output leads.

In the case of the multi-tone tests, a more clearly observable, signal-related intermodulation-product noise is apparent. There would seem to be little doubt that such effects can cause a degradation in the sonic clarity of a musical signal and, although the interference noise signals of Figures 5 to 12 may, in themselves, not be strongly audible, they almost certainly possess the ability to complicate the intermodulations situation, and perhaps by this means they can detract from the sonic transparency of a system.

All of these things point to mechanisms which, under different circumstances and as a part of different systems, can produce noise-like signals which can pollute the purely musical sounds, thus eroding the difficult-to-define transparency and openness of high resolution monitor systems. In the case of loudspeaker cables, screening would seem to be a good thing, and complex reactive loads would seem to be a bad thing. Many audiophiles would already claim to know this, but in this report we have presented some very repeatable hard evidence.

Finally, Figures 20 and 21 clearly show the differences from one end of 50 metres of cable to the other. The loudspeaker, in each case, was a TAD 2001 on an AX2 horn, producing about 70 dBSPL at one metre. The upper trace of each display is the response at the amplifier end of the cable, and the lower trace is the response at the loudspeaker end. In both figures the upper pair is the RG59, the middle pair the OFC, and the lower pair the RG59 inverted. In all cases the left hand plots are for 5 metres of cable and the right hand plots are for 50 metres. Figure 20 is the response to a 1.6kHz square wave, and Figure 21 a 1.6kHz sine wave. The fact that loudspeaker cables do change the signal would seem to be incontrovertible. The audibility of the various effects, however, still needs further investigation.

(Figure 20 and Figure 21 on the following pages)

REFERENCES

1. John Watkinson; “The Cable Snake”, Resolution, Volume 1, No 2, p 57, U.K., (July/August 2002)

2. Martin Colloms; Chapter 6, p 289 in: John Borwick (Editor), “Loudspeaker and Headphone Handbook”, Third Edition, Focal Press, Oxford, U.K., (2001)

3. Hervé Delétraz; “Reflections, Echoes & Music”, Stereophile magazine, pp 59-69, U.S.A., (November 2001)

4. These tests were carried out by Alexander Voishvillo, Alexander Terekhov and Eugene Czerwinski, at Cerwinski Laboratories, Simi Valley, California, U.S.A., in September 2002.

5. Ben Duncan, ‘Black Box’, Hi-Fi News and Stereo Review, p 65; U.K., (September 2000). Figure 19 was supplied directly to the authors of this paper by Jenving Technology AB, Sweden.

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or by fax +34 986 413412.

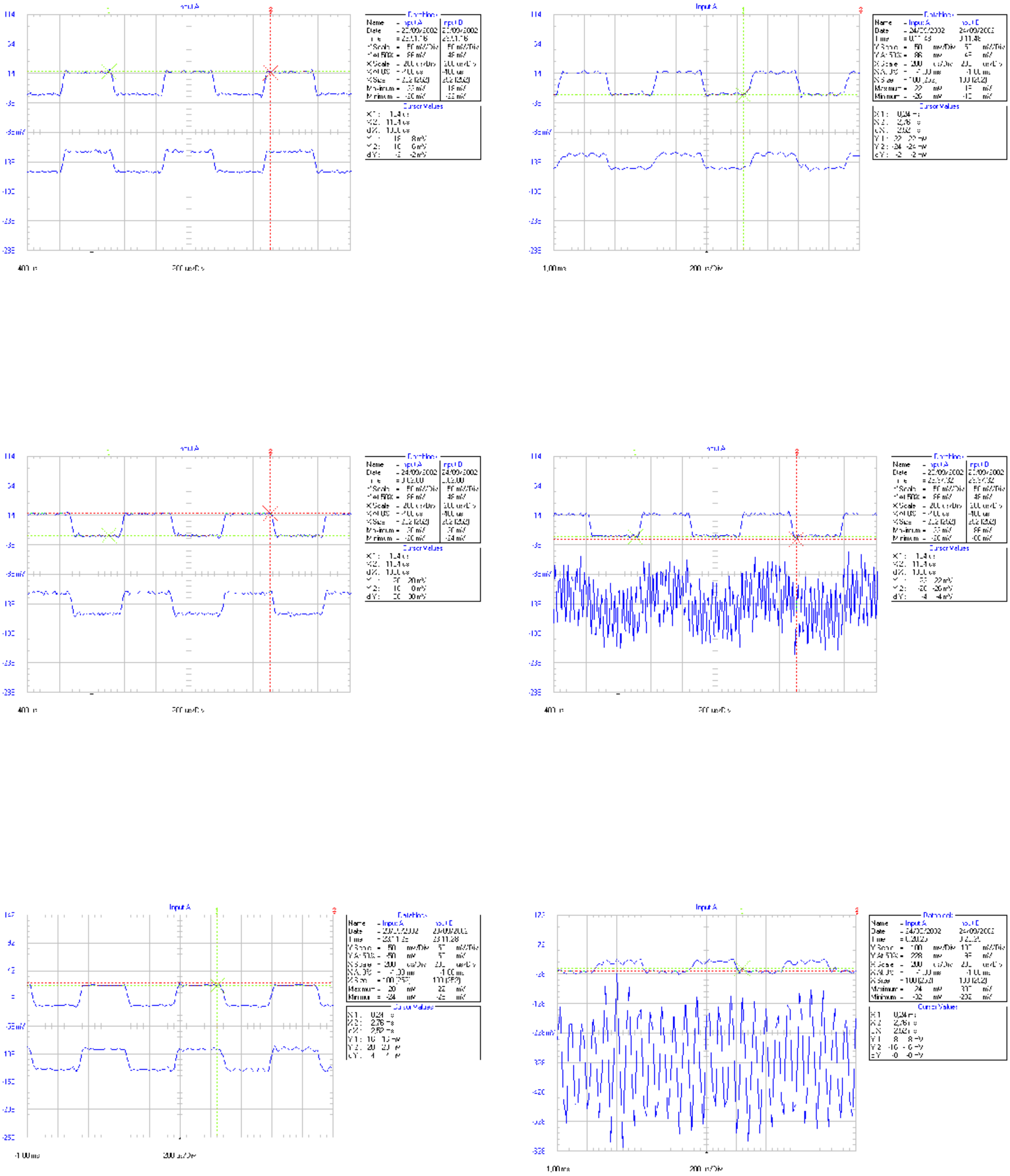

Figure 20

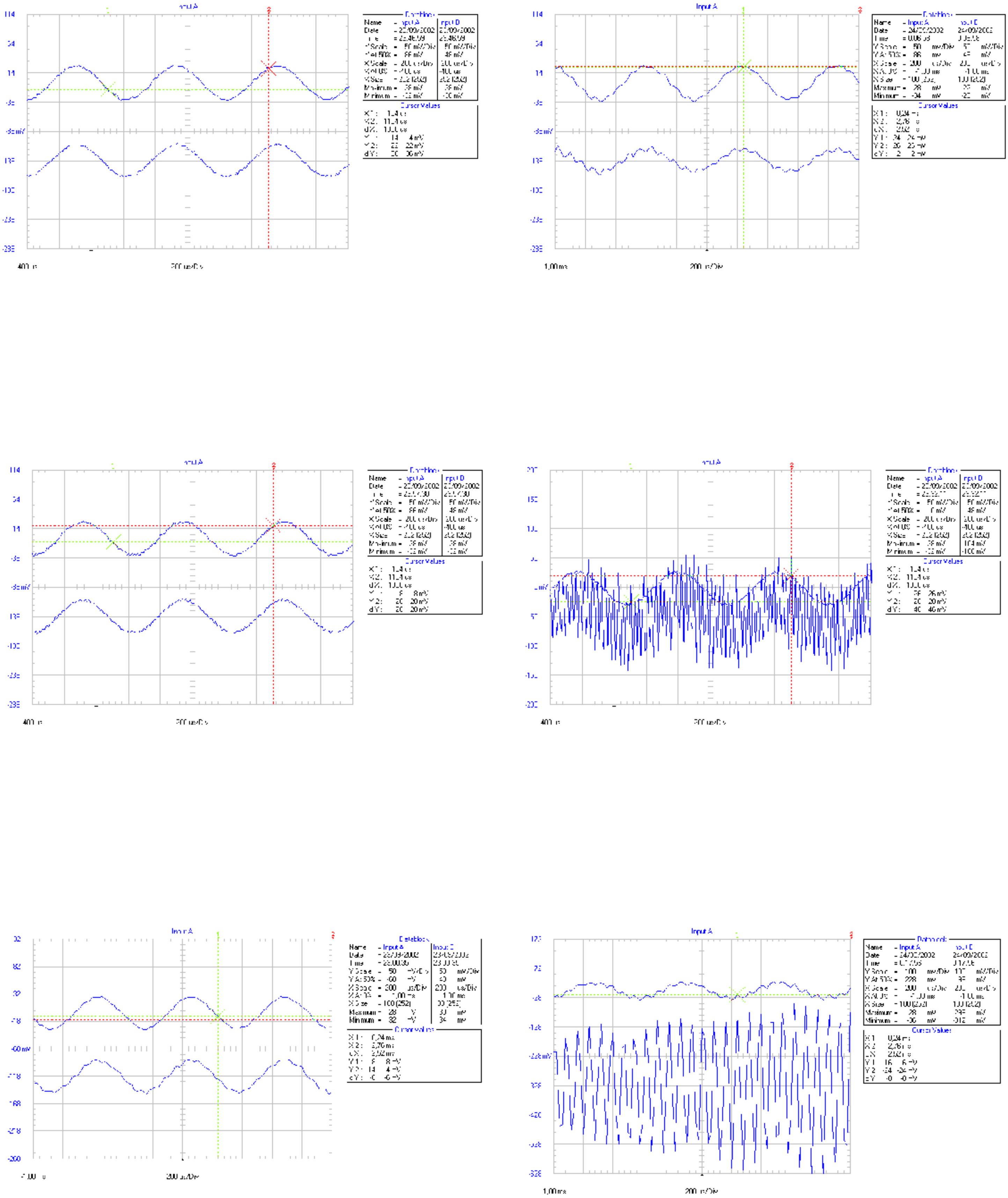
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Figure 21