

A Word About Speakers and Single-Ended-A-Triode Amps

A Short Introduction

by Barbara E. Gerhold, "TUBECLINIC"

A HISTORICAL APPROACH

During the old days of tube audio, speaker systems were quite simple. Mostly there was only one full-range driver in a cabinet, which was open at the rear or the driver was mounted to an open baffle. There were legendary speakers in Europe, which followed this recipe.

However, why they were sounding so good?

- The diameter of the speaker cone was big.
- The sensitivity was very good.
- The linearity of the impedance was good.
- No speaker dividing network (crossover) produced any phase or impedance problems.

Why did they disappear during the decades?

- Solid-state amps came along.
- The research and calculations of Thiele and Small (TS) made it possible, to design a speaker of predictable characteristics, while giving increased bass response in smaller closed or Bass-Reflex cabinet.

Why does this only work with solid-state amps?

This is no question or a decision between solid-state or tube design, but only a decision between (severe) negative feedback (NFB) or no one at all. The difference between both approaches is that an amp with no NFB shows rather the characteristic of a current source, while applying NFB makes it more and more a voltage source.

Speakers - using soft edge and low sensitivity drivers, designed for calculations along TS-parameters NEED a voltage source to function properly. Current sources are NOT recommended!

WHAT IS A CURRENT SOURCE?

A current source is a circuit, which translates the input voltage to a congruent, regulated output current. The load only determines output voltage.

$U_l = I_l * Z_l$	Load voltage	U_l	[V]
	Load current	I_l	[A]
	Load impedance	Z_l	[Ω]

WHAT IS A VOLTAGE SOURCE?

A voltage source is a circuit, where the voltage is regulated at the output according to the input signal, while the output current only depends on the load.

The most severe example of a voltage source is that of the OP-Amp: It shows a voltage amplification factor of more than 10 million (that reads $1\mu\text{V} \Rightarrow 10\text{V}$) if not feed-backed (open loop) and with NFB applied, it will be able to shut down amplification to 0,00001 (that reads $1\text{V} \Rightarrow 10\mu\text{V}$), because there will be the boundary between signal and emitted noise. The voltage source model can therefore be applied to a range of about 10^7 to 10^9 – dependent on the type and the facilities – in a useful way. That makes it easy for developers to design circuitries.

Nevertheless, NFB has also big drawbacks:

- It cancels out even order harmonics – during amplification as well as a subtraction from the original input signal.
- Odd order harmonics are the ones that stay (awful !!!).
- Capacitive load conditions can evoke stability problems (ringing, oscillations).

Designers of the Fifties found out – that ...

- Amps with no or really weak NFB sound best.
- Single ended amps do best work, although they show very poor power efficiency (electrically spoken).
- All kinds of NFB, symmetrical designs, balanced designs and even push-pull designs show the same problem $\Rightarrow$ cancelling of even order harmonics.

Even order harmonics esp. k2 (twice the frequency of the fundamental tone), are the origin of good sound:

- They give you the ability to distinguish between a Stradivari and a more common violin.
- They help to improve dimensional listening. Most of the imaging of a well-designed amp & speaker combination depends on how good k2 is processed.
- They help to improve articulation and intelligibility of speech. That's an increasing issue with age! Correctly spoken, it starts directly after puberty.
- If cancelled, an overdriven electric guitar or a sax will not sound cute anymore!

Recording engineers know about this fact, so they use "Aural Enhancers" sometimes also called "Aural Exciters", which in fact don't anything else but adding even order harmonics to the recorded sound.

The big bargain of the SET-A amp is, that it does not need overall NFB. They behave commonly as a current source, which means - theoretically spoken - they translate the input signal voltage into an output current showing the integrity of the input voltage. This I/U conversion is done by the load (speaker), very similar to that of a current output DAC. Theoretically spoken (and for testing) - a purely resistive load will show best results.

Such a speaker-load will not be achieved easily, but there are some very good approaches using Full Range drivers (FR) in back-loaded horn-speakers ...

If you are a Pro in electronics, you should have learnt about "Lorentz' Rule"ⁱ during your studies. It tells, that the resulting force [F_{res} in N] to a conductor, which is aligned rectangular in a magnetic field is dependent on the current [I_{rms} in A] across the conductor, the magnetic flux density [B in T] inside the magnetic gap, the length of the conductor [l in m] and the number of conductors [n].

"Lorentz' Rule" $F_{\text{res}} = I_{\text{rms}} * B * l * n$	F_{res}	resulting force	[N]
	I_{rms}	AC-current	[A]
	l	length of the conductor n	[m]
	n	number of conductors	

When considering the voice-coil of a loudspeaker as the above-mentioned conductor, three components of the equation (B , l and n), will not change during operation - so we can say, that the resulting force [F_{res}] is essentially dependent on the current (I_{rms}) across the conductor. No dependency will take place vs. frequency, impedance et al.

What does that tell us:

The conductor in the magnetic field is the voice coil in the magnetic air-gap of the driver and the AC current across it is the signal, of which's form and value is directly proportional to the input voltage of the amplifier.

The force is fully independent from the frequency of the signal and the impedance of the load (driver). This leads to a proportional motion of the voice coil and – concurrently also - the cone, resp. a dual cone assembly.

Phase shift is no problem, since the motion of the voice coil is related to the current and therefore the voltage becomes shifted while not the current. This will lead to the best performance ever.

Points or frequencies of resonance lose their importance; because the driver (better its voice coil) is forced to a sudden motion by the current across and the resulting voltage across is only a meaningless result of it.

But – any current, which can bypass the voice coil (e.g. in a crossover) is lost and that also understands lost for moving the cone.

THE IMPEDANCE PROBLEM

A single driver, mounted to an open baffle of ample area, will show a rise in impedance at its resonant frequency point on the bass side and afterwards following it will show an area of nearly linear impedance (nominal or typical impedance, e.g. 8 ohms) if we increase frequency. Behind this nearly linear area, it will show an increase in impedance the more frequency increases due to its inductance.

A two-way system of drivers will show similar results, but will show irregularities at the jointing frequency (Woofer/Tweeter) of the crossover. These irregularities will increase, the higher the order of the crossover becomes. It can be said, that a first order crossover is better from this point of view, than a third or fourth order crossover. Worst are acoustically matched filters within a crossover, because they will ONLY work with voltage sources showing extremely low source resistance. That means they will work ONLY with amps, having severe NFB applied.

The more ways in a speaker system – the more problems you will have with impedance linearity!

Impedance problems in a – say two-way – speaker system can be solved but not turned away completely.

THE PHASE PROBLEM

Mostly all I pointed-out within the preceding chapter about impedance problems may also be applied to phase problems. The phase of a single driver, mounted to an open baffle of ample area, will show a rise of phase shift in reactive direction the more frequency increases. This is due to the inductive resistance component of the voice coil.

Again, filters of any kind will lead to irregularities within the phase response.

Because phase irregularities harm a voltage source (showing extremely low source resistance) only if they tend to become capacitive (ringing will be the result), most speaker designers ignore this effect.

Phase problems cannot be solved any easy within a crossover -driver-cabinet combination like impedance problems because they usually affect the acoustic response of the combination.

Components, that should linearize impedance within a speaker combination may (mostly will!!!!) increase phase problems! So please be careful!

- Any closed, bass reflex or transmission-line design will show individual phase problems because of the interaction between the cone and trapped air, volume of the cabinet, tunnel dimensions, wavelength and/or runtime effects and electrical parameters.

A CONSIDERATION ON MATCHING

When solid-state amps came along during the Sixties, they nearly always showed severe NFB. This comes due to the fact, that bipolar transistors show high amplification factors while also showing a broad spread of their characteristics. In addition, the temperature influence is very high. All this can be tamed only by applying heavy NFB. From this point of view, the NFB helps to make a circuitry stable.

At the same time, also tube amps for use in home audio systems were built using NFB. Because tube circuitry is less prone to the before mentioned behavior, it did not need so heavy/severe NFB. The result was better sound. Almost all designs used a push-pull configuration of power tubes (mostly pentodes) at the output, so the refuse to apply NFB could not really increase the sounding capabilities.

Both designs use NFB for to solve stability issues and to lower overall harmonic distortion (THD). NFB cancels out even order harmonics, which are the highest percentage (app. 90%) in the THD figure, so the selling factor increases if a product can be merchandized with a very low figure. Nobody from the industry will tell you, that then the figure left is only odd order harmonics!

HiEnd-Audio tube amps at any time tried to come along avoiding NFB as well as push-pull (PP) configurations, because PP-configurations by themselves delete even order harmonics. Therefore, SET-A designs show the best sounding capabilities while not showing lowest THD figures. 10% of k2 at full power output is no uncommonness to a SET-A amp – then and now. Anyhow – like said before, this will increase sounding capabilities but maybe not increase merchandizing to people who do not know about.

SET-A amps are best matched with speakers of high impedance and phase linearity and excellent sensitivity. Single-driver speakers not needing a crossover will show best results. However - such systems are expensive! If you cannot afford such a system, you could use as a second-best choice a coaxial driver, but then you had to design the needed crossover in a way, that impedance and phase problems are kept to a minimum.

Best cabinet choice will be a back loaded full range horn (BLH), because it will support bass response to a maximum while leaving enough pressure to the backside of the cone, so the full range capabilities of the chosen driver will perform at their best.

Second choice will be a so-called “cut or tailored resonator” design (CR). This is a bass reflex cabinet, where the port is coupled to a horn, leading to the outside. This design is not so renowned today but was used in the older days very often in home audio designs as well as in professional instrumental stage boxes, cinema sound and PA systems. It shows a little lower overall sensitivity than a full range horn, so only drivers with very high sensitivity should be used (100dB SPL or even more). Unfortunately, today there are not so many drivers on the market, which are usable for such a design (sic!).

Third choice will be an open baffle or a design where the rear of the speaker is open to the outside. Rear-open speakers show a similar behavior like open baffles, but will slightly increase bass according to their construction. Design has to be done in a way, that enough pressure will remain to the back of the cone, that it will show best full range performance.

Closed speakers, Transmission Line or Bass Reflex speakers are not quite usable designs. When using driver for such TS designs in a BLH or a CR, they tend to lose all the bass or even never had good

sensitivity due to the usable TS parameter range of such designs. Please keep in mind that the parameter range (e.g. of Q_{ts}) is very narrow, to build a good closed design. All drivers from the market meeting these parameters will have a soft rubber or foam edge and so they will show low sensitivity and very low high frequency response – not useable for a full range design! Only drivers with stiff, hard paper or resin filled fabric edge will show good high frequency response and good sensitivity. The initial design of such drivers will not need trapped air within a cabinet for repositioning the cone. This is achieved by mechanical force only, while current through the voice-coil does the rest in leading the cone by force. In addition, it must have dual (or twin-) cone design for delivering bright treble response.

- Big cone areas lead to improved bass response.
- Coaxial drivers using treble horns are a good choice but please keep in mind that the cross-over has to be designed very thoughtfully and clean. Many sophisticated audio designers worldwide made it a lifetime project to make this possible – so please be aware of this instance!

THE SENSITIVITY OF SPEAKERS

As I wrote in my article about “Modding the Music Angel 845”, 95dB SPL are a minimum for a well-suited speaker matched to SET-A amp. The more - the better! Because high sensitivity always comes along with high price you must decide, how much money you could spend for them. Not in all cases, high price brings predictable high performance, so you should choose the model well too.

Generally, it can be said, that the highest sensitivity will show the highest resolution in sound. If you are a fan of Jazz Music, you know what I mean: It is not common to even highly priced speakers, that a brass section can be recognized as several instruments instead a broad summing sound of all of them - or - a choir can be heard as separate voices instead the sum of it. Female voices in an opera recording also will show very hard to solve problems for a speaker, if you want to reproduce them in a natural way. Woodwinds will make the same problems.

If you design your speakers by yourself, best look for a dual cone, full range or a coaxial driver (second best choice) of best sensitivity. Keep thinking about a full range horn (if your physic and math skills allow) or follow a well-known and fully developed project.

If you want to buy your speakers, the air is getting very thin. There are only a few speakers in the market, which will fulfill your demands. And believe me – these speakers are really expensive! In this case, you should better visit a HiEnd-Audio show and chose a speaker you like and which you may trust in. Always insist on a performance in connection with your own SET-A amp!

BEST MATCHING SOLUTIONS

A SET-A amp needs a speaker with a behavior I described in the preceding chapters. If you want to match this kind of amp with anything else, you should be aware of having many drawbacks. If you intend to use your SET-A amp AND already own speakers of this “any other kind”, you should look for a customer to sell the speakers. The other way around you could also sell the SET-A amp. A transistor amp of good make, quality and power will meet your “any other kind” speakers better, because it will bring you better sound to your home.

If you are seeking for the best sound reproduction possible AND start-up your HiEnd-equipment, please follow my advice and you will own one of the most beautiful sounding systems in the world.

I know that many of you will call me snotty for this last sentence, but I am confident, that you will be straight to my opinion if you should try this recipe. In this particular case of HiEnd-Audio reproduction, the number one speaker of your audio magazine will NOT be the best choice, while their number one solid-state amp will also NOT be the perfect partner for a high sensitivity full range horn speaker.

Full range horns, cut resonators and rear-open speakers will be big furniture at your home. Beware also, that a living room will also need at least 35m² to perform well with this type of speakers. Do you have that ample space?

Everything has to be selected carefully!

MY OWN HOME AUDIO SYSTEM CONSISTS OF:

- Vintage **DUAL CS701** direct drive turntable equipped with anti-resonant magnet suspension tone arm and **ORTOFON M20E** cartridge (bi-radial elliptic diamond tip) plus **ORTOFON 2M BLACK** cartridge (with Shibata diamond tip).
- CD transport **MUSIC NOTE MU20**, equipped with DAC **D300 BY SMSL** and my genuine **"EL CHEAPO-Mk2-PRO"** DAB+ and output circuit.
- Media player **MX-1 Pro** and a 4TB-HD for reproduction of DSD and HiRes-PCM files.
- Vintage Tape deck **DENON – DRM-800**, all Audio output circuitry substituted by my genuine JFET **"STC"** circuitry.
- Phono (RIAA) and line preamp **"TEQUILA Mk3-SST"** of my own construction and manufacturing.
- Current sourcing SEA Solid-State SST-power amp **CABERNET**.
- Headphone-amp **BAROLO**, the miniature version of CABERNET. Plus 600 Ω Headphones K180 by AKG and 20 Ω Headphones by SENNHEISER momentum-2.
- **FULL RANGE HORN** speakers of my own design and construction, manufactured by a very able carpenter among my many friends. Driver is a 12" dual paper cone FR **SP-30PATC BY ILP**, no crossover, 102 dB_SPL sensitivity. Horn length is 270 cm and mouth is 70 x 40 cm. Overall dimensions (HxWxD): 105 x 45 x 65 cm. Very beautifully made furniture quality speakers; surface mahogany dark red! (Driver alternatively Celestion, ALTEC, TANNOY, Lii, Tang Band ...)
- **GUZI (PURE SILVER) RCA AUDIO INTERCONNECTS** from all signal sources to the preamp - except the interconnect from the DAC to the preamp is a **TARALABS RSC VECTOR II**.
- MIL grade **RG213** copper audio interconnects of my own manufacturing from the preamp to the power amp (each 8 m long).
- **SPEAKER CABLES** of my own construction and manufacturing are made of 3 wires 1mm²; loosely braided arrangement, where the third wire is only connected at the speaker side to the ground wire, leading to a compensation line. Length each 2,5 m.

My many audiophile friends call this system the best they have ever heard, while some of them are still searching for the non-existing "Hidden Million Euro Golden Ear Tweeter" ...

If you have further questions, please contact me at: support@tubeclinic.com.

¹ **Hendrik Antoon Lorentz** (* 18. July 1853 - † 4. February 1928) was a Dutch theoretical physicist who was awarded the Nobel Prize in 1902. With his investigations into the electrodynamics of moving bodies, Lorentz laid the foundations and precursor theories on which Albert Einstein's special theory of relativity was built. Terms such as "Lorentz force" and "Lorentz transformation" were named after him. (Source → translated from Wikipedia)