Resistance, Impedance, Damping factor, Cables.

Impedances and resistances are not the same but are closely related.
A **resistance** is a **constant value** that does not alter with varying frequencies or power. The current flowing through a resistance has a linear correlation to the voltage across the resistor.

An **impedance** is a **varying resistance** which differs in value for various frequencies and thus the current does NOT have a linear relation to the applied voltage.
The current can also have a different **phase** relation to the applied voltage.

The **damping factor** is the number you get when the load resistance (headphone impedance) is divided by the output resistance of the amplifier **(R_{LOAD} / R_{OUT})**. It is said that the higher the damping factor is, the more 'grip' the source has on the transducer (driver/speaker).

Cables have resistance, capacitance and inductance and above certain frequencies have an impedance.

Headphones are specified to have a certain 'Ohmic' value, but in reality most have an impedance, some headphones have an almost 'resistance' alike behavior though.

The DC resistance of the **voice-coil** is, in most cases, equal to the impedance around 1kHz and is specified in Ohm(Ω). You can measure this resistance with a multi-meter in the 'Ohm' setting.
The test current of most multi-meters is very low so the driver won't be damaged when you measure it.

Loudspeakers usually are specified to have impedances between 4Ω and 8Ω but may have impedances as low as 1Ω and as high as 100Ω in certain cases on specific frequencies. This may be caused by badly designed crossover filters in such loudspeakers.
The impedance of most speakers will not drop much below their rated impedance, but can increase to several times that of the nominal value at a certain frequencies.

The majority of headphones does not have crossover filters as there is only one driver, so the impedance will always be higher than the Ohmic resistance.
Some balanced armature (in-ear) headphones with multiple drivers can have impedance rises and drops at other parts of the frequency spectrum as 'normal' headphones.
Ortho-dynamic headphones usually have a very linear (flat) resistance, this has to do with their construction.

***In short*:**

Headphones and **loudspeakers** have **impedances** (i.e. varying resistances dependent of the frequency).
Amplifiers have **constant** output **resistance** (within the audible range).
All headphone amplifiers have a certain output resistance, which mostly are NOT specified in the spec sheets.
In most cases only the range of headphones that can be used is mentioned, for instance: 16 Ω - 600Ω or 32Ω - 300Ω or 16Ω - 64Ω.
The output resistance of the amplifier/source, however, **CAN** influence the sound signature of the used headphone, in some cases more then in others. The cause of all this is the **varying impedance** of a headphone in relation to the fixed resistance of an amplifier.
The **reason** for this is nothing more than **voltage division**, the **damping factor** says something about the relation between these 2 values.

In general:

Low impedance headphones (16Ω to 50Ω) with considerable rises in its impedance (above a factor 2) usually are designed to be driven from low output resistance amplifiers will sound best on those amplifiers. Low impedance headphones that only have small variations in their impedance don’t change their sound signature much with higher output resistances and might even **sound** better on higher output resistance amplifiers, certainly if they are designed to be driven with a higher output resistance.

For medium impedance headphones (60Ω to 120Ω) the influence of the output resistance is less obvious and more subtle. Again some headphones may sound better from low Ohmic amps, other headphones may sound better from higher Ohmic amps.

Higher impedance headphones (150Ω to 600Ω), also depending on the rise of the impedance in certain areas again may sound better on higher output resistance amps where other models may sound much better when driven from low output resistance amplifiers. There is no rule that dictates which headphone sounds best from what impedance.

The generalization that all headphones sound best from a low output resistance amp are simply **NOT true**.

Why do some headphone amplifiers have a higher output resistance?

They are there to **protect** low impedance headphones from receiving **too much current** and thus too much power which could potentially destroy certain headphones. They act as cheap current limiters. This could be needed when the amplifier section must also deliver higher voltages (above $5V_{RMS}$).

Can headphones be destroyed by some amplifiers ?

Headphone drivers have extremely thin wires in their voice-coils because the driver membranes need to be extremely lightweight to be able to reach the highest frequencies without much problematic behavior.
Thicker copper wires means more weight, which adds weight to the whole diaphragm construction. This construction should be as lightweight as possible to move exactly to the applied electrical voltage.
Thin wires also means they cannot handle much current. They will glow like a light bulb, burn out or get loose from the material they are wound on. This can cause the drivers to distort or fail if they receive too much power.
Most dynamic headphones (certainly not all) are specified to have a power handling capacity somewhere between 50mW and 200mW regardless of their impedance. They can easily handle short peak values that are several times higher though.
Music signals aren't continuous but are varying constantly in amplitude with most of the electric energy being in the lows to lower-mids.
Above the specified power most headphones do not react linear anymore meaning the excursions of the diaphragm do not accurately follow the applied electrical signal anymore, but are smaller then 'expected'.
A form of soft-clipping/distortion/compression.

Output stages of most (solid state) headphone amplifiers provide an output **voltage** and have an output resistance of around 0Ω (between 0Ω and 1Ω in general). Headphones exist with quite different nominal impedances ranging from 16Ω to 600 Ohm nominally. This would result in considerable different power levels when the same voltage is applied.
High impedance headphones will draw a **low current** at the maximum **output voltage** of an amplifier.
Low impedance headphones, however, will draw a **high current** at the same maximum **output voltage** if there were no output resistors or some other form of current limiting present. To ensure different impedance headphones ALL receive an about equal amount of maximum output power current limiting is needed and the cheapest way to do this is by adding an output resistor.

Ohms law:

U(Volt) = **I**(Amps) **x R**(Ω) shows the relation between voltage, current and resistance.
P(Watt) = **U**(Volt) x **I**(Amps) which shows the relation between power, voltage and current.
Power can also be calculated with the equation: $P=I^2 \times R$ or $P=U^2/R$ when these laws are combined.

Some math:

10V output voltage on a **300Ω** (high impedance) headphone will result in a current of 10V/300 Ω = **33.3mA**.
The output power can be calculated as: 10V x 33.3mA = **330 mW**.

10V on a **32Ω** (low impedance) headphone will result in a current of 10V/32Ω = **312mA**, calculating the power gives 10V x 312mA = 3,125 mW (**3.125 W** !) in case there is no current limiting.

This level may certainly burn out the coils of most headphones in an unguarded moment as most can only handle about 200 mW (0.2 W) max.

The same amplifier as mentioned above BUT with a 120Ω output resistance fitted in it's output path will result in the following output powers.
For high impedance headphones: 10V / (120Ω + 300Ω) = **24 mA**.
Because of the **voltage division** which occurs the voltage on the headphone is no longer 10V but only a certain percentage of it.
The voltage across the load (headphone) can be calculated as $U_{HP} = U_{OUT} \times (R_{HP}/(R_{HP}+R_{AMP}))$.
The calculated **power** in this case will be: $(24mA)^2 \times 300Ω$ = **173mW** which cannot destroy high impedance headphones.

For low impedance headphones: 10V/(120Ω + 32Ω) = **66mA**.
The power can be calculated by: $I^2 \times R$ so $66\ mA^2 \times 32$ = **139 mW** which cannot destroy the low impedance headphones.

In this example it is shown that an amplifier fitted with a certain output resistor will always provide about the same maximum output POWER into different impedance headphones without the risk of destroying low impedance headphones.

Why was a 120 Ω used in the example ?

This value has been set as a 'standard value' and is described in the 1996 **IEC 61938** standard.
How many manufacturers use this (old) standard is unknown.
The sound of these headphones has been 'tailored' to sound correctly (as intended by the manufacturer) when an amplifier with this (120Ω) output resistance is used.

The relation between power supply voltage and output voltage

Roughly, the output voltage in V_{RMS} (Root Mean Square) is about 1/3 of the total power supply voltage used in the amplifier design (provided no output transformers are used).
An amplifier with a single 9V battery can thus deliver about $3V_{RMS}$.
An amplifier with a single voltage rail of 24V can deliver $8V_{RMS,}$
A dual voltage supply rails of +15V and -15V (total 30V) can thus deliver $10V_{RMS}$.

An MP3 player (or other battery operated device) with a (rechargeable) Lithium battery for instance only has 3V available so can deliver max. 1V, provided they don't use an internal DC/DC voltage converter (booster) to create a higher voltage.
It is obvious different amplifier designs can/will have different maximum output voltages and thus also output powers depending on the circuit used and the supply voltage(s).

Why are output resistances of some amplifiers lower in value, say 30 to 50 Ohm ?

This has to do with the maximum output voltage that the amp can deliver (without a load).
The output voltage that an amplifier can deliver is dependent on the power supply voltage and output stage configuration.

IF the maximum **output voltage is low** (several Volts) it will not be able to deliver serious power into high impedance headphones (remember **$P=U^2/R$)**, but CAN deliver enough power in low impedance headphones.
Low output voltage amplifiers (9V C'Moy's or portable players for instance) therefore don't need current limiting resistors in the output path as the current can never be very high. These amplifier designs are therefore mostly low resistant in the order between 0.01Ω and 10Ω in general.
High output voltage amps can drive high and low impedance headphones to about equal power via a series resistor.
Amplifiers with a **medium output voltage** therefore often have a resistance between 10Ω and 50Ω so they can drive low impedance headphones with sufficient power as well as higher impedance headphones.

Impedance matching ?

The part above has shown what output resistors are used for in headphone amplifiers (current/power limiting).
These output resistances thus have **nothing** to do with impedance matching as is often mentioned in forums.

Impedance matching is **only needed** for very high frequency signal transfer (FAR beyond the audible range and way above 100kHz) with cables that have a similar impedance as the in and output resistances of the source and receiving end (mostly 50 or 75Ω). Connections that DO need impedance matching are digital links (SPDIF), data transfer links, video and radio/TV frequencies.
Impedance matching is **NOT** needed **nor applicable** in the entire audio range, even up to 50kHz.

In short:

1: The output impedance does **NOT** have to **match** the impedance of the headphone NOR is this desirable.
2: Output resistors are used to **limit** output currents/powers to protect low impedance headphones when amps can deliver higher output voltages (say above $5V_{RMS}$).
3: Output resistor values are dependent of the range of suitable headphones and maximum **output voltage**.
4: Current limiting can also be done in other ways but **using a resistor is simple and cheap**.
5: Needed if the manufacturer of the amplifier wants to **meet** the **IEC 61938 standard** (120Ω)

Why are there so many different headphone impedances ?

Low impedance headphones are designed to be used with **portable equipment**, which does **not** have a **large output voltage** swing. These headphones are thus optimised for usage with portable equipment.

High impedance headphones are designed to be used with **higher output voltage** amplifiers (**desktop or studio**). High impedance headphones can not be driven to a reasonable SPL from lower voltages and are thus not suited for portable usage unless an extra amplifier is used that CAN deliver a considerable higher output voltage.

Because high impedance headphones draw **less current** at the same power level compared to low impedance headphones, the voice coil wire can be **thinner** which means **lighter in weight**.
This can result in a faster transient response and a wider frequency range. Higher impedance versions of the same headphones have been reported to sound more refined for this reason.

Is the sound affected by different output resistances ?

The answer is **YES**, how **much** the sound is affected depends on a couple of variables.
The value of the output resistors in the amps, the impedance of the headphone and above all how **much** this impedance **varies** with over the entire frequency range.

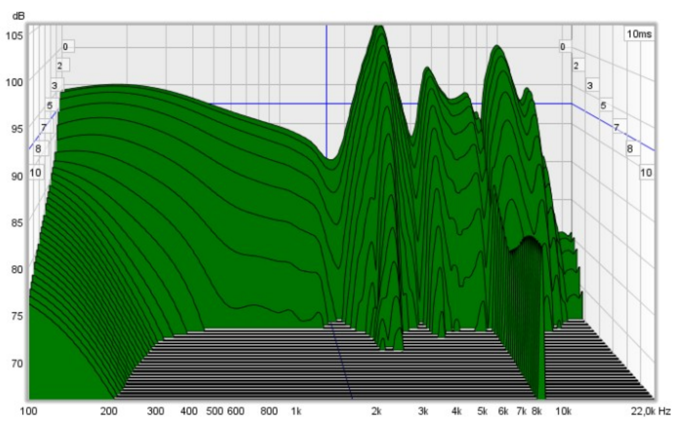
IF the headphone is optimized to comply to IEC 61938 it is essential to drive this headphone from a higher output voltage amplifier with an output resistance of 120Ω in order for it to sound as intended by the manufacturer. Failing to do so, driving it directly from a low voltage/output resistance amplifier, will result in a tonal balance that is not as intended. In most cases this could mean the headphone will lack in bass quantity ot have too much treble (relatively).

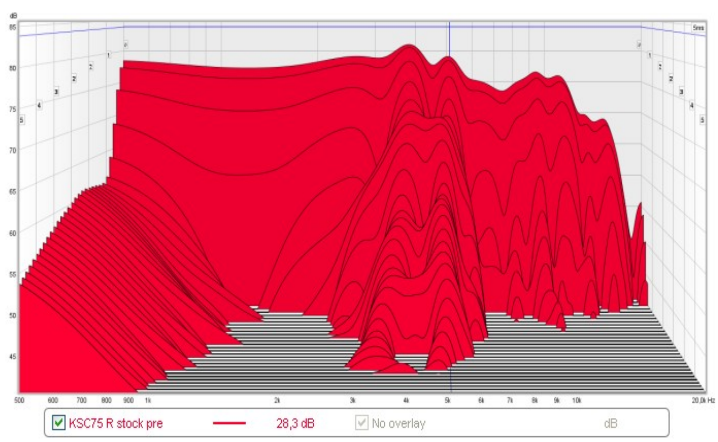
Headphone as well as amplifier manufacturers strangely enough rarely mention anything at all about the optimal output resistance of amplifiers or if it meets a specific standard yet is a sound determining factor.

How MUCH does the output resistance of an amplifier influence the sound?

The impedance for low frequencies is mostly determined by mechanical properties of the driver.
Everything in nature wants to vibrate on their preferred frequency or even on multiple preferred frequencies.
When these resonance point(s) is/are neared, or reached, there is less power needed to get the same excursions as would otherwise be needed, as the driver also acts as a generator at this point it generates a 'counter voltage'. The higher this counter voltage is the less current is needed. Ohms law states that the resistance is voltage / current and since the applied voltage is constant (from a 0 Ohm amplifier) and less current is drawn (because of the counter voltage that is subtracted from the applied voltage) the 'resistance' (more accurately impedance) increases at that point.

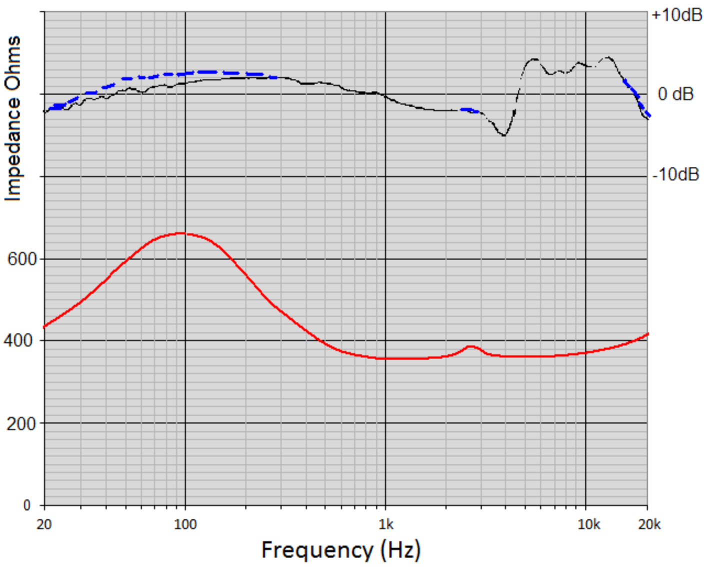
So at resonance frequencies (the resonance point of speakers as well as headphones) the impedance becomes higher.
This can also happen at higher frequencies (somewhere in the midrange) if the driver has certain resonance points.
These can be seen as **little peaks/bumps** in the **impedance plot** and shows the driver **resonates** at this frequency. This is not a good thing in general but may not make it sound bad. This would depend on several other properties of the driver, the frequency at which it occurs and how 'broad' that part of the frequency band is and the severity of the resonance. This can be seen in CSD or waterfall plots. The longer the resonance lasts the worse it is in general. Below a picture of vary narrow-band ringing around 8.5kHz on the left and on the right broader but shorter lived resonances between 3kHz and 6kHz. The narrow one is longer lived but very narrow and may not be obvious in certain music but can give an 'edge' to other types of music.
Broader resonances above 6kHz often dilute finer details in music. Around 3-4kHz the ear canal also resonates so these resonances may not be that obvious.

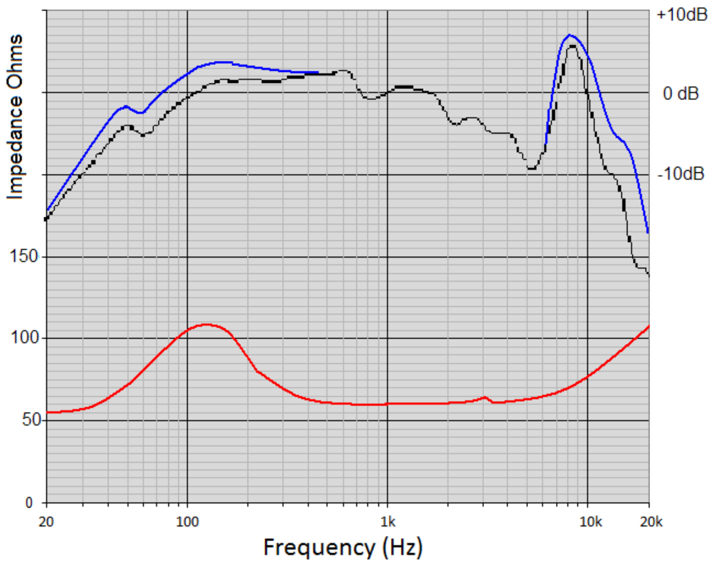




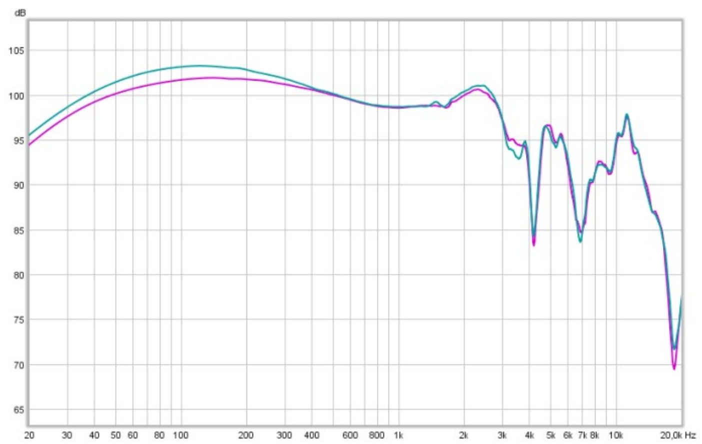
What are the sonic consequences of output resistances ?

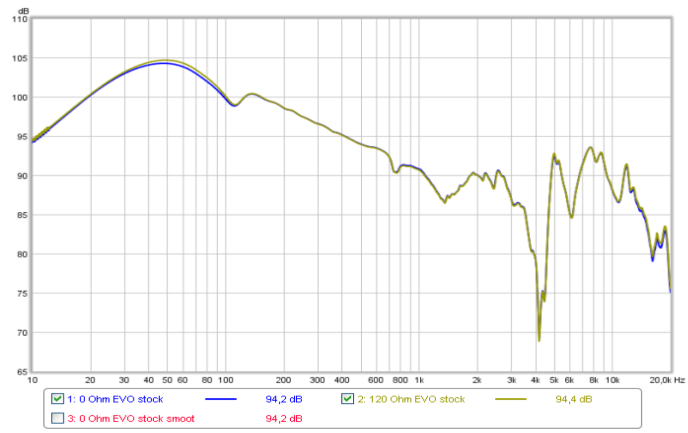
The influence of a **120Ω output resistance** on the frequency plot of various headphones is made visible. The red trace is the impedance plot, the black trace is the measured frequency response (*assuming a low Ohmic amplifier was used to create the frequency plot*) and the drawn blue lines represent the expected changes in frequency curve. Because of sonic properties the lows in general should have an amplitude about 5dB higher than the middle of the graph (300z to 3kHz) to sound realistic.
2 examples of the effect of a 120Ω output resistance amplifier on the frequency spectrum of 2 headphones. On the left the **Sennheiser HD800** (300Ω) and on the right the **AKG K271-II** (60Ω). How much influence is there depends on the impedance of the headphone itself, how much this impedance varies and the ratio between the output resistance and the impedance. The bigger the output resistance the bigger the sonic effect will be (when the impedance varies)





Below on the left a measurement of the 60Ω Koss KSC35 driven from 0Ω and driven from 120Ω. The bass response is increased by about +1.5dB which is just audible.
Below on the right the 32Ω Superlux HD681-EVO driven from 0Ω and driven from 120Ω. The influence is negligible because the impedance doesn't vary that much. This shows not all headphones sound that much different from higher output resistance amplifiers.

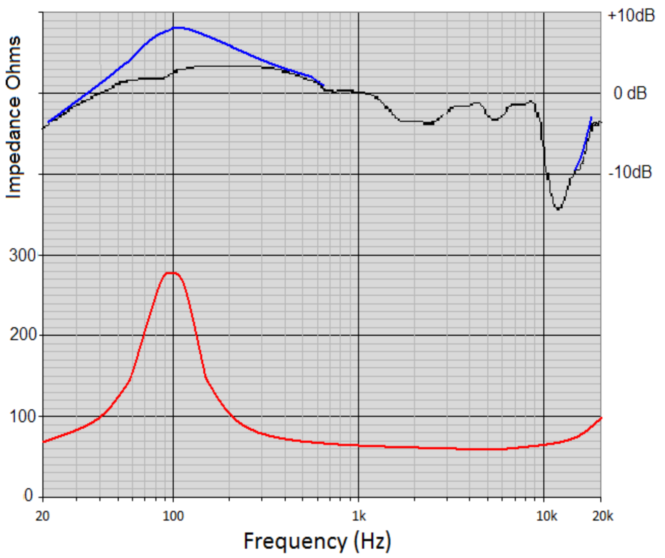




What can be observed is the (wide) hump in the 100Hz region of the **Sennheiser HD800,** which almost doubles in impedance around that frequency, to well above 600Ω. The impedance rises again at frequencies from 10kHz and up. At 20kHz the impedance is already 450Ω. The rise in the impedance above 10kHz is not due to resonances but is caused by the **inductance** of the voice-coil that starts to play a role as well as the mechanical properties of the membrane.

The AKG K271-II is a low impedance headphone and has considerable less bottom end frequencies and highs as well, when used with a low Ohmic amplifier. The blue line shows how the graph alters when a 120Ω output resistance is used.
It is obvious that lower frequencies are more present and the highs extension is also better. This headphone may well be perceived as 'better sounding' when driven from a high output resistance amplifier.

Orthodynamic (planar) headphones usually have an impedance characteristic that is as good as resistive and looks like a straight line due to their construction (there is no voice-**coil**) and is, beside the obvious drop in SPL due to voltage division, not affected in the frequency domain nor is the **damping factor** of any importance in these types of headphones. Maximum power levels, however, are restricted when driven from higher output resistance amps. For ‘dynamics’ reasons and the much higher power handling capacity the Ortho-dynamic headphones can best be driven with low output resistance amplifiers that can provide a high voltage and deliver a high current.



Some headphones **don’t react well** to higher output resistances. Examples are the Sennheiser HD555, HD595 and HD598 for instance. It’s impedance rises from **60Ω** to **270Ω** at 90Hz which will give an increase of over **6dB** around 90Hz, making it sound **bloated** and **fat**. This headphone really needs a low Ohmic source. These headphones are **clearly** designed to be driven from low output resistance amplifiers and portable equipment.

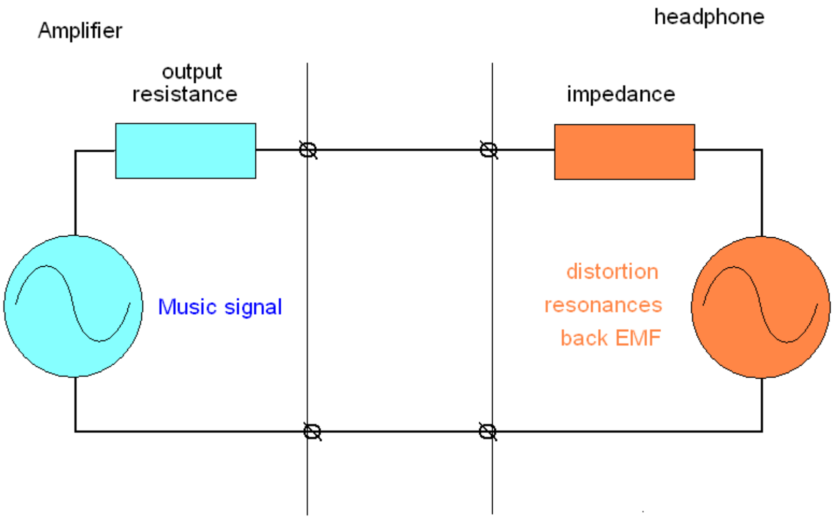
Headphones that have a 'bathtub' type frequency graph (boosted highs and lows) might benefit from a low output impedance amplifier as well, because the bass will be reproduced lower in level which will make the bass sound tighter which isn't a bad thing for these types of headphones. Of course this is also depending on impedance plot, taste and preferences.

What about the damping factor ?

The damping factor is the number you get when the load resistance is divided by the output resistance (R_{LOAD} / R_{OUT}). It is, more often than not, mentioned as being very important for the sound quality and must be as large as possible. This means the R_{OUT} must be as low as possible. Also with headphones this is said to be of great importance and as the R_{LOAD} is relatively high large numbers can be published which looks 'impressive'.

When a coil that is situated in a magnetic field and that coil has a CURRENT flowing through it will move. This is the principle a dynamic driver is based upon. It moves as dictated by the (audio) current. Amplifiers are VOLTAGE sources and the excursion of the membrane 'follows' that applied voltage. The current is determined by the applied voltage and impedance of the headphone+output resistance of the amplifier.

It also works the other way around. When a coil moves inside a magnetic field it generates a VOLTAGE. A dynamic microphone works this way. Each 'generator' has a resistance. An amplifier is also a generator with its own output resistance. In reality there are 2 voltage generators and 2 series resistances coupled together. The output resistance of the amplifier and the voice-coil resistance.

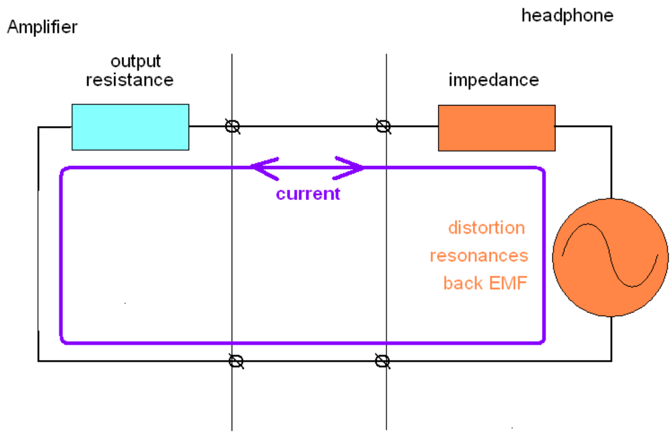


The illustration on the left shows how these circuit components are tied together (one channel).
The left part is the amplifier section where the music signal is a 0Ω amplifier and the blue resistor is the output resistance. That could have a value between 0.01Ω and 120Ω for instance.

The right part is the headphone driver. This generates back EMF (Electro Motor Force) the part that increases the impedance. It generates electrical voltages that are not present in the applied signal. Those voltages are harmonics (the distortion the headphone itself creates) and resonances.

As can be seen in this illustration everything is in series which means there is only 1 current path. The current in all components is thus the same and is determined by the **2 voltages added / 2 resistances in series.**
To electrically 'damp' a mechanism there needs to be a current. This is easily demonstrated by a car running stationary. When something in the car that requires a lot of electricity is switched in (rear window heater, headlights etc.) you can hear the engine drop revs or having to work harder as the generator in the car 'damps' the engine.

The same is true for a loudspeaker or headphone driver. The circuit as 'seen' by the headphone itself is shown on the right. The amplifier signal itself is left out to make it clearer.
As the amplifier itself is 0Ω it can be substituted for a short, seen from the driver side.



When the output resistance is close to 0Ω the current that can flow is solely determined by the generated signals from driver and the voice-coil resistance (orange 'impedance resistor).
Most people, however, including many EE's seem to forget that voice-coil resistance is there and assume that the generated voltage is completely 'shorted' by the amplifier load and thus the damping current is VERY high when the amplifier is close to 0Ω.
In which case it would make sense to have really high damping factors of 100 or even 1000 or more !

Alas the reality is the voice-coil resistance is always there and is the major contributor to determining how much of the unwanted movements of the driver is electrically loaded/damped/braked by the current.

It is important to realise the part that **does the damping** is the **CURRENT** and NOT the **VOLTAGE** across the output terminals of the amplifier.

So how important is this damping factor in reality ?

The impedance of the driver is **300Ω** and the output resistance is **0.01Ω**.
When we calculate the **damping factor** we get an impressive number of **30,000** !

For a higher output resistance of 10Ω the damping factor numbers are less impressive.
The impedance of the driver is **300Ω** and the output resistance is **10Ω**.
When we calculate the **damping factor** of **30**, still well above 10 though.

For an even higher output resistance of 100Ω the damping factor numbers are less impressive.
The impedance of the driver is **300Ω** and the output resistance is **100Ω**.
When we calculate the **damping factor** of **3**.

The damping factor numbers differ enormously from 30,000 to 3 so one would expect the higher number to have MUCH more electrical damping.

Lets say the generated signal is **1V** and consists of a pure sine-wave, just to make the math simpler.
As can be seen above the current (that does the actual damping) is determined by the generated voltage divided by the driver voice-coil resistance + output resistance, as these are in series.

For the combination with a damping factor of 30,000 the actual damping current = 1V / 300.01 = **3.33mA**
For the combination with a damping factor of 30 the actual damping current = 1V / 310 = **3.23mA**
For the combination with a damping factor of 3 the actual damping current = 1V / 400 = **2.5mA**

In reality there isn't much difference in damping current at all. Between a damping factor of 30,000 and 30 the current is only 3% smaller and thus there isn't more damping in reality. Even between a damping factor of 30,000 and 3 there isn't that much difference in damping current. The current is 25% less. This seems substantial but considering the hearing is logarithmic the difference is just 2.5dB.

For lower impedance headphones it is more drastic though.
The impedance of the driver is **30Ω** and the output resistance is **0.01Ω**.
When we calculate the **damping factor** we get an impressive number of **3,000** ! = **33.3mA**

For a higher output resistance of 10Ω the damping factor numbers are less impressive.
The impedance of the driver is **30Ω** and the output resistance is **10Ω**.
When we calculate the **damping factor** of **3 = 25mA** which means 25% less damping current.

For an even higher output resistance of 100Ω the damping factor numbers are as good as irrelevant.
The impedance of the driver is **30Ω** and the output resistance is **100Ω**.
When we calculate the **damping factor** of **0.3. = 7.7mA**

The damping current drops more for low impedance headphones than it does for high impedance headphones.

When looking at the numbers for damping factors it is clear that extremely high damping factor numbers do not bring much improvement in actually damping the driver much better.

For a 32Ω headphones the difference between an amplifier with 0.01Ω and 2Ω for instance are rather big in damping factor numbers (3,200 vs 16) but for the actual current that does the 'damping' this doesn't really matter (31mA vs 29mA) just a 7% difference in current but 20,000% difference in damping factor.

It is clear to see that damping factor numbers above 10 are pointless and do NOT contribute in more damping as the current is determined by the voice-coil. Even the usually considered minimal damping factor of 10 is therefore not really needed for most headphones and may be lower. A damping factor of around 1 should suffice.

Damping factor numbers seem to be not that important for headphones.

The **Benchmark paper on low output resistance amplifiers** suggests otherwise. This article is often used as an argument that distortion increases when higher output resistance amplifiers are used. Of course the measurements are correct and do SEEM to indicate there is more distortion measured at the OUTPUT terminal of amplifier. Because this is part of their selling point they actually leave out the real reason why the plots suggest the distortion increases.
The reality is the increase in distortion that is visible in the plots ignore the voltage division that takes place. What is actually shown in the plots is the original applied signal + the, by the driver generated, distortion/back EMF signals that are MORE attenuated by a low output resistance (voltage division) than when falling across the (added in this case) output resistors.
The 'driver generated' voltages are already relatively small in amplitude (about 40dB to 70dB lower) than that of the applied signal. Because of voltage division and the fact the measurements are done between the output resistance and the headphone impedance it is obvious that the smaller the output resistance is the smaller the generated signals by the driver will be in the plot. So what the plots show is a voltage division effect rather than the difference in damping current which isn't that big as argued above.

How to drive headphones optimally

Balanced armature drivers (8Ω to 32Ω In-Ear-Monitors), because of their sometimes weird/spiky impedance behavior, should to be driven from low Ohmic amps with an output resistance no higher than 1Ω or 2Ω. This has nothing to do with damping factor but more with the change in the sonic signature due to (considerable) impedance variances which causes considerable voltage division problems within the 200Hz to 5kHz range making them sound rather poorly/strange. Peaks or dips in the frequency range up to several dB can be quite audible.

Lower Impedance (32Ω to 80Ω) dynamic headphones are mostly intended for portable usage. These headphones should be driven from an output resistance between (close to) 0 Ω and 10Ω. Most portable equipment meets these requirements. When the headphone is designed to be used with an amplifier that meets the IEC 61938 standard. In this case these headphones designed to work properly on 120Ω. They also may sound O.K. from lower output resistance amps but often sound more pleasant/less edgy/full bodied on amps with output resistances between 60Ω and 120Ω.

Higher impedance headphones (above 300Ω) really don't get 'damped' much more with a low output resistance than with a higher one as the current that is needed to 'damp' their own swinging motions are not much different (300Ω vs 400Ω) as the damping current is mainly determined by the impedance of the headphone. For differences in sound the damping factor thus is not responsible but voltage division is.
Some high impedance headphones may sound better driven from low output resistance amplifiers and others may sound better out of low output resistance amplifiers.

The perceived increase in 'muddy-ness' when a headphone (with considerable differing impedance) is driven from a higher output resistance amplifier/source is thus not caused by a considerable less amount of 'damping' but more the result of an increase in lows caused by voltage division.

Also taste comes into play when it comes to subjective evaluation.

In short:
the 'damping' in headphone drivers is mainly achieved by mechanical properties and only a small percentage of the 'damping action' is due to electrical damping. Low Impedance headphones are more affected than high impedance headphones, depending on their impedance graph.

Another mystery in headphone land is the influence the cable (reportedly) has on the sound.

What is the influence of cables on the electrical signal ?

Headphones cables may have some influence in channel separation with certain headphones/cables.
This could potentially influence stereo imaging.
Cable swaps have been reported to improve bass reproduction and or highs have improved (sometimes even dramatically).
Reasons for these sonic improvements have been debated often in various forums, but decisive technical evidence is not never presented. Very small differences can be measured in capacitance, inductance and resistance between various cables, but the question remains in what extend these differences are audible.

Some properties of headphone cables that should be present in my opinion:

1: Supple (so not stiff)
2: Low in microphonics, so tapping on the cable doesn't end up in mechanical coupling of sounds to the ear-cups.
3: low resistance of at least the 'return' conductor/wire in case a 3 wire cable is used.
4: the diameter, small enough to be supple/lightweight, yet big enough to be sturdy/handle pulling on it.
5: preferably is should not tangle too much/at all.
6: having a suitable length.
7: Aesthetically pleasing if possible.

Length is dependent on the application, short for portable gear, 1 to 3 meters for stationary use.
In some cases a longer cable (or extension cable) may be needed.

As can be seen cable capacitance and inductance is not mentioned and cable resistance is only mentioned for the (most common) 3 wire connections (3.6mm and 6.3mm jack plug with a common ground).

Capacitance, Inductance and resistance and their importance

Often **capacitance** and **inductance** and **resistance** of cables is mentioned as the **reason** for **cables sounding different**.

Because headphone impedances and output resistances are relatively small in value (between 8Ω and 600Ω) the influence of **capacitance** is extremely small.
Large capacitances (long cables, meaning 5m or more) with high impedance headphones MAY in some rare cases cause a not well designed amplifier to oscillate. Most amplifiers are not afflicted with this problem.
Some argue that the cable capacitance causes a roll-off in the highs or cause phase shifts because they are forming a low pass filter in the upper part of the audible range (around 20kHz).
Simple calculations will prove this to be a myth.
Even with an **output resistance** of **120Ω** the capacitance of a cable doesn't cause roll-off at higher frequencies. Low capacitance headphone cables have a capacitance of around **100pF/m**, screened cables may reach a value of **250pF/m** in worst case. Exotic/expensive cables may have a low or very high capacitance depending on the designers 'philosophy'.
Some math: an amplifier with **120Ω** output resistance and **5 meter** of worse case capacitance (**250pF/m**) will have a high frequency cut-off of **1MHz** (1,000kHz). Capacitance thus is of no importance for rolled off highs but could destabilize the occasional amplifier feedback loop that reaches frequencies between 1MHz and 10MHz. Most amplifiers will not have such bandwidths though, nor do they need to.

The **inductance** of a cable is MUCH smaller than that of the voice-**coil** and even long distances of cable do not come near that of a driver.
A cable has an inductance of around **1µH/meter**.
The inductance of a voice-coil is in the **mH** region so at least **1,000x higher** and therefore also is not of any importance as a sound changing parameter. As the cable inductance is in series with that of the driver the increase of the total inductance by the cable is negligible.

In short:
the cable inductance and capacitance have no influence on the electrical signal within and even far outside the the audible frequency spectrum (way above 20kHz).

How about resistance ?

The **resistance** of a headphone cable may have some influence on the stereo imaging IF the headphone has a very thin cable which has a noticeable resistance AND the impedance of the headphone is low.
Higher impedance headphones are far less sensitive because this effect is caused by voltage division.

Some numbers:

Thin cables found on portable headphones and such often have a resistance of around **0.5Ω/m**.
Note these cables are usually short (max 1m) as they are intended for portable gear.
Cheaper **cables from budget class headphones** may have a resistance between **0.1Ω/m** and **0.2Ω/m**
Cables from the **better headphones** generally have resistances between **0.04Ω/m** and **0.1Ω/m**.
Screened cables have **core-conductors** with resistances between **0.05Ω/m** and **0.1Ω/m** and **screens** have a resistance of around **0.03Ω/m**. Also contact resistances of connectors may play a role and dirty connetors or the ones that make a bad connection can even cause (non linear) distortion.

Copper vs Silver:

Silver has a better conductivity than copper (in case the silver is not corroded). The difference is not much, about 6%. Solid silver wire and copper, however, do not change their conductance at different frequencies so the bandwidth of a silver cable is not bigger/wider or different than that of a similar copper constructed lead.

The skin effect (electrons traveling at the edges of the wire and thus increasing in resistance) starts from around 10khz and above 100kHz becomes noticeable in an increase of resistance.
The theory is that copper cables coated with a 6% better conduction edge (silver plated) would increase conductivity of the higher frequencies as they travel only around the edges of the cable due to the skin effect.
Since it is a question of simple voltage division this effect can be calculated.

Worse case scenario: 16Ω headphone with a thin very long (3 meter) cable.
In case **all copper wiring** is used the voltage division dictates a loss of **1.5dB** compared to the condition where ideal wire (with no resistance) was used. When a pure silver wire is used the loss would be **1.4dB**.
In essence a pure silver wire will conduct ALL frequencies **0.1dB** louder.

Skin effect.

At 100khz (for those that believe these frequencies matter) the increase in impedance in a wire is only **10%** in increase of the DC resistance.
At 20kHz the decrease in conductivity (thus increase in impedance) is no more than **2%** of the cable's DC resistance.
When the scenario above is used (3 meter of thin cable and a 16Ω headphone) the VERY small increase in impedance of the cable is negligible compared to that of the 16Ω headphone.

This means that at 20kHz in the above circumstances with a 16Ω headphone the 20kHz signal (because of **skin effect**) in a **pure solid copper** or **pure solid silver** cable will only give an attenuation (with respect to 1kHz) of **0.03dB.**
Because in reality a headphone cable consists of multiple strands of very thin wire, which often are even insulated with enamel the real differences will be even smaller !

The differences between a solid/stranded silver or copper wire opposite and a silver-coated copper cable will be very small and the attenuation of 20kHz will become 0.028dB approximately.
A whopping difference of **0.002dB at 20kHz** ! and this is WORSE CASE scenario so in practice will always be smaller.

The differences will become increasingly smaller as the impedance of a headphone increases and normal wires are used.
A **quick calculation** for a modest **60Ω headphone** on a perfect amplifier with a **3 meter standard quality headphone cable**, differences between a copper and pure silver cable amount to: **0.007dB** louder silver wire over the entire frequency range. The audibility of a 0.007dB increase in overall amplitude cannot be perceived.
Research has shown that a decrease of smaller than 0.1dB is **inaudible.**

In short:
the audibility of silver versus copper versus silver-plated copper wires for headphone applications cannot be scientifically attributed to conductivity improvements in the HF area because of the dreaded skin-effect.

How can a cable influence the stereo image?

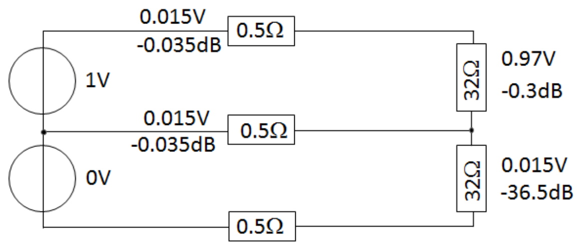
Those who have experienced a dodgy ground connection or a broken common wire might be familiar with the effect, but in this case it is a HUGE exaggerated version of it.
What one hears when a stereo signal is applied and the common (return) wire is interrupted is the absence of vocals and instruments that are normally placed in the center of the 'stereo image' (bass among those) and only reverb and strange sounding ‘thin’ instruments with no clear ‘placement’ in a weird ‘mono’ sound is heard.

This is because only the **differences** between the left and right channel signals are reaching the drivers.
The same effect but only in a VERY small amount is also present in common 3 wire cable constructions.

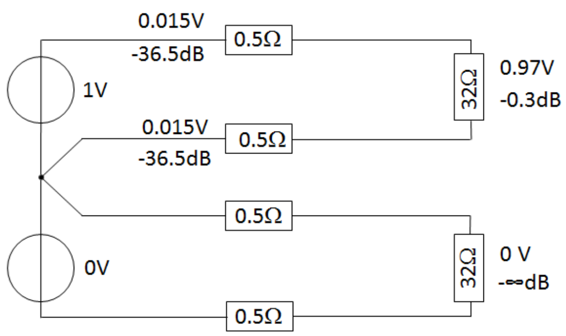
These cables are mostly found in single entry headphones, where the cable enters only 1 ear-piece and the other ear-piece is fed via a short cable (or rods) through the headband construction.
Dual entry headphones usually have 4 wires where the return wires (the common of the plug) are connected at the headphone plug and thus do not share signals beyond the plug.

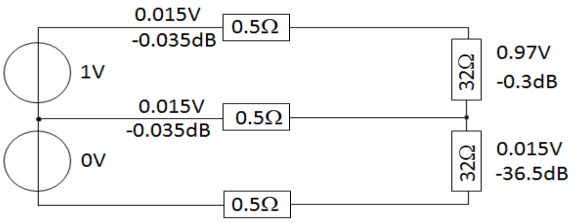
Dual entry headphones are not ‘afflicted’ with this effect and thus changing the cable won’t lead to a technical improvement in that case. Replacing 3 wire cables by 4 wire cables where the return wires connect in the plug can certainly lead to a small measurable improvement. Below the technical differences are shown.

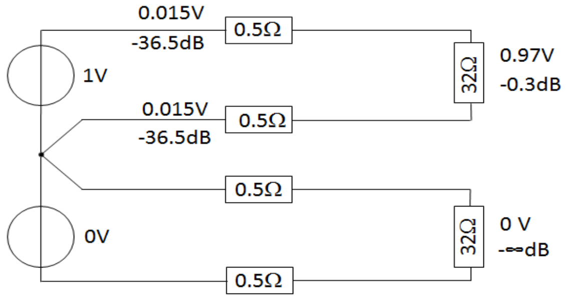
3 wire cable



4 wire cable

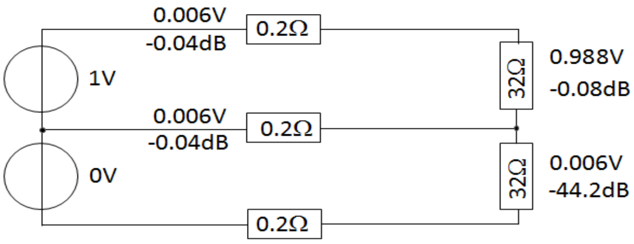




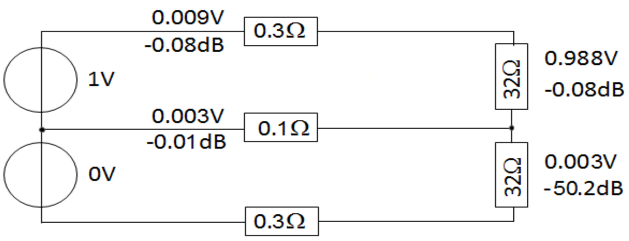


Above a realistic situation of a 3 meter cabled budget 32Ω headphone connected to an ideal 0Ω amplifier that puts out $1V_{RMS}$ for both a 3 wire cable (on the left) and a 4 wire cable (on the right).
The 3 wire cable has cable resistances of 0.5Ω. The associated voltage levels (and dB level) drops are given. Only 1 channel (the upper one) has a voltage, the other channel is silent (0V).
It is not that easy to see but the voltage drop **over the common return wire** falls effectively over the 0V/0Ω amplifier, 0.5Ω cable and 32Ω driver of the other channel. Due to the fact these resistances are in series and the driver has the biggest resistance practically the complete voltage across the return wire effectively falls across the driver that is should have been silent. Instead of total silence it now puts out a -36.5dB sound that is opposite in phase with the signal on the other side.
On the right picture one can clearly see the separated path of the 4 wire configuration and it shows the voltage drop on the return wire does **not** fall across the other driver.

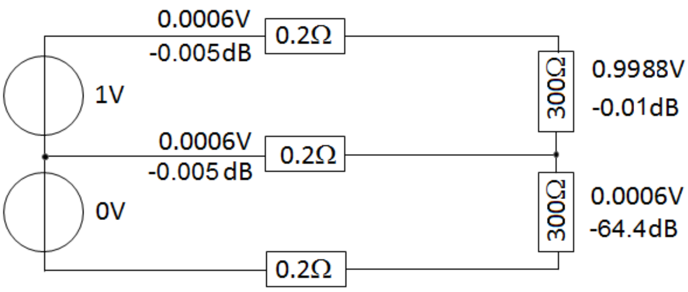
Below the numbers for a better cabled 3 wire, 32Ω headphone are improving.



Below the same headphone but using a screened cable, where the common screen is used as a return wire:



Below calculations for a 300Ω headphone with a good quality 3 wire cable:



A channel separation of -40dB is considered to be 'sufficient' as in normal situations BOTH drivers would be receiving signals and those signals will mask the signals below -40dB as they usually contain stereo information with a limited stereo effect unless one is listening to early stereo 'the Beatles' releases .

Technically speaking, a 4 wire headphone cable, where the **return wires** are joined in the headphone plug is measurably better though. Those looking for excuses to re-wire a headphone just because it is technically better can have a good point when replacing a 3 wire cable for a 4 wire one.

For higher impedance headphones the advantages for a re-cable job to 4 wire is questionable since it is not likely to be audible in real life situations.

Solderdude http://diyaudioheaven.wordpress.com/