 By Ari Polisois

# Three Novel Transformers for SE Amps

Introducing the next generation of output transformers.

For many reasons, I am convinced that in the sound reproduction amplifiers field the single-ended topology, combined with triodes, produces a better sound than any other. Many readers will agree with this statement, others will not. I must specify that most of those who support the push-pull layout are motivated by the power output they can get from this kind of amp, which can easily reach 50, 70, 100 or more watts with just a pair of strong output valves per channel. On the other hand, the single-ended (SE) units, in order to deliver such power, require very large and expensive output transformers.

This explains why SE amps in excess of 20W are not the rule. The cause is well known: the idle DC (direct current) at which the valves operate in their still condition in a SE layout.

When designing a standard SE transformer, you must consider that part of its core magnetic headroom (that depends on the size: cross-sectional area and length of the magnetic path in which the flux travels, as well as the quality of the ferrous material) will be "occupied" by the magnetization due to this direct current. Enough availability must be reserved in the core for the alternating current signals to prevent an excess of flux density to cause its saturation, in which case the distortion of the sound increases.

Many well-known scientists have spent some time trying to find a solution to the SE transformer's drawbacks, starting with the non-productive DC field, but their suggestions were not considered justified to replace the gapped[1] system that remained the best alternative to the push-pull. Being deeply interested in using the SE topology, but with more power, I resumed the search to find a solution to this unacceptable lack of efficiency.

## SC-OPT (SELF-COMPENSATED OUTPUT TRANSFORMER)

Who hasn't thought about a system based on an extra winding generating a magnetic field of the same strength as the primary's, but in the opposite direction, in order to accomplish a complete and automatic offset of the DC fields? It is certainly the first idea that comes to mind, if you overlook the fact that if this works for the direct current, the same offset also applies to an AC signal applied to the primary. Consequently, no voltage would be transferred to the secondary[2] **(Fig. 1)**.

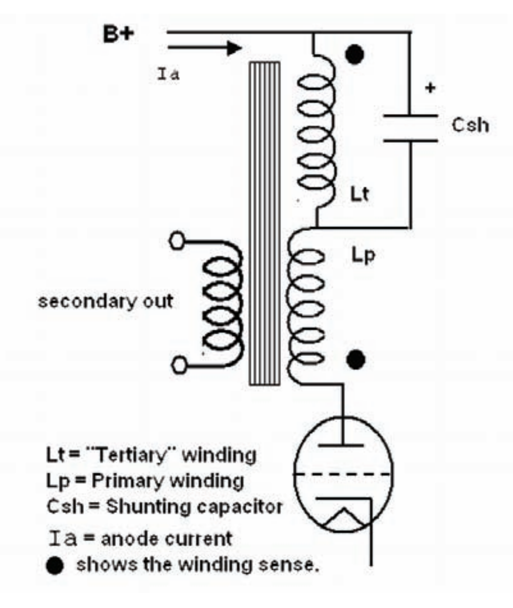



**FIGURE 1: The self-compensated output transformer.**

To save the AC of the primary, you need to suppress the AC voltage that fights against it, in the opposed winding (that I will name the "tertiary"). A suitable capacitor shunting the tertiary can do the job, for it hits only the AC, not the DC, but you soon realize that the primary's inductance is severely affected, as you will see later. Consequently, if, on one hand, it is quite easy to achieve the DC offset, and short-circuit the opposed AC potential, another problem arises, and you must restore the primary's inductance that has collapsed, due to this short circuit.

You know, however, that the reduction of inductance is greater if the coefficient of coupling between the opposed windings is high[3]. This coefficient, in practice, ranges from very close to 1 (if the coupling is tight) and falls below 0.9 (if the coupling is loose). It becomes obvious that if you want to limit the damages of the tertiary's AC short-circuiting solution, you must reduce the coupling between, on one side, the tertiary and, on the other side, the primary with its secondary(ies). Irrespective of the coefficient of coupling between the main opposed windings, tertiary and primary, the latter must have an extremely high coupling coefficient with its secondary, which means a good winding geometry and interleaving.

I started bench experiments on this basis and included the physical separation of the conflicting windings, using suitable C or UI cores. But the real solution came when, encircling the tertiary's bobbin with a few turns of magnetic band on

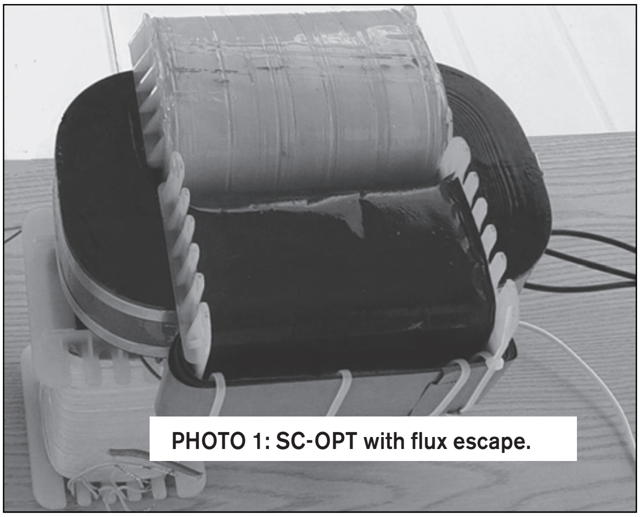


PHOTO 1: SC-OPT with flux escape.

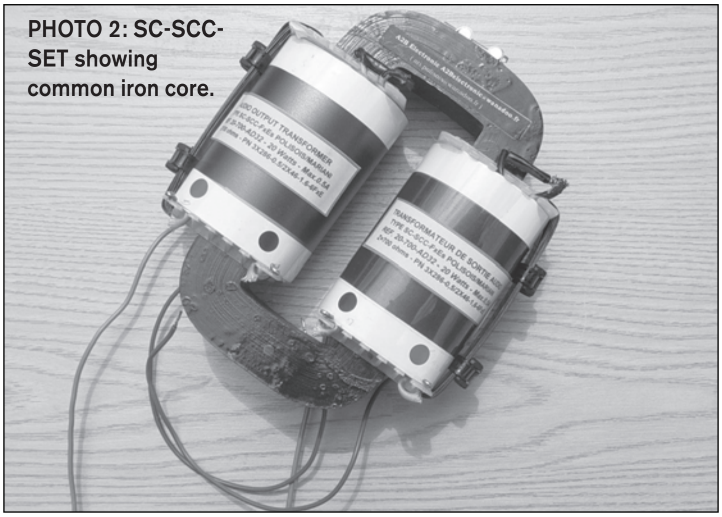


PHOTO 2: SC-SCC-SET showing common iron core.

the outer side, I noticed a significant reduction in the loss of inductance of the primary. **Photo 1** shows the "magnetic flux escape." This device can be considered an auxiliary magnetic core that absorbs part of the magnetic lines, thus reducing the effective number of lines that the tertiary and primary have in common (and, consequently, the coupling factor).

As an example, I consider the case of an output transformer built for a 6C33C-B valve, the powerful tube with about 100Ω internal resistance. Initial primary inductance (measured, without load, with an inductance meter) = 4.8H (1200 turns – core area 7.6cm$^2$ – magnetic length 0.43m). This inductance, with the tertiary (same number of turns) shorted, falls to 0.48H (1/10 of the initial). I calculated the coupling coefficient to be 0.95.

The –3dB point at low frequencies results (theoretically) in 35Hz[4]. By adding six turns of a 0.35mm thick magnetic band around the tertiary bobbin, the primary inductance was restored (due to the magnetic lines leaking from the tertiary field in the main core to this additional external magnetic circuit) to over 1H.

In spite of an improved bass response, the advantages I was seeking (reduced bulkiness and weight, compared to a standard SE output transformer) had not been fully reached, and, from an efficiency point of view, you could not consider the unit able to compete successfully against a push-pull transformer. Nevertheless, the fact that a SE amp using low internal resistance valves, when equipped with an SC-OPT, delivers much more power than with a gapped transformer of the same size, is a real, substantial improvement.

A pleasant surprise was the discovery that the sound it produces is extremely clean and airy, as many listeners noted. However, no scientific explanation was found for this sonic feature. This unit was presented at the AES 118$^{th}$ convention (Spain, May 2005, paper 6346).

Despite its use, for best results, of low internal resistance valves, this special SC-OPT features several advantages with respect to sound quality[5].

An amp I listen to very often at home is fitted with two paralleled 2A3s per channel (equal to 400Ω internal resistance). It uses a self-compensated output transformer and even if its bass range extends to only 46Hz, at –3dB, it is my preference, because of the unequalled midrange and high frequency sound quality.

## SC-SCC-SET

In May 2006, engineer Giovanni Mariani, technical director of Graaf, Modena, Italy, specializing in output transformer-less (OTL) amps, and I presented a paper describing another novel transformer, the SC-SCC-SET (split core, stereo common circuit, single-ended transformer) at the 120th AES Convention held in Paris, France (paper 6831).

Considering the fact that a loose coupling in the same magnetic core allowed some freedom for the primary winding to work, producing an ideal separation with the help of the opposed DC fields, both the right and left channels (two primaries with their closely coupled, interleaved secondaries) were fitted on the same common iron core (**Photo 2**). This solution required a phase inverter, as with the push-pull transformers.

The DC offset was also ensured, as in the p-p OPT, by feeding the left and right primary coils, having opposed winding senses, with the same amount of anode DC current. Obviously, there was no self-offsetting feature, and the balancing of the DC fields must be accomplished with a suitable, manual device.

The advantages were:

- extended bass range (as low as 5Hz at –3dB) with a very good high-frequency limit (**Fig. 2**)
- saving space, weight, and cost, with regard to the former SE transformers[6-7]
- getting as much power as the push-pull configurations, but with the properties of the SE layout (sensibility, lower content of odd harmonics, simplicity of the circuits, and so on).

This transformer was also designated as "double-ended," as opposed to the classic SE transformer.

Its disadvantage, however, is that some [crosstalk][6] is present, but limited to the low frequencies (thus not affecting the stereophonic effect). It is practically unnoticeable, if the loudspeakers are three or more meters apart.

As stated, the two primaries (left and right channels) in this setup produce opposed fields (as in a push-pull transformer). The DC magnetic fields produced cancel each other, provided the idle currents are of the same intensity (but, as mentioned, this is not automatically ensured), whereas the AC ones, thanks to the opposed phases, do not interfere with each other.

How does the sound of this OPT compare with that of an SC-OPT? What strikes me immediately is its richness, due to the healthy presence of the bass range. At ease with a jazz quartet as well as with a philharmonic orchestra, it does not miss any detail and it handles powerful transients effortlessly.

The sonic scene is filled and uniform and, depending on the recording approach and orchestras, can give the impression that the instruments are there in front of you, playing next to each other, but distinctly. The sound does not "jump" from one place to the other. The instruments can be heard as in a natural, wide angle space. People who are unaware of the output transformer's secret notice a difference with the characteristics of the sounds they are used to, but they cannot describe the difference, still being positively impressed. No doubt that an SC-SCC OPT is worth a try, not only for the special sound, but also for its advantages (lower price, less than half of the two SE transformers it replaces, improved simplicity, and efficiency)[6-7].

The curve in **Fig. 2** pertains to a prototype of an amp that has been duplicated eight times by eight young students (13- to 15-years old) in Italy (**Photo 3**), under the supervision of my friend Antonio Tucci[8]. This result proves that, with this transformer, the SE topology compares favorably to the push-pull, still keeping its appreciable character.

## 4 × SC-SCC-SET DEVICE

After my initial enthusiasm, a doubt crept into my mind. Was it possible to achieve further improvements?

Consider **Fig. 3** and **Photo 4**. As explained in the AES 122$^{nd}$ Convention Paper #7151 (Vienna, Austria, May 2007), the number of primary/secondary windings' bobbins is increased (two for each channel in the basic setup, with the possibility of more), connected in such a way that the currents that cross them lead to an automatic compensation of the magnetism, reducing the same very close to zero, independently of the idle DC intensities flowing to the valves.

The advantage of this layout is that, with proper connections, it does not require an external direct current balancing device—everything is done automatically *inside the transformer itself*. It also eliminates the need for matching parallel valves.

**Figure 4** shows that, in every branch, the direction of the DC flow is the same,

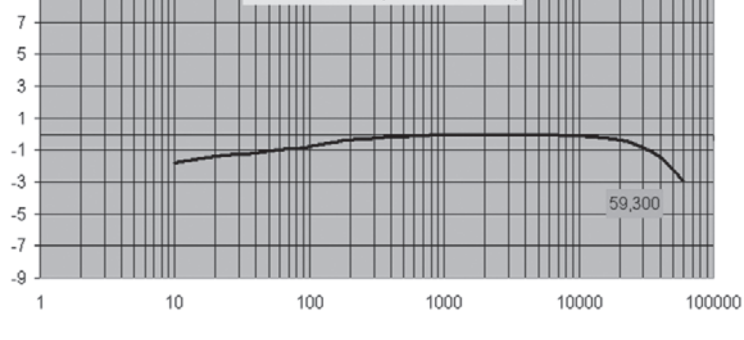



**FIGURE 2: Frequency range of the SC-SCC-SET.**

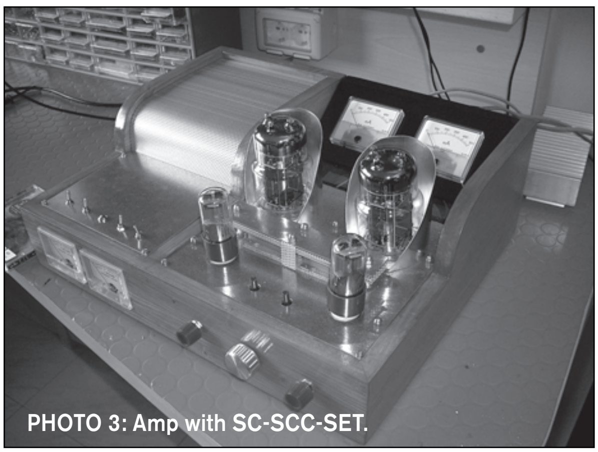


**PHOTO 3: Amp with SC-SCC-SET.**

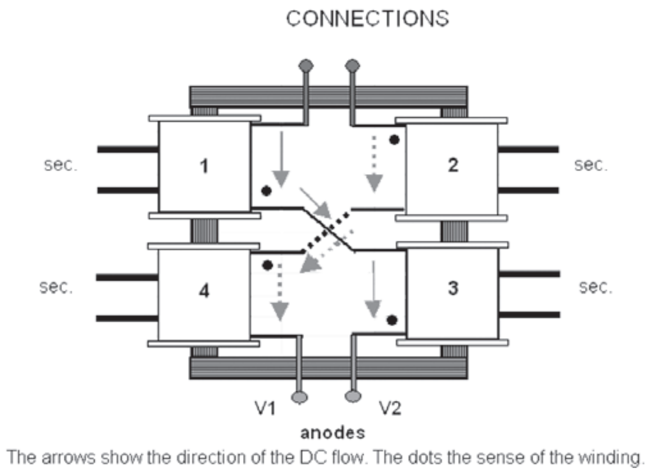



**FIGURE 3: Physical layout of the 4 × 4 output transformer.**

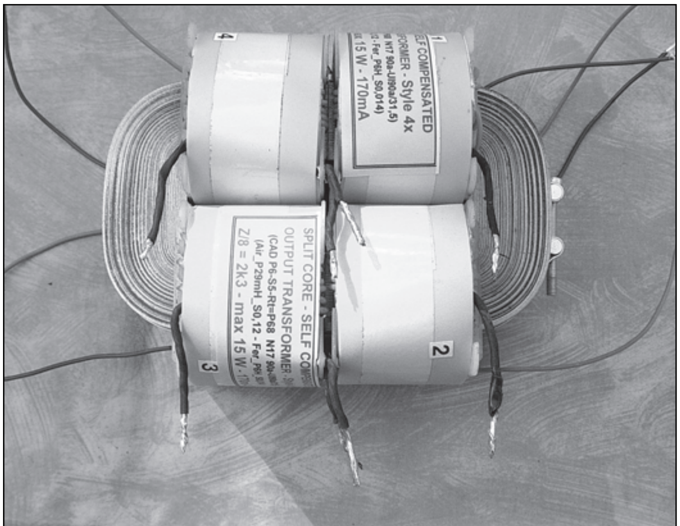


**PHOTO 4: SC-SCC-SET configuration with two bobbins per channel.**

but the winding sense of each primary is opposed to the other and that the primary coil's terminals are connected in a crossed way, from one branch to the other.

The power supply current flows in the primaries 1 and 3, connected in series, but on different branches of the magnetic circuit, until it reaches the anode of valve 2. Primaries 2 and 4 are in the same situation as the other valve. Four fields are produced by the DC, that, under certain conditions, fight each other. As a result, the overall magnetization is close to zero.

The simplest case is when all windings have the same number of turns (N1-N2-N3-N4) as in cases 1 to 5 in **Fig. 4**. No matter how strong or weak the anode currents are—their relative levels—the cancellation of the magnetization takes place.

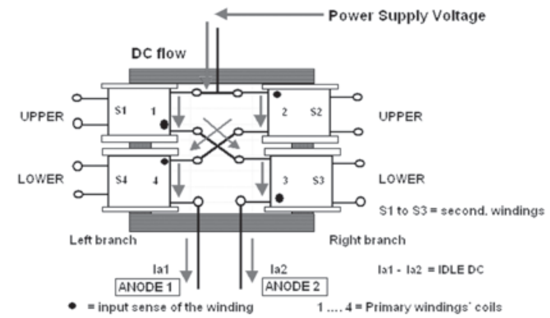
In cases 6 to 9 of **Fig. 4**, as a result of the four fields strength (aiding and opposed) produced by the windings operating in the magnetic path, whose algebraic sum is zero[9], the magnetization of the core is also cancelled.

Some other alternatives—with the number of turns of the primaries equivalent in pairs—also produce the same result (cases 6 to 9). However, some combinations do not work, such as cases 10 and 11. Thus, the DC offset can be ensured in the favorable cases.

With regard to the alternating current, due to the fact that valve 1 and valve 2 are modulated with signals 180° apart, the primary windings concerned operating in series aiding condition are not antagonist and they work freely. An important point is that if *one transformer and a pair of valves (or more) are used for each channel, no [crosstalk] takes place*. The 4x-SC-SCC is currently undergoing extensive tests in order to check that the expectations are fulfilled also as regards the sound quality.

## ONE OPT USED FOR BOTH CHANNELS

In this case, the [crosstalk] is present, but as with the SC-SCC, it concerns only the low frequencies with a negli-

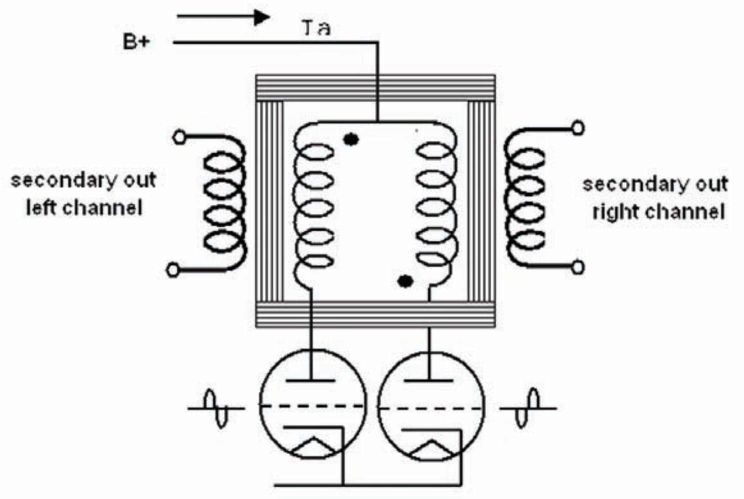



Glimpse drg

U = UPPER L=LOWER and LEFT R=RIGHT N=Number of turns

| | Ia1 | Ia2 | N1(UL) | N2(UR) | N3(LR) | N4(LL) | Whole core Field | Bobbins Position Left Right |
|---|---|---|---|---|---|---|---|---|
| | Amperes | | Turns | Turns | Turns | Turns | | |
| Case 1 | 0.2 | 0.2 | 1000 | 1000 | 1000 | 1000 | 0 | U |
| OK | | | | | | | | L |
| Case 2 | 0.23 | 0.18 | 1000 | 1000 | 1000 | 1000 | 0 | U |
| OK | | | | | | | | L |
| Case 3 | 0.18 | 0.23 | 1000 | 1000 | 1000 | 1000 | 0 | U |
| OK | | | | | | | | L |
| Case 4 | 0 | 0.2 | 1000 | 1000 | 1000 | 1000 | 0 | U |
| OK | | | | | | | | L |
| Case 5 | 0.2 | 0 | 1000 | 1000 | 1000 | 1000 | 0 | U |
| OK | | | | | | | | L |
| Case 6 | 0.18 | 0.23 | 1500 | 800 | 1500 | 800 | 0 | U |
| OK | | | | | | | | L |
| Case 7 | 0.23 | 0.18 | 1500 | 800 | 1500 | 800 | 0 | U |
| OK | | | | | | | | L |
| Case 8 | 0.18 | 0.23 | 800 | 1500 | 800 | 1500 | 0 | U |
| OK | | | | | | | | L |
| Case 9 | 0.23 | 0.18 | 800 | 1500 | 800 | 1500 | 0 | U |
| OK | | | | | | | | L |
| Case 10 | 0.18 | 0.23 | 800 | 800 | 1500 | 1500 | -35 | U |
| no offset | | | | | | | | L |
| Case 11 | 0.23 | 0.18 | 1500 | 1500 | 800 | 800 | -35 | U |
| no offset | | | | | | | | L |

FIGURE 4: 4× SC-SCC offsetting conditions.




REMARKS :

- If the anode current Ia is the same in both branches, the number of turns of the left and right primaries must be the same.
- To obtain the most extended frequency range, at the bass end, the left and right channel valves must operate with opposed phases.

FIGURE 5: The split core—stereo compensated circuit SE transformer (one magnetic core for both channels).



gible impact on the stereophonic effect. However, it would be possible to control the [crosstalk] by shunting the upper blocks 1 and 2 with suitable capacitors, for instance, as is done in the SC-OPT to the degree (depending upon the value of the capacitor) that it does not cause a collapse of the other primaries' inductances.

With this solution the [crosstalk] is moved to lower frequencies. Readers with comments or questions about the behavior of the 4X SC-SCC are invited to e-mail Ari.polisois@wanadoo.fr, P.touzelet@orange.fr, 1polisois@yahoo.it, or, preferably, A2Belectronic@wanadoo.fr.

## UPCOMING DEVELOPMENTS

Tests are being conducted on bench units to utilize fully and advantageously the principles discovered with the former versions (SC-OPT, SC-SCC-SET, and 4× SC-SCC) in order to:

a) Reduce the [crosstalk] (when the 4× is used for *both channels* on a common core). As mentioned, in a layout using *one 4× transformer per channel*, with parallel valves, obviously, there is no [crosstalk]. This corresponds to a push-pull having SE sound character, but it does not require an auxiliary offsetting circuit.

b) Extend the high-frequency range beyond the current limits, the goals being 5-10Hz and 70-80kHz at –3dB.

c) Obtain the offset and balancing conditions automatically, without the use of *any external device*.

d) Improve the simplicity of the single- or double-ended amps by integrating the loudspeakers' crossover units into the output transformer, for instance.

This feature, which took years of research, is practically concluded and will be the subject of a presentation at a coming AES convention.

Today, the SE topology has a new life and the future is promising. I have been striving to give DIY audiophiles a wider choice of transformers (output or interstage) they can fit to their amps, according to their objectives. On behalf of engineers Mariani, Touzelet, and myself, many thanks for your interest in this field. Please do not hesitate to contact us with any questions or comments. aX

## REFERENCES

1. Why a gap in a SE OPT (or choke)? Just because you must avoid the saturation of the core due to an excess of permeability, which is an improvement on the core magnetization capacity obtained by inserting a ferrous or similar material inside the windings. However, permeability has a particular characteristic that you might consider a defect: It changes with the field strength, and when the latter is relatively too strong, it starts lowering, due to the saturation of the core. When this happens in an audio transformer, the sound becomes greatly distorted.

2. In practice, this is absolutely true as far as the low-frequency end is concerned, but you still get a weak one on the high-frequency side.

3. In the case of opposing coils in series, such as the primary and tertiary of the SC-OPT, the formula that applies is: Lt (total inductance) = Lp + Lt – 2M, where Lp is the primary inductance, Lt the tertiary's, and M the resulting mutual inductance according to their coefficient of coupling, calculated as follows: M = k*√(Lp*Lt), where k is the coupling factor (equal to 1, if the number of lines of force passing through one coil is exactly the same as those passing in the other, which is practically impossible) to less than 1.

4. Because of the load and other actual working conditions, the effective inductance is different.

5. There are many valves having a low internal resistance (6C33 – 6336 – 6080 – 6550 – KT, and so on, triode connected) that can eventually be reduced by putting several tubes in parallel. Until now used for other applications, such as voltage regulators, this family of valves comes, luckily, back to active life. Most of them do not require extremely high anode voltages.

6. This novel device was presented at the AES 120th convention, held in Paris in May 2006 (paper 6831). More details on the transposing of the low frequencies are given in the above paper.

7. To better illustrate this result, the OPT (bi-channel) in **Photo 2** replaces two OPTs 50% bigger in size.

8. Thanks to Antonio, these kids have discovered the sound of a valve amp and some of them will surely become *audioXpress* readers.

9. The electric fields strength of each winding, (producing aiding or opposing magnetism) result from the product:- N (number of turns) × Ia (DC anode current).


## ACKNOWLEDGMENTS

The 4× SC-SCC transformer is the latest step in a program that started about ten years ago to improve the sound of valve audio amplifiers.

With the invaluable support of engineers Menno van der Veen and Pierre Touzelet as well as, most recently, Giovanni Mariani of Graaf, Italy, sensible improvements have been achieved that led to the application of several patents, five of which have been granted by the French INPI (Institut National de la Propriété Industrielle).

I am also grateful to Edward T. Dell, Jr., Editor of *Glass Audio* and *audioXpress* magazines, for publishing my first article on the subject ("A Universal Phase Splitter," p. 32, *GA* 1/00) and subsequent ones, and also to the staff of the Italian magazine *Costruire HI FI*, for printing several other articles, and, recently, also to Elektuur and Elektor Deutschland of the international periodical of electronics, *Elektor*. Finally, I would like to mention engineer Menno van der Veen (worldwide known for his works in the audio reproduction field), whose support has been of the utmost importance.