Max Townshend is the CEO & founder of Townshend Audio, an innovative manufacturing company focused on high fidelity upgrades and electronics founded in 1975. Embracing well-established electronic theory for undistorted signal communication, Townshend has, for the last 40 years, shown that impedance matching in speaker cables matters.

"To Ascertain By Measurement Why Various Speaker Cable Geometries Sound Different"

ABSTRACT

This paper describes a simple experiment to identify the performance of a number of different speaker cables by measuring the "error" introduced into an audio system by each cable, i.e., the voltage drop between the amplifier and the speaker. The signals used are both white noise (https://en.wikipedia.org/wiki/White_noise) and music.

The results show that the principal factor determining the error of a cable is its geometry. Cables with very widely spaced conductors have the greatest error, closer-spaced conductor cables have less error, and very closely-spaced, flat conductor cables have the least, or near zero error. *Townshend Audio's Isolda speaker cable is such a design* the results have been presented both visually and sonically at https://youtu.be/v11hmOE1Vcc.

The experimental method has been described in detail, to enable researchers to repeat the tests in order to verify the conclusions. The results of this experiment may embarrass those cable sound deniers who have hindered the advance of hi-fi for the past 50 years, and hence may allow the quality of high-fidelity sound reproduction to advance.

The Sound of Music – How and Why the Speaker Cable Really Matters

Researched and authored by Max Townshend, BEng.

"This investigation reveals that a major factor determining the 'sound' of a speaker cable is its characteristic impedance, Z_o, which is determined by the cable's 'geometry,' i.e., the way it is constructed. For a 'perfect' cable the Z_o should match the impedance of the speaker load it is driving."
Jack Dinsdale

Jack Dinsdale MA, MSc, sometime engineering professor at Cranfield and Dundee Universities, was co-designer in 1960 of the transformer-less transistor power amplifier, the first of its kind to approach "hi-fi" performance.

1. INTRODUCTION

There is little doubt that speaker cables affect the sound of audio systems. Audiophiles have known this since the 1970s and there has been an ongoing debate ever since. Many explanations have been proposed as to why cables make a difference, but as of now there appears to have been no single consistent explanation.

This report describes a method of testing speaker cables by measuring their characteristic impedance; it then relates this to the way in which they are constructed. This method is consistent with electrical theory and computer simulation.

The paper goes on to show that speaker cables behave as transmission lines, and for correct (distortion-less) transmission of the audio signal from power amplifier to speaker the cable must match the impedance of the speaker load. This analysis clearly describes the cause of audible differences between a range of cables, and the examples included demonstrate this effect.

2. MEASUREMENT

The measurement principle adopted here, shown in Fig 1. was to take a series of cables and examine the signal waveform voltage between the amplifier ground terminal (black) and the speaker ground terminal (black). Ideally, this signal should be an identical version of the signal between the amplifier ground (black) and the live terminal (red) with a reduced amplitude due to the low, but finite, resistance of the cable conductor. The frequency response over the audio band should ideally be "flat" between 20Hz and 20kHz. Any deviation from "flat" should be measurable and will most likely be audible as a tonal change in the audio signal. A number of tests were carried out, using the following basic circuit, Fig 1.

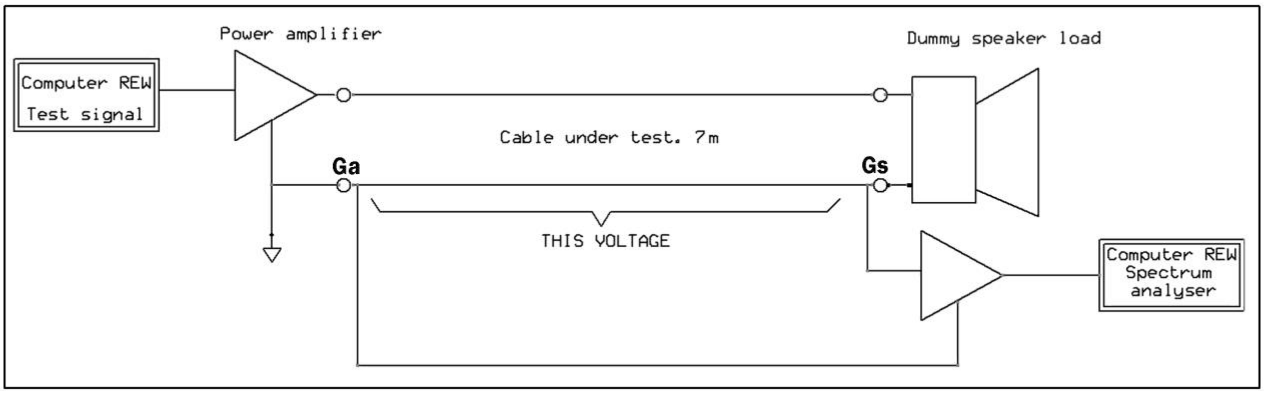


Fig 1. Cable tester simplified circuit.

A standard 7m length of each cable under test was connected as shown, with a power amplifier driving the amplifier end using a switchable white noise or music source, Fig 1. The load end of the cable was connected to an industry-standard 8ohm two-way speaker dummy load, shown in Fig 2.

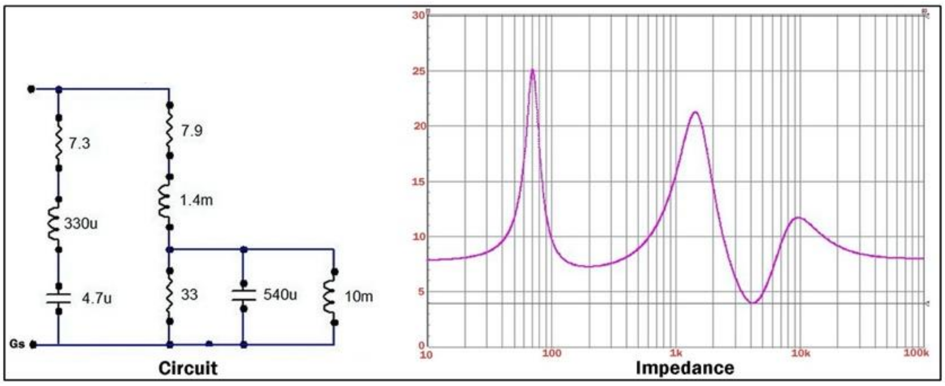


Fig 2. Dummy load.

In the first series of tests the signal voltage between the amplifier ground terminal Ga (black) and the speaker ground terminal Gs (black) was fed to a computer spectrum analyser and to a speaker via a suitable amplifier. This signal was chosen as it shows what is *wrong* with the cable; it is a very low resistance source and the ground reference is ideal. The results, Fig 3, show the frequency responses of a series of cables from 30 Hz to 20 kHz, together with their characteristic impedances Z_0.

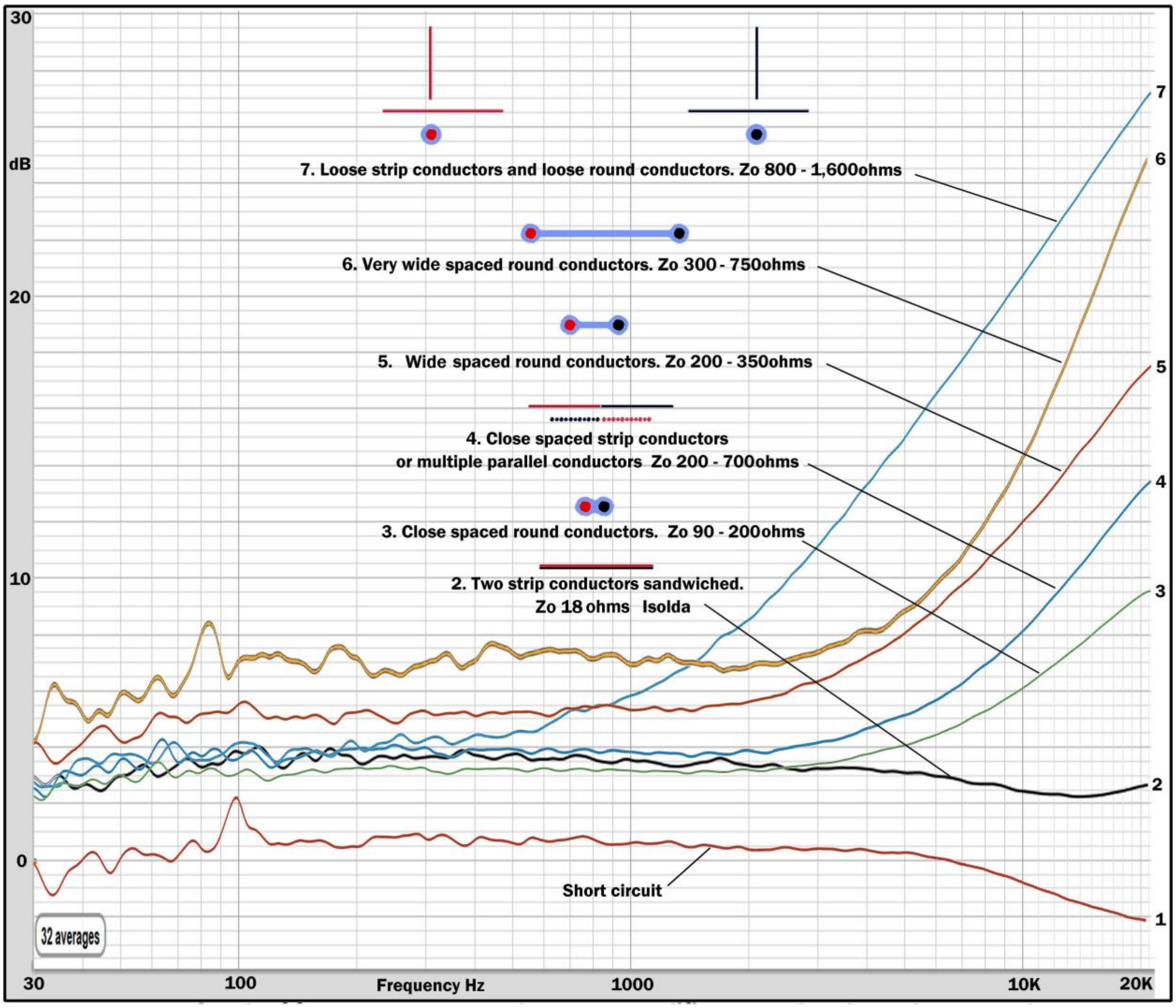


Fig 3. Frequency response of the test cables.

Each trace shows the difference in the voltage between the amplifier and the speaker of each cable. The frequency response should be as close as possible to the short circuit, trace 1 in Fig 3. The basically flat, level response at low frequencies between 30 Hz and 400 Hz is due to the resistance of the cable. The increasing rise in response above 400 Hz is due to multiple reflections caused by the mismatch between the cable characteristic impedance, Z_o and the impedance of the load. Note that the load impedance varies between 4 and 25ohms, which is an approximate match with the 18ohm cable.

- Cable 2 comprises two flat strip conductors separated by very thin insulation and has Z_o between 8 and 20ohms, Fig 4. The response is shown in trace 2, Fig 3.

Fig 4. Isolda cable

- Figure-of-eight, or zip cables, have Z_o between 90ohms and 200ohms, Fig 5, with response as in trace 3 in Fig 3.
-

Fig 5. Figure-of-eight or zip cord.

- Cables with two flat strips side-by-side, or two arrays of parallel conductors side-by-side, have Z_o between 200ohms and 700ohms, giving the response shown in trace 4, Fig 3.

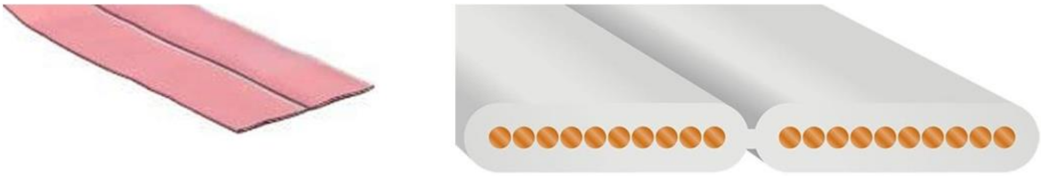


Fig 6. Two flat strips or two parallel bundles.

- Cables with circular cross-section conductors, separated by between 10 mm and 15 mm, Fig 7, have Z_o between 150 and 350ohms with response shown in trace 5, Fig 3.

Fig 7. Two closely spaced round conductors.

- Cables with round conductors very widely spaced at between 20 mm and 50 mm, have Z_o between 300ohms and 500ohms, Fig 8, giving a response shown in trace 6, Fig 3.

Fig 8. Round conductors very widely spaced.

- Cables with two conductors, either round or strip, arranged completely separately from each other have Z_o between 800ohms and 1,300ohms, Fig 9, with response as in trace 7, Fig 3.

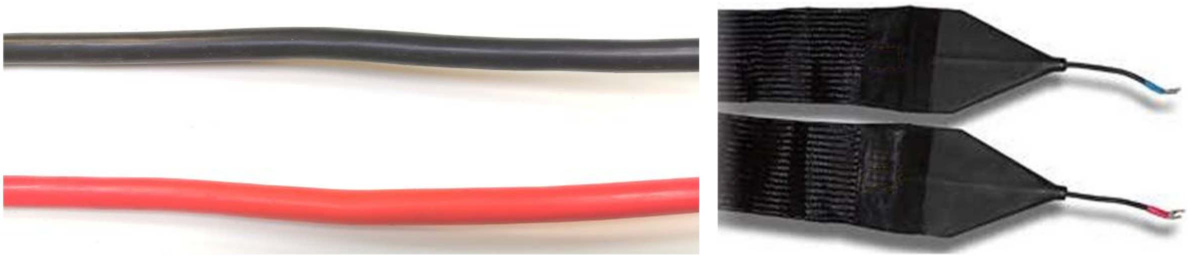


Fig 9. Two separate round or flat conductors.

To illustrate how variations in Z_o affect the sound, a comparison was made between two identical conductor pairs, where the only difference was the geometry. The first cable, Isolda’, comprised two parallel, closely spaced copper strips, 20mm wide by 0.3mm thick, separated by 0.1mm of polyester insulation. This cable has a characteristic impedance, Z_o, of 18ohms. It has very high capacitance and very low inductance (0.01uF, 6.6uH). Fig 10.

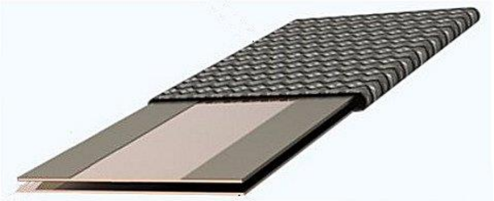


Fig 10. Two flat strips close together, ‘Isolda’.

The second cable comprised two identical Isolda cable strips as above, but in this instance, they were separated by about 300 mm to 500 mm, in two entirely separate bundles, Fig 10. The response of this arrangement, which has very low capacitance and very high inductance (0.000028uF, 49.0uH), is shown in trace 7 in Fig 3, where, Z_o is 1,300ohms.

Fig 10. Two flat strips wide apart.

The different responses of these two cables are shown in traces 2 and 7 in Fig 3. It is important to note that the ONLY difference between two cables is the *geometry* of the two conductors comprising the cables. To listen to the difference, click here: https://www.youtube.com/watch?v=v11hmOE1Vcc

In time order, the white noise samples are: short circuit, resistor equal to one conductor, Isolda, trace 2, Fig 3 and separated strips trace 7. Then music with the same sequence.

Notice how the first three samples, short circuit, resistor and two flat strips, Isolda, Z_o 18ohms, have the same musical balance, whereas the two conductors widely separated, Z_o 1,300ohms, sound bright and edgy, due to the extreme rise in the error at high frequencies.
The longer a high-impedance cable, the greater is the error at high frequencies. The responses of 3.5 m and 7 m lengths of cable 6 are shown in the two traces in Fig 11. The longer the cable, the greater the error.

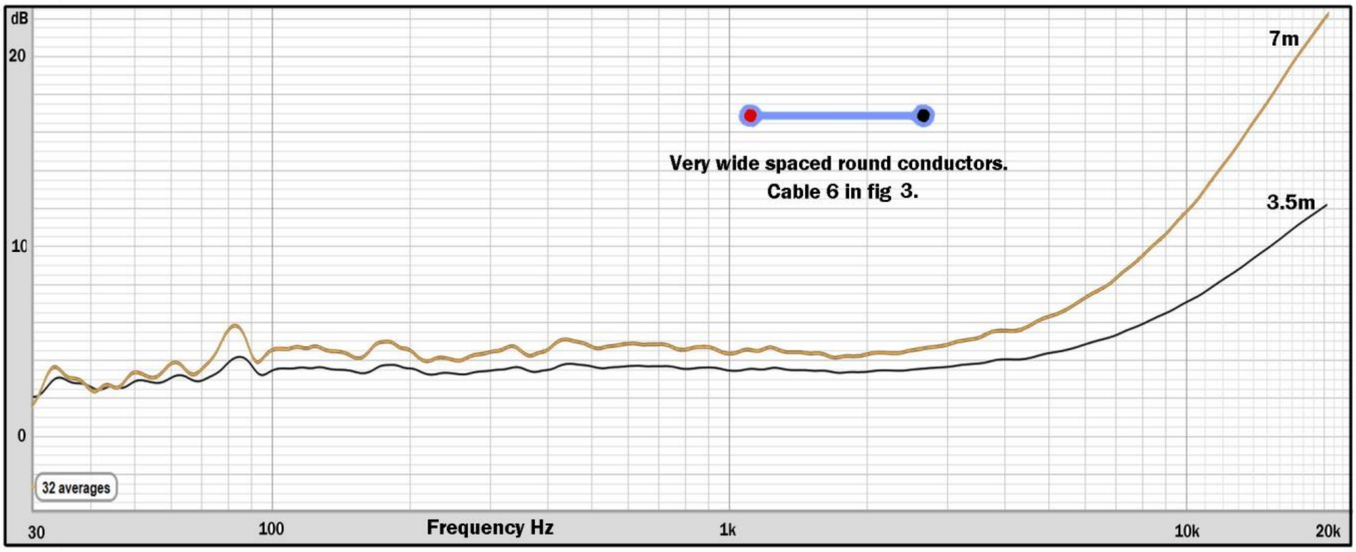


Fig 11. Response of cables 3.7 m and 7 m long with very wide spaced conductors, Z_o 350ohms.

3. WHAT CAUSES THE ERROR?

Transmission line theory states that if the load impedance is much lower than the cable impedance, there will be multiple reflections. See chapter 14, page 483 of:

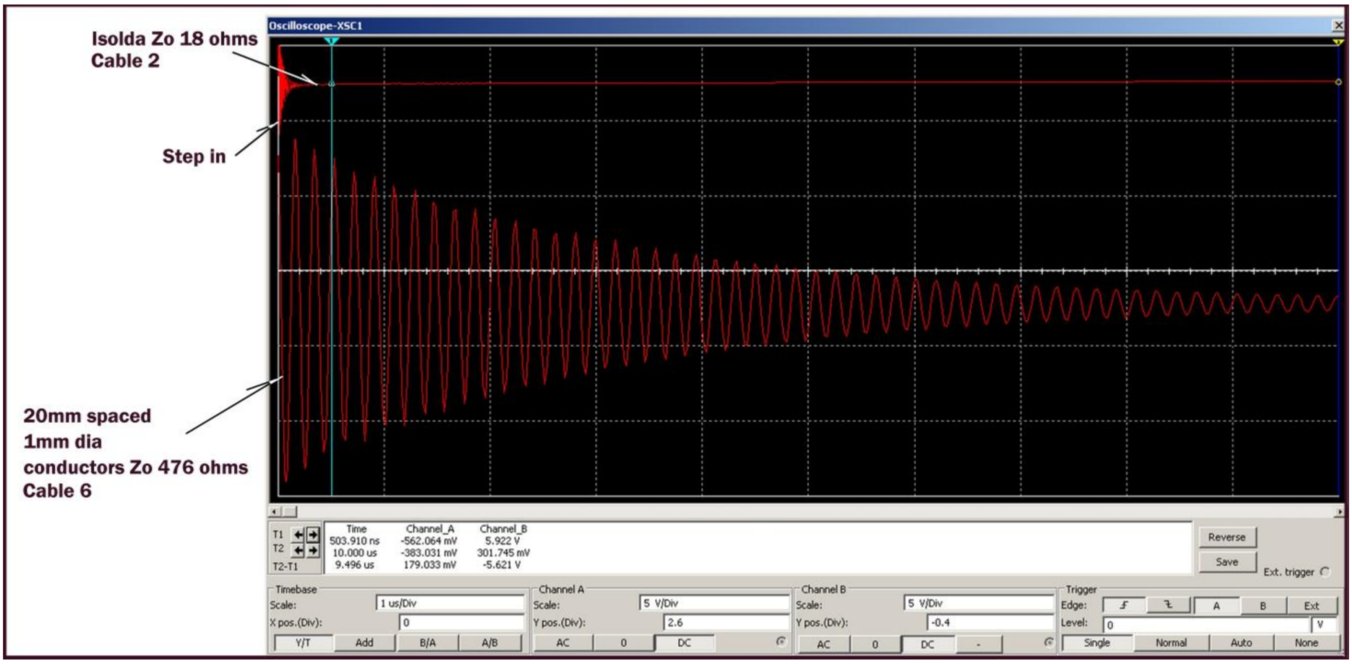
https://www.allaboutcircuits.com/assets/pdf/alternating-current.pdf

The conclusion is that a transmission line's characteristic impedance (Z_0) increases as the conductor spacing increases. If the conductors are moved away from each other, the distributed capacitance will decrease (greater spacing between capacitor “plates”), and the distributed inductance will increase (less cancellation of the two opposing magnetic fields). Less parallel capacitance and more series inductance result in a smaller current drawn by the line for any given amount of applied voltage, which is a higher impedance. Conversely, bringing the two conductors closer together increases the parallel capacitance and decreases the series inductance. Both changes result in a larger current drawn for a given applied voltage, equating to a lesser impedance.

Further, any two conductors in space form a transmission line – even two bits of wet string – and transmission line effects extend down to DC.

4. SIMULATIONS

If there is a close match between the impedance of the cable and the speaker, there will be very few or no reflections. If there is a mismatch, there will be multiple reflections on *every* musical transient. Fig 12 shows a simulation of cables 2 and 6 in Fig 3 for the simplest transient, a step.



Isolda Zo 18 ohms
Cable 2

Step in

20mm spaced
1mm dia
conductors Zo 476 ohms
Cable 6

	Time	Channel_A	Channel_B
T1	503.910 ns	-562.064 mV	5.922 V
T2	10.000 us	-383.031 mV	301.745 mV
T2-T1	9.496 us	179.033 mV	-5.621 V

Timebase
Scale: 1 us/Div
X pos.(Div): 0

Channel A
Scale: 5 V/Div
Y pos.(Div): 2.6

Channel B
Scale: 5 V/Div
Y pos.(Div): -0.4

Trigger
Edge:
Level: 0 V

Fig 12. Simulation, step into load matched and load mismatched.

Computer simulation, using National Multisim 13 software, shows that there are 1,000 or more reflections triggered by the transient when there is an impedance mismatch. (similar results are observed with other software, for example, SPICE).

For cable 6, Fig 3, with Z_o 476ohms, driving the dummy speaker load with a step input from a square wave (the simplest transient) gives rise to severe ringing that has many oscillations. This is due to the transient reaching the mis-matched speaker load where only a small fraction of the signal is absorbed by the load. The remainder of the signal is reflected back to the source (the amplifier) where it is reflected back to the load. Again, only a small fraction of the now-diminished signal is absorbed by the speaker, with the remainder reflecting back to the source and so on. Over time, all the reflections will eventually be absorbed in the load.

Compare that with the high capacitance, low inductance cable (Isolda), where there are no reflections.

It is the multiple reflections generated on *every* transient because of the impedance mismatch that give rise to the error, which appears as an analogue treble roll-off. The higher the characteristic impedance, the greater is the roll-off; the longer the cable, the greater is the roll-off. Double the length, double the roll-off, as shown in Fig 11, for two lengths of cable 6.

5. OSCILLOSCOPE MEASUREMENTS

To verify the results of the simulations, a square wave was fed into cable 3, Z_o 330ohms, and the traces shown in Fig 13 were obtained. The left-hand trace is with a mis-matched load of 10ohms, where ringing is clearly visible. This is similar to the ringing predicted by the simulations. For the right-hand trace, where the load resistance matches the characteristic impedance of the cable, the square wave is nearly perfect with no ringing, again as predicted.

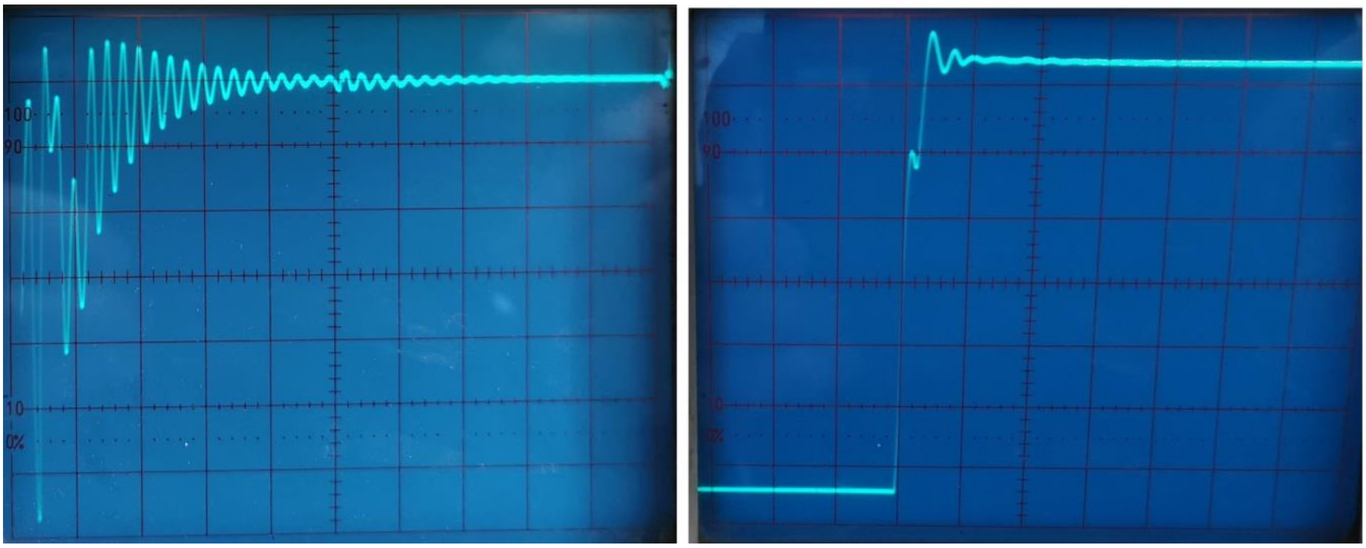


Fig 13. Cable 6, Zo 324ohms into 10ohms (left) and 330ohms (right).

In the next case, Fig 14 the cable is Isolda, Zo 18ohms, driving the 10ohm load.

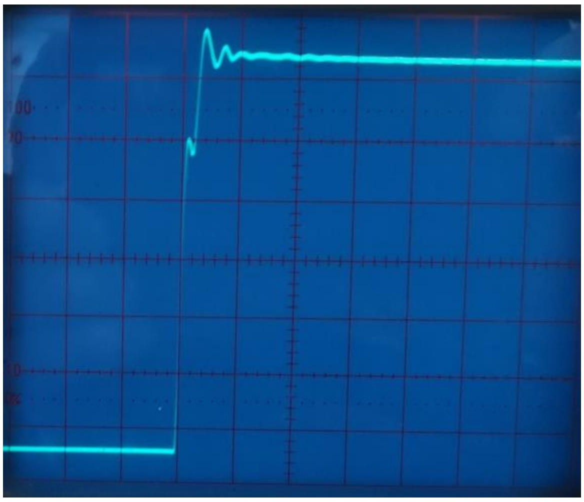


Fig 14. Cable 2, Isolda, Zo 18ohms, driving a 10ohm load.

In this case, there are no reflections and the signal in the load (speaker) is the same as at the amplifier terminals.

With a matched cable and load, the signal is completely absorbed by the load with no reflections. With a mis-matched load, there are continuous, multiple reflections triggered by every change in the music, and it takes time for each transient to be completely absorbed by the load. It is the delayed nature of the absorption of the multiple reflections that gives rise to the high frequency roll-off, clearly shown in Fig 3.

Ironically, the mismatched cables do *not* sound dull, as one would expect because of the roll-off, but they sound bright. This is due to the time-smear caused by the delayed energy release from the multiple reflections. Note that *every* transient should be one single event, not thousands and thousands of events as it is with every music transient when using mis-matched cables. Note that the effect of the reflections may be measured down to 400 Hz with a high-impedance cable as is clearly shown in Fig 3. With impedance-matched cables this does not occur; one transient is transmitted as just one transient.

An analogy is to imagine steady waves from the open ocean arriving at a gently sloping shore where all the energy is dissipated in the white water as heat and sound and there is no back wash or reflected wave. The shore break is effectively impedance-matched to the waves and there is no reflection. The waves just off the shore are the same as the waves further out, as shown in the left-hand picture, Fig 15.

Contrast this with sea waves hitting a solid wall where little energy is dissipated, resulting in the back wave reflecting off the wall. These waves interact with the oncoming waves, and the resultant sea is chaotic, as shown in the right-hand picture in Fig 15. This is analogous to the chaos in speaker cables where there is a mismatch between the cable and the speaker. This chaos is the main reason for the all-so-common brightness and hardness heard in audio systems.

Fig 15. Waves breaking on gently sloped shore (left) opposed to hitting a sea wall (right).

Many hi-fi companies release demonstration tracks which, more-often-than-not, are very simple in structure, such as a guitar and vocal, lone simple piano or simple percussion. This is because the extra brightness, caused by mis-matched cables, may fool the naive listener into believing there is extra clarity since the reflections do not blur the music. However, if complex music is played, such as Mahler's Symphony No. 2, the result is inevitably a disaster.

Since almost all systems use mis-matched cables, they will never sound as clear as a system using impedance-matched cables. Staff at Townshend Audio have known this since 1978 when they introduced the first Isolda cable comprising six 50ohm coax cables connected in parallel to give a characteristic impedance of 8.2ohms. Many customers said that once they had experienced the improvement wrought by impedance matching, it was very hard to go back.

Note that there is traditionally a reluctance to use high-capacitance cables because, in a simple RC [resistor-capacitor] circuit, a high capacitance load will cause a roll-off of high frequencies, but this investigation has found the exact opposite.

Note also that many amplifier designers omit the mandatory 3 microhenry (3µH) inductor at the output of their Class AB amplifier and rely on the inductance of 3.5µH or more of widely spaced cable conductors to stabilise the amplifier. It is common knowledge that this is a cynical ploy to force the customer to purchase their own highly inductive cables. The approach at Townshend Audio is to place a 1.5µH inductor in each leg at the amplifier end of all Isolda cables. This has successfully countered these design faults.

The results of these measurements, both by scientific measurement and by listening tests, would appear to demonstrate conclusively why the various designs of speaker cables sound different from each other. They have also shown that, for a cable to make no difference to the audio signal leaving the amplifier, its characteristic impedance must closely match the impedance of the speaker it is driving.

Details of the test equipment and methods used here have been provided in Appendix A.

6. CONCLUSIONS

This detailed investigation into why speaker cables affect the sound of a high-quality audio system in different ways has reached the following conclusions.

1 The property that most affects a cable's performance is its characteristic impedance (Z_0), *(see definition in Appendix C)* which is determined by its physical construction.

The characteristic impedance (Z_0) increases as the conductor spacing increases. If the conductors are moved away from each other, the distributed capacitance will decrease (greater spacing between capacitor "plates"), and the distributed inductance will increase (less cancellation of the two opposing magnetic fields).

Less parallel capacitance and more series inductance results in a smaller current drawn by the line for any given amount of applied voltage, which is a higher impedance. Conversely, bringing the two conductors closer together increases the parallel capacitance and decreases the series inductance. Both changes result in a larger current drawn for a given applied voltage, equating to a lesser impedance.

2 The speaker cable acts as a transmission line *(see definition in Appendix C)* which, if not terminated by a load (in this case the speaker) with the same impedance as the characteristic impedance (Z_0) of the cable itself, will cause a series of reflections, which have an audibly deleterious effect on the transmitted sound signal.

3 The following notes should be observed:

- With a matched cable, the response does not change with length, so un-equal lengths of speaker cable may be used with no change in the sound.

- With a mis-matched cable, having Z_0 greater than 30ohms, the longer the cable, the higher is the error and to get a balanced sound between channels, the cables must be of equal length, left and right.

- The impedance match does not have to be exact to get very good results. Below 20ohms is fine.

- With a mismatch, of maximum 2 to 1, the performance changes little.

- Commonly found mismatches of around 20 to 60 times, delivers a compromised sound, which is often bright, edgy and lacking fine detail.

- The use of high-resistance wire and very lossy insulation may tame the brightness, but the system will never sound good because the sound is still riddled with reflections.

- The error increases with longer cables. Typical professional speaker cables that have about 10 mm spacing, resulting in an impedance of around 300ohms.

- If the cable is matched to the load, the source impedance is not relevant, as there will be no reflections.

- The output (source) impedance of the power amplifier should be as low as possible, for maximum power transfer to the speaker, as any source resistance will waste power. This is for one-way power transfer, source to load, known as simplex transmission. Do not confuse this with duplex transmission, where signals travel in both directions. Here the source, cable and load impedance must all be the same [as in the case of an] (ancient telephone).

- For low-level interconnect signal transmission, typical cables have an impedance of between 50 and 100ohms and drive a 10 kilohm to 20 kilohm load. There are reflections from the load, but the source resistance is typically the same as the cable impedance, so the reflections will be absorbed in the source resistance and there will be no further reflections. This is known as “back matching” and usually occurs by default in audio and is *de rigueur* in video.

- There is no frequency component in the basic formula for the impedance of a cable, just the geometry.

- High DC resistance results in poor bass performance.

- A high-loss dielectric distorts the electric field which has a second-order effect on the sound. The best practical insulators are air, PTFE and polyester. The worst is PVC.

- Copper purity, cryogenic and [our proprietary] Fractal™ treatments improve the sound markedly.

- All cables have a unique inductance, capacitance and resistance, regardless of how many strands of conductors make up the cable or how fancy is the weave.

- For widely-spaced cables, changing the spacing or coiling alters the capacitance and inductance, which alters the characteristic impedance and hence the sound.

- For closely-spaced cables, there is little or no interaction between adjacent cables or conductive objects.

- For mis-matched cables, the longer the run, the more blurred, brash and brighter is the sound. For matched cables, the sound does not change with length, just a minute drop in the volume of sound due to resistance loss, for very long lengths.

- Townshend Audio Isolda and F1 Isolda have similar geometry and both have Zo of 18ohms, which is typical of the impedance of most speakers above 1 kHz, where it matters most.

Researchers at Townshend Audio have known since the late 1970s that the characteristic impedance, Z_o, is the “elephant-in-the-room” that defines the basic difference in the sounds produced by different speaker cables. If one really wants high fidelity, ignore this at one’s peril. Cable mismatch is one reason why listeners cannot tell the difference between CD and high-resolution music. The other major reason is that external vibration is blurring the sound.
See https://www.youtube.com/watch?v=dW9-r83IvhI&feature=emb_logo

One astute audiophile remarked that utilising the Isolda speaker cable “ended his Alice-in-Wonderland experience with high-end cables” and he is now able to sit down, relax and listen to music.

These measurements and results are expected to be controversial, but critics are invited to duplicate the tests themselves before rushing to judgment.

APPENDIX A: Test Method

For the signal generation and spectrum analysis, Room Equalizer Wizard (REW https://www.roomeqwizard.com/) software was used.

For the computer to analyser, the Focusrite 2i2 Scarlett Solo USB audio interface, Fig 16, was used, connected to a PC.

Fig 16. Focusrite Scarlet Solo 3rd Gen Pro Audio Interface.

The monitor speaker output 1 from the rear of the Focusrite 2i2 was connected to the cable under test. The speaker end of the cable was connected to the dummy load.

Input one was connected to the black/ground/cold end of the cable at the dummy load end. The REW was set to output white noise and the spectrum smoothing was set to 1/6.

To facilitate these connections and to directly compare cables, the Cable Analyser shown in Figs 17 to 19 was constructed.

Fig 17. Cable Analyser.

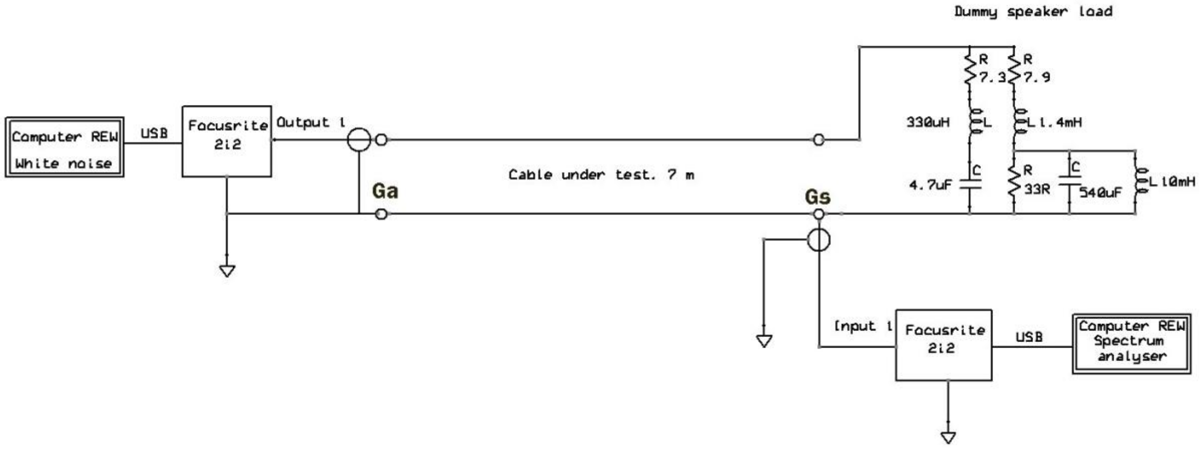


Fig 18. Basic circuit of the tester.

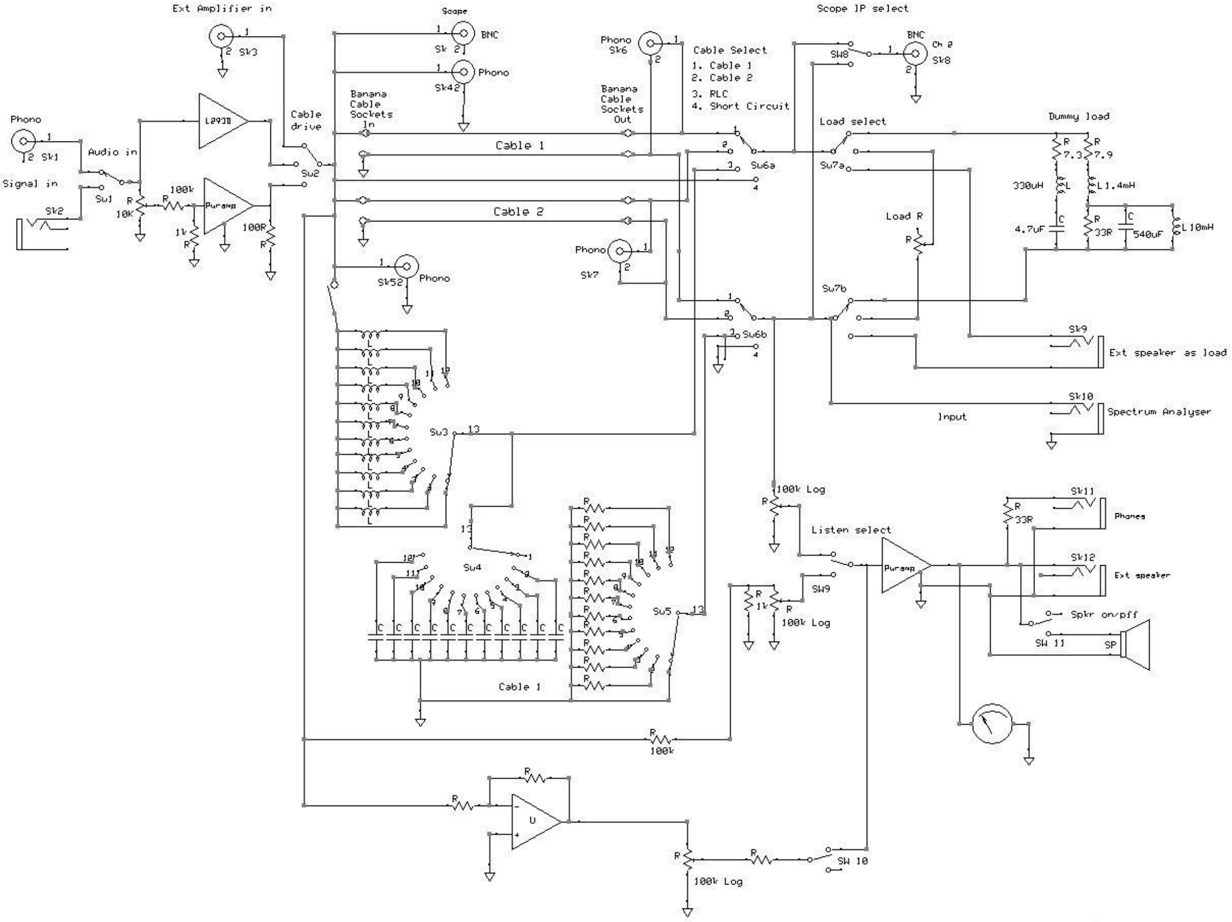


Fig 19. Complete tester circuit.

Cables 1 and 2 are connected in parallel for convenience.

The amplifiers are included to amplify the music and to play the results on the speaker.

The sound on the audio tracks are taken directly from the spectrum analyser output of the Focusrite 2i2.

Alternate Method Using Android Phones

Two Android smart phones with the Audio Tool app (https://play.google.com/store/apps/details?id=com.julian.apps.AudioTool&hl=en_GB) installed may be substituted for the Focusrite Scarlett external soundcard, the REW software and computer. Use one phone as the source, with the signal generator set to white noise, with the headphone output(s) connected to the cable under test. Connect an 8ohm resistor or speaker to the other end of the cable. Use the second phone and connect the black speaker end connection to the microphone input via a 0.47µf DC blocking capacitor. Set the readout to spectrum analyser. Connections are shown in Fig 20.

Nokia, Lenovo mobile		
Pin Number	**Pin Name**	**Description**
1	Tip	Left Audio Out
2	Ring-1	Right Audio Out
3	Ring-2	**Microphone**
4	Sleeve	**Ground / Common**

iPhone, Samsung, Blackberry, HTC		
Pin Number	**Pin Name**	**Description**
1	Tip	Left Audio Out
2	Ring-1	Right Audio Out
3	Ring-2	**Ground / Common**
4	Sleeve	**Microphone**

Fig 20. Connections for 3.5 mm jack.

The effects of the differing cable geometries using this method are quite clear.

APPENDIX B: Three Methods of Deriving Characteristic Impedance

METHOD 1 – Use a VICI DM4070 LCR Meter or Similar

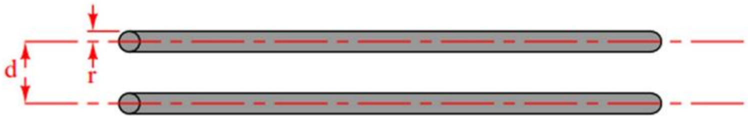
1. Measure the capacitance (C) of the cable with the cable open circuited.
2. Measure the inductance (L) of the cable with the end short circuited.
3. With capacitance in microfarads and inductance in microhenries calculate the impedance by this formula $Z_o = \sqrt{L/C}$ ohms.

The table below shows the results of measuring various lengths of each test cable. (BTW, the length of the cable is irrelevant for this calculation).

Cable	Cable Fig 2	L µH	L µH/m	C µF	C µF/m	Zo ohms	Length m
F1 Isolda	2	9.3	1.3	0.024	0.0034	19	7
Isolda	2	6.6	0.94	0.0109	0.0015	18	7
2 Strips far apart	7	49.0	7	0.000028	0.000004	1300	7
XXXX	5	14.8	2.1	0.0002	0.000028	272	7
XXXX	4	14.9	2.1	0.00024	0.00003	249	8
XXXX		30.6	3.0	0.00015	0.000015	476	10
Jump Leads	7	19.2	3.8	0.0001	0.00002	440	5
Twin & Earth	3	15.4	2.2	0.00056	0.00008	165	7
XXXX	6	14.5	2.0	0.00014	0.000023	324	6
Zip	3	38.2	0.95	0.00407	0.0001	96.8	40*
Polk		18.8	2.35	0.014	0.00017	36.6	8

METHOD 2 – Calculate the Characteristic Impedance

Formula for calculating Z_o



$$\boxed{Z_0 = \frac{276}{\sqrt{k}} \log\frac{d}{r}}$$

Where,

Z_0 = Characteristic impedance of line
d = Distance between conductor centers
r = Conductor radius
k = Relative permittivity of insulation between conductors

This formula is for zero resistance conductors.

METHOD 3 – Measure the Characteristic Impedance

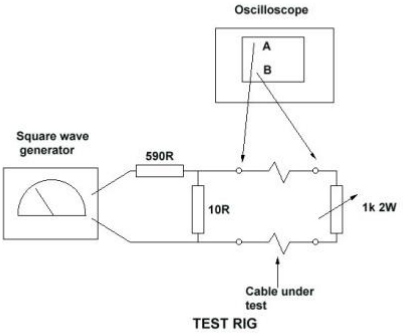


Fig 21. Measuring Z_o.

Connect the cable as shown in the schematic Fig 21. Set a 10 kHz square wave on the oscillator and adjust the potentiometer so that an identical square wave is seen on the oscilloscope at each end of the cable. Disconnect the potentiometer and measure the DC resistance. That is the characteristic impedance, Z_o, of the cable. See Fig 13 and Fig 14 above.

Measure your cable and calculate the Zo then compare it with the cables depicted in Fig 3, to see your cable error.

APPENDIX C: Definitions

Characteristic Impedance

The characteristic impedance is the resistance a cable would exhibit if it were infinite in length. This is entirely different from leakage resistance of the dielectric separating the two conductors, and the metallic resistance of the wires themselves.

- Characteristic impedance is purely a function of the capacitance and inductance distributed along the line's length and would exist even if the dielectric were perfect (infinite parallel resistance) and the wires superconducting (zero series resistance).
- Characteristic impedance (Z_0) increases as the conductor spacing increases. If the conductors are moved away from each other, the distributed capacitance will decrease (greater spacing between capacitor “plates”), and the distributed inductance will increase (less cancellation of the two opposing magnetic fields). Less parallel capacitance and more series inductance results in a smaller current drawn by the line for any given amount of applied voltage, which is a higher impedance.

- Conversely, bringing the two conductors closer together increases the parallel capacitance and decreases the series inductance. Both changes result in a larger current drawn for a given applied voltage, equating to a lesser impedance.

Transmission Line

A transmission line is a pair of parallel conductors exhibiting certain characteristics due to distributed capacitance and inductance along their length.

- When a voltage is suddenly applied to one end of a transmission line, both a voltage “wave” and a current “wave” propagate along the line at almost the speed of light.

- If a DC voltage is applied to one end of an infinitely long transmission line, the line will draw current from the DC source as though it were a constant resistance.
-
- A reflected wave may become re-reflected off the source end of a transmission line if the source's internal impedance does not match the line's characteristic impedance. This re-reflected wave will appear, of course, like another pulse signal transmitted from the source.

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Acknowledgments

Jack Dinsdale MA, MSc, sometime engineering professor at Cranfield and Dundee Universities, was co-designer in 1960 of the transformer-less transistor power amplifier, the first of its kind to approach "hi-fi" performance.

Further Reading

Richard Black: Cable theory for sceptics
Richard Black website: https://crosseyedpianist.com/2013/03/27/meet-the-artist-richard-black-repetiteur/

Impedance matching Deletraz paper
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SOME CABLE SOUND DENIERS

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