

## Obtaining the ultimate mobile sound quality

And accidentally creating a new device not available in consumer market!

If you ever heard good music with headphones like a top-line STAX or Sennheiser model, than there is no doubt: you will never go back hear your favorite music like the *Le Sacre du Printemps* or *The Death and the Maiden* or *Like the Way I Do* with any other headphone! All smaller speakers are simply less good (even the 300 Euro ones) or even extremely bad (the 30 Euro ones). Unfortunately really all the high-end headphones are designed for home-equipment connection. Some like the Stax even need full load-speaker drive and a special transformer. Most others like the Sennheiser, Philips, Beyer, etc. have a much higher impedance (the famous HD 650 has 300Ω instead of the usual 30 to 60Ω - look at [http://reviews.cnet.com/headphones/sennheiser-hd-650/4505-7877\\_7-30840714.html](http://reviews.cnet.com/headphones/sennheiser-hd-650/4505-7877_7-30840714.html) or <http://www.headphone.com/guide/by-manufacturer/sennheiser/sennheiser-hd-650.php> ) and need therefore a larger voltage drive. So the question is how to provide a high-quality high voltage-level signal to your headphone if you are mobile? PC sound-cards, mp3-players, etc. usually have *not* enough driving voltage for high-impedance phones, so just an additional amplifier is needed. This means, in principle you can connect such high-impedance phone to your mp3-player, but it will be simple *not loud enough* to fully enjoy the music. Of course, such audio power amplifier (PA) should be:

- compact (you want to stay mobile)
- cheaper than an mp3 player
- high-quality (to get desired high-quality sound)
- low power (to allow long-battery life)

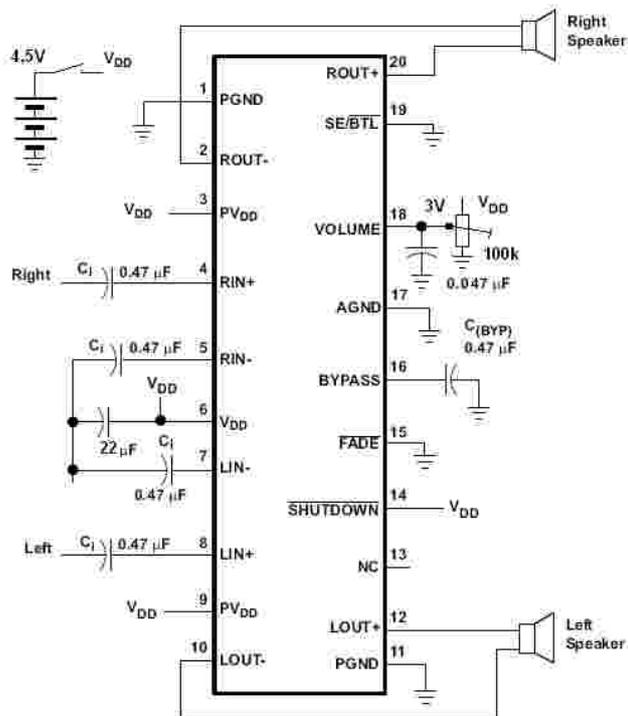
Unfortunately there is no real commercial solution available! For a compact amplifier an *integrated* audio power-amplifier should be used, and luckily many are available for low prices, e.g. Texas Instruments is a leading manufacturer. Discrete solutions can achieve even better sound quality, but are much harder to design and to build, and the potentially better quality may also come *only* if you pay for it with: larger batteries, larger power consumption, larger size, etc. Unfortunately most older PA IC's are not really suited for high-end applications (e.g. having a total harmonic distortion THD beyond 0.5% and no real rail-to-rail output, i.e. wasting a significant part of the supply voltage) and require a large supply voltage (like 6V, 9V or even 12V), which makes the design bigger due to larger battery size for a given capacity. Newer chips can easily achieve THD below 0.1%. They typically work at 5V (default USB supply), which unfortunately makes the generation of large voltage drive level harder.

So we have the dilemma that new chips are low-power, high-quality but voltage-limited, and older ones (like the LM386) have lower sound quality and need larger batteries. One workaround is using bridge-load connection (BTL), because this *doubles* the voltage output and allows high sound-levels even at 4.5V supply. Also BTL allows removing the usual big coupling capacitors at the outputs even with a single supply voltage.

So I planned for this configuration using the Texas Instruments chip TPA6021A4 which has the advantage of a conventional 2.54mm pitch DIL package. THD is 0.07% at 1kHz even at 8Ω load and 20dB gain, so for 280Ω (measured at my HD 650) and 10dB at will be even better (maybe 0.02...0.01%). Such DIL20 package is easier to solder than more modern SMD packages and the area penalty is minimum compared to the battery size needed anyway. For headphone-drive no heatsink is needed, because the theoretical maximum load current would be around  $4V/280\Omega=14mA$ , which is not much larger than the low bias current of 7.5mA. This means also that for high-impedance headphones the PA works in a near-Class-A mode, which is best for sound quality. Assuming a battery capacity of 900mAh (good Alkali cell), we can expect a hearing time of approximately 30 hours or more, good enough for a travel week. One positive side-effect is that the mp3-player playing time will increase by our PA, due to high input impedance (app. 20kΩ compared to e.g. 50Ω).

One further advantage is that in BTL the distortion is smaller than in single-ended configuration (for same output current), because in BTL some harmonics cancel each-other (SE operation leads to typical THD of 0.3% using the TPA6021, a pure SE device TPA302 achieves appr. 0.1% - depending on gain setting).

So this could be the circuit, which is very close to the TI application recommendations:



Mainly I made the caps at supply smaller for space reasons and due to much lower currents in the circuit (compared for load speaker application with  $8\Omega$  loads).

Supply voltage can come from 3 small AAA batteries (also called LR03 or micro). Also a VDD switch is added to switch the PA fully down. The  $100k\Omega$ -poti allows gain adjustment and sets the maximum output-level for given input. It can be adjusted so that only some distortions occur if you hear at maximum level. If you don't want to have any adjustment, just replace the poti by a fix voltage divider feeding app. 3V to pin 18 (e.g.  $100k\Omega$  to ground and  $47k\Omega$  to VDD to set the gain to 10dB). Note: In principle you can set the gain also higher (up to 20dB with pin 18 at VDD), but this has to be paid with a bit worse signal-to-noise ratio SNR, higher lower cut-off frequency and higher chance for undesired PA overdrive. The 10dB has been found more or less by trying, it is interestingly very close to the difference in sensitivity between the HD 650 and a typical in-ear earspeaker (sensitivity usually given at 1Vrms).

After some more thinking one overlooked problem comes up: Normal headphones have a standard stereo 6.3mm connector with *shared* ground pin for left and right channel. That makes stereo BTL-connection *impossible* (look into the schematic!). Unfortunately the other solution of using a higher DC supply voltage, would allow only the usage of more power-consuming PA's and/or older ones with less good audio performance!

Luckily the solution is simple: Like in an airplane the stereo connector can be replaced by 2 mono connectors, which requires some simple soldering at the headphone connector. For Sennheiser headphones simply an additional headphone wire can be ordered (price around 15 Euro). Or just take the advantage of the any too long wires for mobile sound.

One extra hint on assembly and component choice: The elements are quite cheap, altogether maybe even below 30 USD, BUT better do not choose the cheapest ones or older components you may already have. Bad mechanics is the death of all electronics, and especially bad audio connectors can cause big trouble! Also the pcb should be a good one, easy to solder. I have used a fully standard breadboard-style pcb with manual wiring, best for prototyping. 1<sup>st</sup> I routed the ground net, then VDD, last the others. Use a text marker in the schematic to check all net connections already done. After soldering and visual inspection, check with a DMM for short-circuits (e.g. between ground and VDD or between neighboring IC pins) and for open-circuits. Then place the PA to the socket, probably some careful bending of the pins is required to make it easier.

For the on-off switch better choose a rock-solid one which also indicates if it is close or not. For the PA itself I have used a standard high-quality socket, because that also reduces highly the risk of damaging the chip (by over-heat or ESD). If you have enough space, better use 6.3mm connectors than the more typical 3.5mm ones for less trouble. Also make shure that all wirings and solderings are reliable and get no mechanical stress. For the input I have directly soldered a cable with stereo 3.5m plug to minimize mechanics, this way achieving a direct connection to the headphone output of my mp3 player (ZEN from Creative – very nice piece!).

On the pcb I put also a 3.5mm socket connected to the inputs to allow driving a normal headphone directly from mp3-player, i.e. without the amplifier active. Good if someelse wants to hear the music with a 2<sup>nd</sup> headphone – of course with no extra-amplification.

After problems with weak contacts at the 2 output mono-connectors, I decided to cut the cable and to solder the ends directly to the board!

If everything works 100% fine (if you follow all instructions – there is a good chance!), then it might be worth a decision to fully put glue over the construction, just because the risk of too much mechanical stress is much higher than of electrical dammage and need for a repair.

Making it smaller? Good idea! If you look at the construction pictures, you will clearly see that the battery space dominates, also the box might be smaller (especially thinner). So option one might be using a smaller battery. However, note you need to stay between 4 and 5.5Volts (the TPA6021 would be damaged beyond 6V)! So this is clearly a possible way, although it may lead to the need for non-standard batteries and - of course - to reduced operating time. Another option is to create a more compact board, e.g. by using SMD components and a smaller on-off switch. A suitable SMD PA would be the Texas Instruments TPA6020A2. This has has also the advantage of working down to 2.5V, so it would use really the full battery capacity in an optimum way. Great would be a fully optimized box, best with integrated easy-to-open battery part. Removing the optional input 3.5mm connector could also save space, and this function could be achieved - if needed - with an external standard adaptor.

Some sound quality remarks: Of course, as home-equipment PA's typically operate with supplies of e.g. 60V, instead of 4.5V, they are able to deliver even higher sound levels than this PA and also a slightly better quality. However, due to BTL our PA delivers a sound pressure level - e.g. with the HD 650 - really *beyond* the one people should accept for longer duration! Also the Texas Instruments TPA6021A4 is definitely better than most other integrated PA within mp3-players, etc. As we have now removed the *weakest* point in the signal chain (just the standard-quality headphones), now for ultimate mobile sound quality also *other* factors become more important such as mp3-datarate (with top-quality headphones you will often find that 128kBit/s is not good enough, suprisingly modern or classical music might be not as critical as older records, just because of artefacts) or mp3-player/PC built-in digital-to-analog converters (which are not as good as more power-hungry DAC's adressed to home-equipment).

BTW, such amplifier we described here is not available as commercial device – even not a similar one! Just one example where soldering your own circuits still makes sense (and some fun)!

## Alternatives?

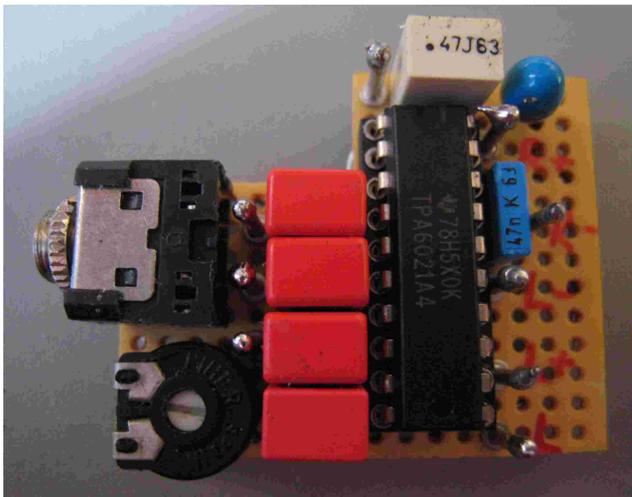
There are few, which could be mentioned here. For instance, the industry often claims that class-D amplifiers are now also suited for high-performance audio application – I would not fully agree. Also for our headphone application the benefit would be minimum, because class-D amps suffer from larger quiescent currents. ClassAB amplifiers automatically get a performance boost from higher load impedances due to larger loop-gain, but this is not really the case for class-D amps! Also class-D amps get no more voltage than class-AB PA's from a given supply. So class-D PA's have their field of application for low-impedance speaker drive (where high-efficiency really matters) and moderately stringent sound quality demands.

If you don't want to solder but accept some mechanical work, then you may look at existing active speakers. They have a built-in PA which would allow also the drive a high-impedance headphone, although that is unfortunately not really true for all active speakers! If they work from 2 batteries only, than in most cases you can expect that voltage-drive level is still not really high enough. For 3 batteries, you have to check if the circuit uses BTL, which can be made with a DMM: If one speaker pin is ground (minus pin of the battery box), than it is not BTL and sound level is still to low! For 4-batteries devices you can expect at least some improvement over a typical mp3-player. 100%-sure you can be only after testing it or for active speakers with 5 or more batteries – and those typically have also bulky heatsinks! So, such kind of active speakers plus the batteries lead to a quite large device – not comparable to the presented compact solution.

Using e.g. only two batteries, but getting a large output voltage is possible by using a DC-DC boost converter. Unfortunately such solution requires more external elements, and available fully integrated solutions (LM48824 or TPA6140) do not yet adress high-performance applications and high-impedance speaker drive.

Really no commercial solutions? I found e.g. companies like Boostara (see <http://www.boostaroo.com>) and IASUS ( <http://www.iasus-concepts.com>), which offer some headphone amplifiers. However, they do not offer any portable product for driving a 300Ω load with 8Vpp – as we do here. This is yet only available for 12V or AC-powered amplifiers. A pretty good device is the Total AirHead from HeadRoom (99 USD) see <http://www.headphone.com>. It can deliver at least 4.5Vpp by using 4 batteries (just because it uses no BTL), so this device is much heavier and a bit less compact than ours (7.5 ounces compared to our 4 ounces).

Top view of the board: poti moved to lower left because not much space at the right due to output plugs



Whole PA box: on-off switch on top, batteries at the bottom, input left, outputs right



Soldering-side of the board: 4.5V-VDD and ground routed in thick non-isolated wires.

