# SINGLE-ENDED AMPLIFIERS, FEEDBACK AND HORNS: SOME HISTORY

## by Dr. Tom Hodgson

I was intrigued by the article on the WE 300B single-ended (SE) amplifier in *SP* #1. Your list of pros and cons for SE versus push-pull (PP) led me to reconsider why SE might be better, particularly with regard to the operation of the output tube into the output transformer (OT) and the value of the resulting voltage distortion. This is worst at low frequencies where the OT primary inductance is usually lowest.

I am a committed tube "freak", never having found musical satisfaction from transistors, for reasons as yet unexplained. My gut feeling on SE, at first, was that a SE output tube and OT ought to be more linear than a PP design. Since the OT carries DC current in the SE case, the silicon-iron core must be air-gapped to prevent saturation. Typical measured BH curves with sinusoidal voltage drive for a) an ungapped and b) an air-gapped OT are shown in Fig. 1a, b.

Note that the magnetization force H axis is ten times bigger for the ungapped case. Modern OT iron saturates at a flux density B of order 18 kilogauss, so if the tube DC current "biases" the iron to 8-10 kilogauss and the music signal swings +/- 3 kilogauss, then it is obvious that the SE design must be more linear, all very simple! Now OT design and the physics of magnetization are not for the faint-hearted. That which follows is by no means an OT design thesis. But I needed further insight into my simple view of SE.

Having grown up in England through WWII and the ensuing golden era of British tube design and recording practices, I turned to searching the pages of the *Wireless World* magazine starting with the year 1920 onwards. It was, at first, a weekly publication. I was an avid reader from WWII on, when it became a monthly periodical. A bonus of such a search was that I might perhaps trace the history of SE and PP and the ensuing use of negative feedback with chronological correctness.

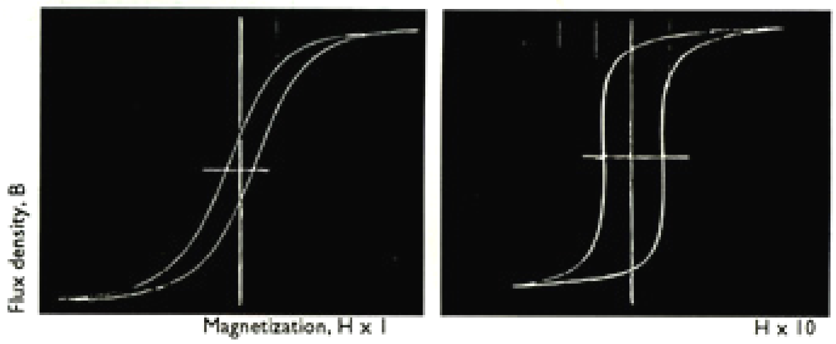
The first constructional article for a quality 4W PP amplifier using a pair of PX4 triodes appeared in the May 11, 1934 issue authored by W. I. Cocking, subtitled "Constructing Distortionless Equipment". The PX4 was a Marconi triode of 2.5W output in SE class A and cost $4 (which was about one-third of the then weekly working wage). The more powerful DA60 12W triode cost $20. I was quite surprised by this article since during the 'thirties the *Wireless World* mainly covered SE radio-receiver output stages and a few transformer winding articles with no mention of air-gaps, although M. G. Scroggie of Mullard gave a graphical method for choke design in the June 1, 1932 issue based on the 1927 Hanna method. However, I discovered the mother lode in the June 22 and 29, July 6 and 13, 1939 issues, namely the article "Distortion in Transformer Cores" by Dr. N. Partridge. This article and his more academic 1942 version in the British Inst. of Radio Engineers are both referenced in the *Radiotron Designer's Handbook, 4th ed.* I learned that Partridge's work appears in most subsequent transformer texts, for example, Sturley's *Radio Receiver Design*, Vol. II (the only text I know that actually designs an SE OT) and the modern day Grossners' *Transformers for Electronic Circuits*. The latter should be easily accessible.

Partridge used both theoretical and experimental analyses to calculate transformer distortion. The output tube may be viewed as an AC voltage source, E, with source resistance Rp driving current, I, into the primary inductance, Lp. (The winding resistance $R_{DC}$ could be included in series with Rp). The loaded transformer would have a load $R_0$ reflected into the primary circuit from the secondary, see fig. 2.

Before one can easily see why this circuit can produce voltage distortion it is necessary to view the BH loop in more detail. When a sinusoidal voltage is applied to a silicon-iron OT core the resulting hysteresis loop is as in fig. 3.

The sinusoidal distortionless voltage source E drives the current through the source resistance Rp into the impedance Z of the primary inductance Lp. The flux $\Phi$ = (flux density B) x (core area A), and B is determined from the BH curve for a given magnetizing force $H = 0.4\pi NI/l$, where N is the number of primary turns and l is the length of the iron magnetic path. It is crucial to think in terms of H or the amp turns NI first rather than B. The unloaded secondary voltage is proportional to the time rate of change of the flux, $\Phi$. Note, however, that $B = \Phi/A$ is a very nonlinear function of H. The core saturates at a value designated $B_{max}$ and also there are two values of B for a

**Fig. 1 - Effect of air-gapping on BH loop**




a) Ungapped b) Gapped

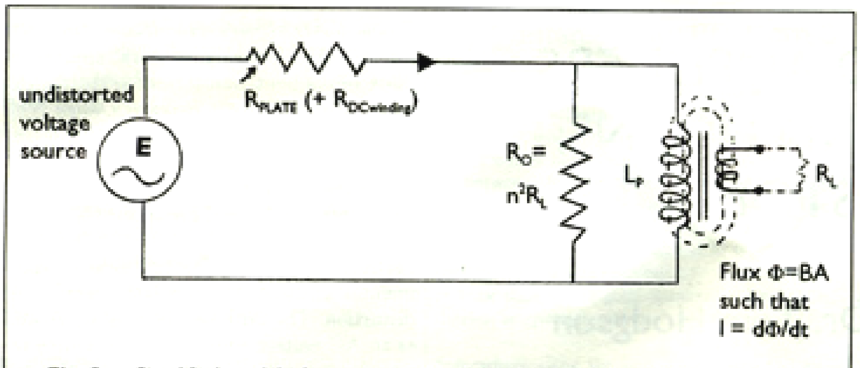



**Fig. 2** — Simplified model of output transformer, referred to the primary as analysed by Partridge. Note that L depends on E, and I, and H, and B, and thus μ !

given current I or H, depending on whether the sine wave is increasing or decreasing. If there is a small sinusoidal ripple in the positive peak, say, of the sine-wave it will produce a so-called minor loop in the BH curve, see again fig. 3.

How, historically, have scientists coped with this very difficult problem of determining B? Even the great acoustician Lord Rayleigh in 1886 looked at this problem. He approximated the loop by the dotted curve, using two back-to-back parabolae. More simply, if the dotted curve is assumed to be a straight line through the origin, we have the so-called quasi-linear magnetics. The relation between B and H is written $B = \mu H$, with $\mu$ called the permeability of the OT iron. For the quasi-linear case it is constant, being the slope B/H of the line (until saturation). Actually, as fig. 3 shows, it depends on I, and H, and B.

Like most transformer texts, I have delayed giving a formula for the inductance Lp. It can be written $L = 0.4\pi NI = 0.4\pi N^2 A\mu/l \times 10^8$ (cgs units), but note that the difficulty of the non-linearity is disguised. What is the value of $\mu$ for the iron, and so the value of Lp? In the absence of DC current, $\mu$ might be 2000 as compared with $\mu = 1$ for air. This explains why the BH curve tilts over to the right so much in fig. 1b, its slope $\mu = B/H$ is relatively smaller. The magnetic "resistance" or reluctance to flux crossing the air gap is high, so that the magnetizing force or (DC) current must be higher to drive the flux across the gap.

With the above background one can now understand Partridge's elegant description of OT distortion. The driving current, I, produces a flux Φ, and hence a voltage across the primary inductance Lp (and secondary) which varies with I (or H), with $\mu$ also varying. So I is distorted, B is distorted as well as the output secondary voltage, and the voltage across Rp will be distorted by an amount opposite in sign to that across Lp (remember the voltage source is taken as distortionless). Because the BH curve is symmetrical about the H axis, the harmonics (h) will be odd multiples of the fundamental source frequency (f). Partridge measured these distortion current ratios $I_h/I_f$ and called them the current distortion factor pertinent to the particular iron used, in his case 3½% Silicon-Iron, and varying with B, or I, or H. He plotted it against $B_{peak}$, see fig. 4. He called this "intrinsic" distortion because it depended on the OT, its iron, and B.

He also showed that these measurements would also closely describe the loaded OT if the secondary load resistance is reflected into the primary circuit multiplied by the turns ratio squared = $R_o$, see fig. 2. The distorted resistive part of the voltage distortion now appears across Rp and $R_o$ in parallel, = R'.

His final result is that: % harmonic voltage distortion = $\left(\frac{Ih}{If}\right).\left(\frac{R'}{Xp}\right)$ where Xp is the impedance of the primary inductance at the fundamental frequency f (=2πfLp). Partridge expanded on this formula in his 1942 papers, but my simpler interpretation follows his 1939 articles.

Let's take a simple PP example similar to one taken by Partridge to demonstrate this result. Say a 2 x KT66 pentode stage is

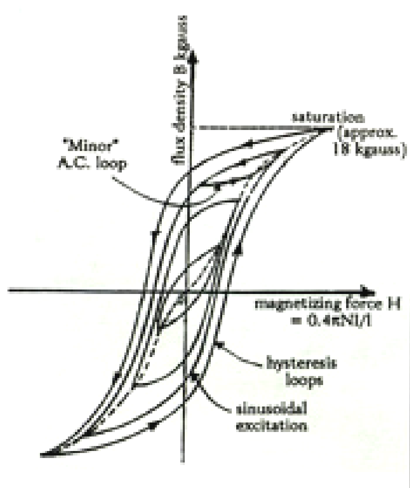



**Fig.3** — The BH curve for OT iron

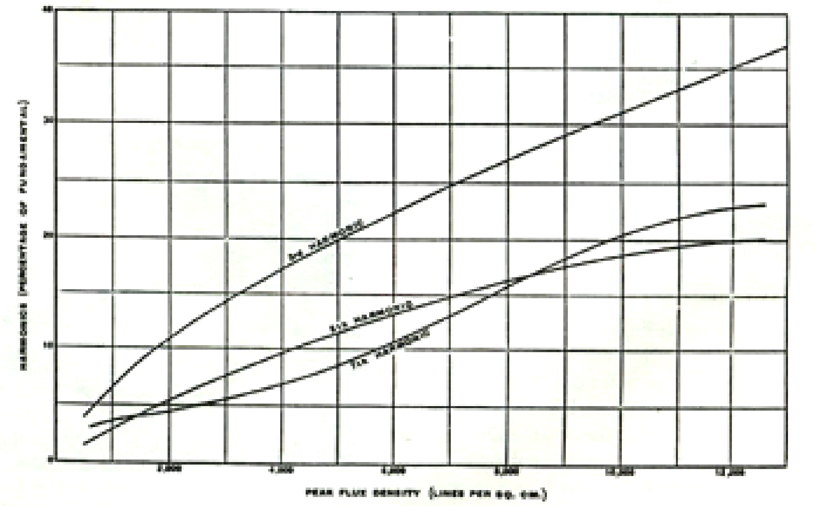


**Fig. 4** — Current distortion as measured by Partridge for 3½% Silicon-Iron, 50 Hz

used, with 2Rp = 50k ohms and plate to plate load resistance of 5k ohms. If $B_{peak}$ = 3000 lines/cm² (gauss) at full output and the impedance of the primary OT inductance is 20k ohms at f = 50Hz, then from fig. 4 the third harmonic current distortion is 14%, giving a voltage distortion = (14%) x $\frac{5kohms}{20kohms}$ = 3.5% in the absence of feedback. The advantage of triodes over pentodes is immediately seen from Partridge's equations. Say one used WE 300Bs and also the same OT is used (an oversimplified approach). A WE 300B has Rp = 700 ohms, so voltage distortion is (14%) x $\frac{2x700}{20kohms}$ = 1% ! in the absence of feedback. This, I feel, is a most revealing calculation in favor of triode output stages.

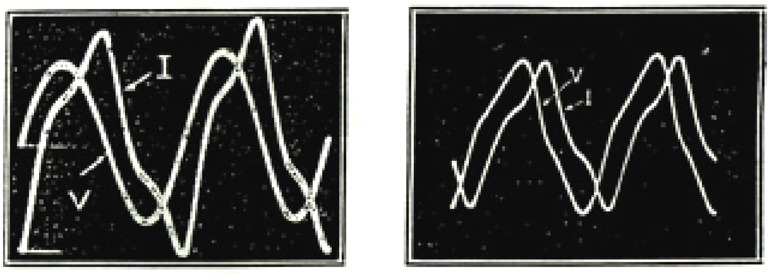
Partridge demonstrated this point elegantly with experimental measurements. If Rp = 0 there is no voltage distortion, see fig. 5a ! A typical current and distorted voltage for Rp ≠ 0 is shown in fig. 5b.

To me, the interesting part of Partridge's work now appeared in his fourth weekly article. He advocated the use of large air-gaps in OTs for PP designs (I calculated some 5 mils, besides the usual 1-2 mils inherently present in EI laminated cores). Now this is precisely the procedure for coping with the skewed BH loop resulting from the DC current present and loss of primary inductance in the SE case, read on.

Now what does an air-gap, size a, do? A simple view is to think in terms of H or amp-turns/inch. Then the total magnetizing force or amp-turns to maintain the flux is $H_{total}$ (l + a) = $H_{iron}$ l + $H_{air}$a, where $H_{air}$ = numerical value of B since $\mu$ = 1 for air. The iron is still working at the same condition as before, so the distorted current $I_h$ is the same. But now $H_{total}$, and so $I_f$ is much larger, say 4 to 5 times. So the current distortion $I_h/I_f$ has dropped by this factor. But, regrettably, as the BH curve has tilted, see fig. 1b, so has the effective permeability (known as the AC incremental permeability $\Delta\,\mu$) dropped by the same amount. So the value of 2πfL.p = Zp has dropped by this same amount also, as has $R_o$/Xp! So the voltage distortion is the same!! I call this fact that Partridge pursued air gaps, even though he knew that voltage distortion does not change with air gapping, the Partridge Paradox, and is the reason why I wrote this note.

Partridge saw this result as no great disaster, believing it was better to know you had an

B = 7,000 Gauss f = 50 Hz (from Partridge)




a) Rp = 0, Current distortion only b) Rp = Zp, Voltage and current distortion

**Fig. 5** — Why Triodes are better than Pentodes.

"intrinsically" more linear OT. Now one adjusted $R_o$/Xp, accordingly, presumably choosing triode output tubes as well as winding big OTs within the restraints of HF response. (Remember that at that time 15 KHz was regarded as adequate for musical reproduction and I detect from certain *SP* articles that some still believe this to be the case!) So his final PP OT was wound with far more primary inductance than necessary for good LF response before gapping.

The same is true of course for the SE OT with unbalanced DC present. Thus, *for a given OT*, SE operation does not straightforwardly reduce the voltage distortion. There is an additional complication in that the BH loop is now a minor loop (like in fig. 3) around the DC bias point, which is taken around a flux density on the order of 8 to 10 kilogauss. The slope of the minor loop is the average incremental permeability $\Delta\,\mu$) and depends on the air gap. So there is an optimum air gap size for maximum primary inductance.

In summary, Partridge suggested keeping the current distortion factor low, then design a good output tube-transformer combination, preferably from a big OT. Now, I know this will prove controversial to some. That's why OT design is an art, better left to professionals. (This is a plug for Mike LaFevre of MagneQuest who has patiently listened to my theories of the history of OT development.) In case Partridge's result may appear to you to be quite obvious, be careful how you might use a toroidal OT with a strip-wound core, for instance. The BH curve would now be very steep sided like the loop for the ungapped case in fig. 1a. Unless the DC current is carefully balanced in a PP stage with a typical toroidal OT, the BH curve will be skewed and *asymmetrical* about the H axis. This results in large (30-40%) second harmonic distortion at bass frequencies, producing a dark and murky bass sound with a dulled treble.

A fitting conclusion for me in trying to trace Partridge's work would have been to have had the opportunity to discuss it with Dr. Partridge himself. I must thank Dr. G. A. V. Sowter (now 93 years old and a colleague of Dr. Partridge) for giving me the sad news that Dr. Partridge was the victim of a WWII V1 rocket bomb in 1944. But his conception of the output tube-OT relationship leads me to make a remark on negative feedback (NFB) and its place in Tube-OT history.

For tube power amplifiers, the publication of the four-stage PP triode Williamson amplifier by Williamson in the April 1947 *Wireless World* proclaimed the use of NFB as a means to reduce the 3rd harmonic distortion from the OT, the triodes' second harmonic being canceled as a result of the PP design. The advantages of tetrodes over triodes (from a power point of view) quickly followed in Baxendall's Jan. 1948 *Wireless World* article. But to quote, "to reduce non-linearity distortion to a given level, it is of course necessary to apply considerably more NFB with tetrodes and pentodes than with triodes" — 3rd harmonic problems again, now from the pentodes as well as the OT.

Now could this be the plus for SE designs? Is it the 2nd harmonic (in small quantities) from the class A operated triode and the DC biased OT that enhances the musical sound? The golden era produced articles on 2nd harmonic distortion and the modern disaster of slew-rate limiting was also mentioned.

I have always viewed NFB, in its usual electronics application, as a way of making a circuit more independent of its active components. The op amp plus two external resistors with high open-loop gain (ßA) such that the closed loop gain is the ratio of the two resistors is an example, with its corresponding large decrease in the output driving resistance.

One theme came across to me in reading well over two hundred articles from the golden era, namely the relative economies of the designs. Box speakers with low efficiency required higher power (pentode) amplifiers. But just looking at OT advertisements in the 1954 *Wireless World,* I came across excellent C-core OTs by the Gardner, Gilson, Parmeko, Partridge, and Sowter companies, typically costing $18 to $20 each. Harold Leak's TL12 12W KT-66 PP mono amplifier and preamplifier cost $120 at the time. I know of only one British amplifier which used a C-core OT and that was the Lowther, costing $130 per monoblock — the stereo LP was yet to arrive. The C-core is, I feel, a partial answer to the Partridge Paradox and the use of big OTs. Economics didn't permit big, air-gapped OTs for commercially produced amplifiers, but I see no reason why hobbyists today shouldn't use superior OT design.

One cannot discuss low power amplifiers like SE without mentioning horn loudspeakers. They are not only very efficient, but their inherent acoustical loading at bass frequencies help zero feedback SE design where its output driving resistance is likely to be high compared with the golden era NFB PP designs.

Following comments in *SP#4*, I too have always enjoyed my Klipsch corner horns and I have admired Paul Klipsch for the way in which he produced a relatively smooth midrange horn by experimental determination of the termination conditions at the horn mouth. This is a difficult problem for horn theory. As an acoustician myself, I can say it is not easy to solve the acoustic wave equation for sound radiation for spherical waves, say with termination in another coordinate system, like rectangular. Classical horn theory carefully avoids this problem. It can be done today on high-speed digital computers (see one suggested method by E. Geddes, *Journal of the AES,* July/Aug. 1987). It is still better, with simple designs, to resort to experiment. I came across a great construction article for a short midrange horn for a 6" diameter driver in the June 1939 *Wireless World,* correctly designed by choosing the exit area first. Edgar has championed the use of the short midrange horn with non-compression, larger than usual, drivers. I am looking forward to listening to a pair of this type of horn with a pair of original Lowther PM6 drivers shortly.

To conclude, what have I (re)discovered? The golden era people certainly knew what they were doing as regards musical reproduction, and I haven't even mentioned the two hundred or so U.S. articles I have collected. I have listened to the Model 91-style 300B circuit presented in *SP #1*, as well as a parallel 300B SE design and a 845 SE design. It is said the wavefront seems to reach one more coherently, some say the silence is darker or the low level resolution is better. I still think the Leak TL12 PP KT66 triode-connected 12W monoblocks are difficult to beat but, as yet, I have not been in a position to do direct comparisons. Now if I could only find a cure for that CD treble!

I am open to correspondence and suggestions on the reasons for the musical sound of single-ended triodes (as are the pages of this magazine—*ed.*) Dialogue on the subject is sorely needed. I hope I have pointed you in the right direction with the preceding discussion, but before you question my humble description of Partridge's work, try to read him first.

# To Be, or Not To Be, Linear!

## The Single-Ended Transformer

by Dr. Tom Hodgson

This is a sequel to my historical note in *SP* #5 on the pioneering work of the late Dr. Partridge on transformer distortion. For those who missed that article, Partridge in the late 'thirties pursued the concept of larger than normal airgaps in push-pull (PP) output-transformers (OT). The airgap reduced the primary inductance and so his OTs were larger. His OTs for the 10 watt PP Williamson amplifier, which used triode-connected KT66s, weighed 14 lbs. for the EI laminated and 10 lbs. for the C-core designs respectively!

Partridge showed that OT distortion was worst at low frequencies and he even suggested a figure of merit or index for OTs using an inductance measurement at the line frequency for the design full-output power. (The industry did not adopt his recommendation). He put amplitude distortion ahead of flat amplitude response since, as he pointed out, for PP OTs the odd-harmonic distortion could subjectively swamp the fundamental at low frequencies.

The part of his work that really attracted my attention was, I quote, "Instead of having an inductance that varies enormously with the signal voltage; with an air-gapped (though larger) OT the inductance remains sensibly constant." He felt that now he could trust the low intrinsic distortion of the transformer and concentrate on the driving output-tube circuit. His theory showed that the plate resistance of the output tube(s) is the primary cause of voltage distortion at the transformer output; and so triodes with plate resistances of order 1kΩ were superior to pentode output tubes because of their plate resistances of order 10kΩ.

My previous article applied Partridge's ideas to the single-ended (SE) OT and in particular the BH magnetization characteristics of gapped and un-gapped OTs (please note that in the first printing figures 1a and 1b are reversed). Since writing the first article I have tried to find a simpler way of describing the electromagnetic difficulties in the operation of a SE transformer, and why SE amplifiers may sound as they do. This view is presented below, together with some magnetic measurements which I have made on two SE transformers, courtesy of Mike LaFevre of Magnequest and Peter Qvortrup of Audio Note, as well as measurements on a poor design.

What one requires of a transformer is that it should be a linear device. Let us view the magnetic properties of the iron as an output voltage V (like the flux density B) versus an input current I (like the driving magnetic force H). This graph is the same as the output versus input characteristics for any electronic device. It can look something like figure 1, which is an approximation to the BH loop for modern OT silicon iron without air-gapping. The characteristic is far from linear. At small signal levels a PP amplifier might have strong odd-order harmonic distortion (the dreaded "crossover" type). At very high signal levels corresponding to the magnetic saturation case for the iron (which occurs at flux densities of order 15 kilogauss) the signal will clip again with strong odd harmonic distortion.

Note the scale of the horizontal axis where I have suggested DC current values of only a few mA to saturate the PP OT iron. Partridge's suggestion of a significant air gap, as well as the use by Peerless of a few permalloy laminations as used in the 20-20 Plus OTs (thanks to Mike LaFevre for this historical note), all help to linearize the PP OT.

Figure 2 shows the case of the SE OT, which has a sizable air-gap, of order 0.006 inches or more, in the iron circuit. The DC current is put to work driving the air gap and this "biases" the input signal over to the right. I have selected the value of 50 mA DC as the design value of the tube DC current for this SE OT. Note that figure 2 has a "dummy" origin along the x-axis, and shows the high slope of the non-gapped iron (high permeability $\mu$) as compared with the now linearized SE OT characteristic.

As I stated in *SP*#5, SE seems to be a very attractive proposition since it eliminates the DC and AC balancing problems of push-pull designs, together with the PP collapsing magnetic fields which can lead to crossover distortion, etc. But there is a penalty for choosing the SE way. As a result of the air-gap, more AC current has to be applied to the primary for a given transformer. To express this point another way, the inductance of the air-gapped transformer drops significantly for a given size. So one has to have a *bigger* transformer than the PP case for a given design value of primary inductance. (Actually, the slope of the line in figure 2, which represents the permeability $\mu$, is clearly much lower than the PP case). Typically the SE OT of figure 2 would have an inductance of one-third of its corresponding PP design.

Figure 2 also shows that a linear output results from the input, see the sine-wave applied at the DC "bias" of 50 mA. This might correspond to a DC flux density of 8 kilogauss, say, with a peak-to-peak swing in AC flux density of ±0.5 kilogauss. Note, however, that for a given SE OT design one cannot increase the tube DC current too much otherwise the output signal distorts due to magnetic saturation, mainly second harmonic distortion this time (see the 100mA DC current value). This latter case is unlikely, see below. With this simplified overview my measurements of the SE OTs should be easy

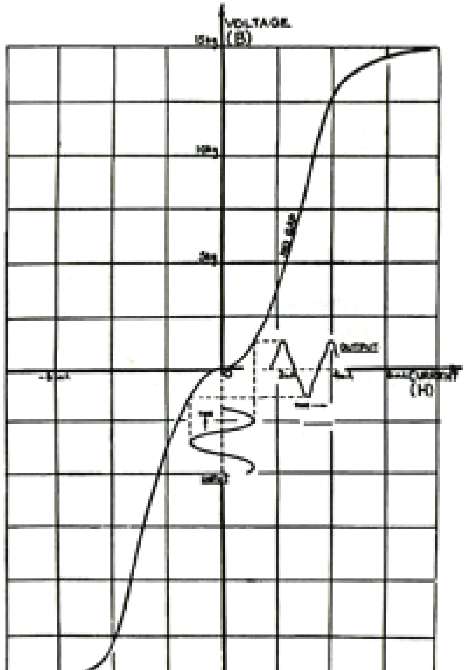



Figure 1. Input/output (BH) curve for PP OT with no air-gap

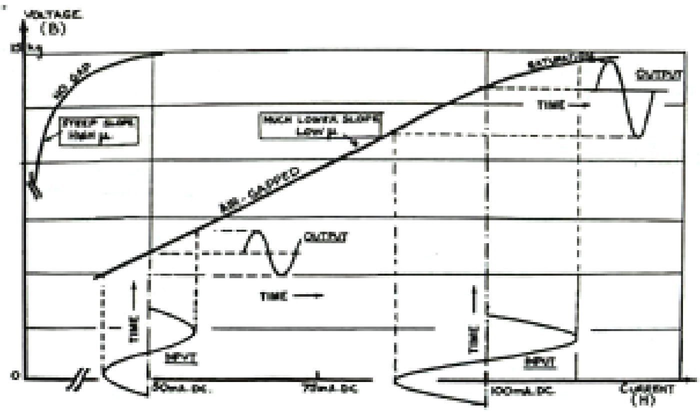



Figure 2. Input/output (BH) curve for SE OT with air-gap. (Note expanded x-axis).

to follow. We need the SE OT to be the so-called *linear inductor*, that is, its BH curve should be a straight line so that the primary inductance does not change with signal voltage, and better still it should remain constant over a range of output tube DC current.

This is demonstrated in figures 3 and 4 which show the BH characteristics for the Magnequest FS030 3kΩ and Audio Note 25W 2.5kΩ SE OTs. Following Partridge I excited the OT primaries with a 60Hz line variac of almost zero impedance. I monitored the driving current *I* and, by integration of the OP voltage, obtained the flux *B*. My results are taken from the x-y traces on an oscilloscope. This follows the standard testing procedure given in electromagnetic texts: the AC flux density swing was of order 15% of the DC value for the very large excitation voltage of 141 Volts RMS (±200 Volts peak). This is at least double the value likely to be encountered with output tubes like the 300B etc., so any non-linearity will be immediately obvious.

There is no doubt that the OTs are linear inductors even when the DC current is at least 50% higher than the design current. The Magnequest is a particularly conservative design. Even at excessive values of DC current both transformers show only slight (2nd harmonic type) curving-over of their BH characteristics. And remember you are never likely to drive these transformers as hard as I did in my tests. Both are excellent OTs.

Following Partridge, I calculated the voltage distortion at the design DC current values for both OTs with results below 0.1% when driven by a 300B. For typical music signals the distortion is probably below 0.02%. Therefore, in my view, a well-designed SE OT such as these *does not produce distortion* driving normal output loads.

To further demonstrate that a good SE transformer is linear I have plotted the measured primary inductance versus output tube DC current in mA in figure 5 and versus signal rms voltage in figure 6. The results are self explanatory and should answer the often asked question of how close to the design value of tube DC current should one operate? I hope my measurements have convinced you that these OTs are linear inductors as seen by, say, a 300B output tube. Any distortion (which will be worst at low frequencies) will come from the tube. That was the message of Dr. Partridge's work. Both of these transformers are fine devices.

So what should you expect in a good SE transformer? First, I will make a comment regarding the primary inductance, core size and the low-frequency roll-off of the amplitude vs frequency response. The -2 dB point at low frequencies is given by Sturley, *Radio Receiver Design*, Vol. 2, as:

$$f_{-2dB} = \frac{2 \times (\text{plate resistance})}{2\pi \times (\text{primary inductance})}$$

For a 300B, if Rp = 750Ω and L = 30H, then $f_{-2dB}$ = 8 Hz. I hope it is obvious by now that low frequency response costs money in an SE transformer.

With apologies to all electromagnetic scientists since I have no name for this law, if one multiplies the transformer weight (lbs) times the primary inductance (H) one obtains a kind of figure of performance per dollar cost. It is equal to 352 per $300 for the Magnequest and 176 per $150 for the Audio Note. (Actually the weight of the transformer is a rough measure of the core size and the amount of wire in the windings). Given today's prices, my "figure of merit" is around 1-2 for a chosen silicon iron OT (less for more exotic designs).

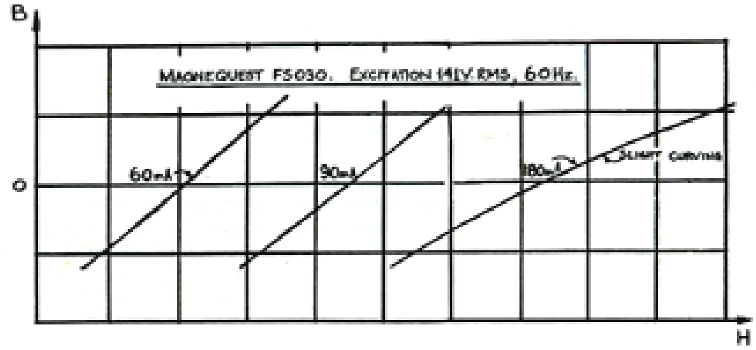



Figure 3. Magnequest FS030 — Cost = $300 Z = 3kohm Wt = 11 lbs
$I_{DC}$ = 60mA Core size = 1.5" x 2.25" Primary L = 32H

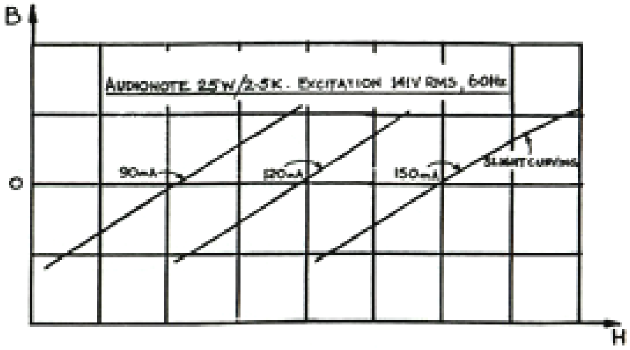



Figure 4. Audio Note 25W — Cost = $150 Z = 2.5kohm Wt = 8.8 lbs
$I_{DC}$ = 90mA Core size = 1.5" x 1.75" Primary L = 20H

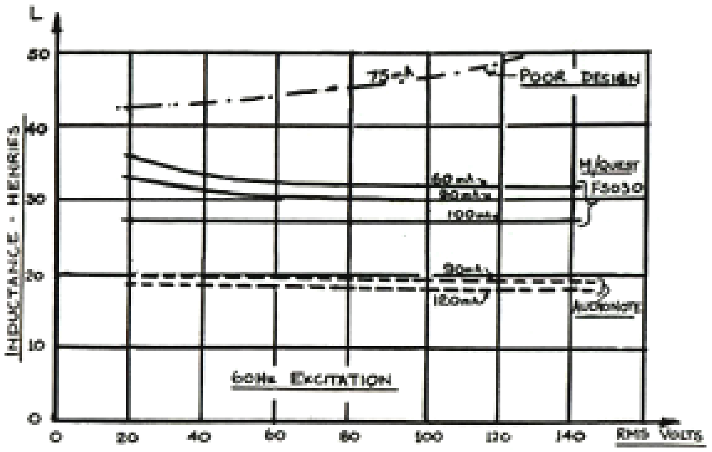



Figure 5. Inductance measurements for given dc current vs. excitation rms volts

To give an example of a "poor" design of a SE OT with non-linear characteristics, figure 7 shows a transformer with 54H of inductance for $I_{DC}$ = 75 mA, wt. = 8.6 lbs but with only a 1½ inch x 1½ inch core-size. Would you use this OT if it cost only $80? The figure of merit is 54 x 8.6/80 = 5.8! Wow, what a bargain! You can really think you are a cheapskate! Now look at the BH curves in figure 7. One is now close to the iron saturation region with a distortion at 60Hz of order 1% or greater at the design DC current value of 75mA, predominantly 2nd harmonic which produces some frequency doubling and a dark sound. What went wrong?

This is easy to answer, one cannot obtain such a high primary inductance (this also takes a lot of primary turns) with such a small core area. But with a small increase in air-gap which drops the inductance to 38H, the transformer is quite linear. (There is another factor which involves the primary and secondary wire resistance which leads to a loss factor. Remember a 1 dB power loss due to wire resistance doesn't sound much but it is 20% of your 300B's input power to the transformer. Typically you need an insertion loss factor of order <0.5 db = 10% loss).

This brings up the subject of the output tube load resistance. Values of 2.5 to 3kohm help the OT designer since the turns count is lower, the wire diameter can be larger. Parallel 300Bs are a good idea as far as this point goes. The 16 kilohm transformer for the Ongaku SE amp (*SP*#2) must be a real artwork item. Yet, I am told, it rolls off above 12kHz. Again I make the point, leave SE transformer design and manufacture to the experts. But I hope this helps in what to look for in choosing a transformer.

Of course, other parameters are important like high-frequency response. Here I have been primarily concerned with the linearity of the transformer at low frequencies where most of the trouble arises. The SE transformer designer has a tougher job at high frequencies since one is not able to employ the cunning inter-winding tricks available in the case of balanced PP designs to reduce leakage capacitance and inductance.

I measured the approximate frequency response of the Magnequest and Audio Note OTs using a 1kΩ resistance in series from an oscillator with 5V rms drive (strictly one should use the output power tube to do the driving) at the design DC currents. Both OTs rolled-off around 35kHz, the Magnequest was flat at 20Hz (because of its higher inductance) while the Audio Note had attenuation of 1.5dB. I also looked at Lissajous figures for both transformers in order to examine the phase at low and high frequencies. The phase angles agreed with the amplitude responses and nothing unusual was observed.

I am still leaning toward the belief that the main advantage of SE may be the excellent linearity for small signal levels. Does this explain the greater musical resolution that can be obtained as reported to date? At low and high frequencies there may be driving problems, certainly favoring horn loudspeakers. I still hope that *SP* readers will have things to report on this matter as more experience is gained listening to SE designs.

Reading between the lines of *SP* magazine I seem to detect a recommendation for a feedback push-pull amplifier for the subwoofer and SE drive for the rest of the music spectrum (unless you have K-horns or Lowthers). I have recently heard two excellent SE amplifiers driving original Voigt corner horns, one used a DA30 output tube, the other used an 845. The bass was noticeably more prominent, much more so than with the excellent PP designs used as a comparison. The SE designs seemed to have more low-level resolution, a more "you are there" presentation with greater depth. Most of the differences probably come from the output triode tube producing 2nd harmonic distortion from its own plate characteristics, *it is not the output transformers*!

But now we know the great failing of the current CD format, i.e. lousy low level resolution and harshness due to zillions of "intermodulation" products (thanks to Keith Johnson in his recent interviews). Is there a vinyl recording expert anywhere who can explain how the great LP recording engineers achieved depth, despite many wonderful, early stereo recordings being in mono at low frequencies? When I know this answer maybe I can R.I.P., but still listen to the music.

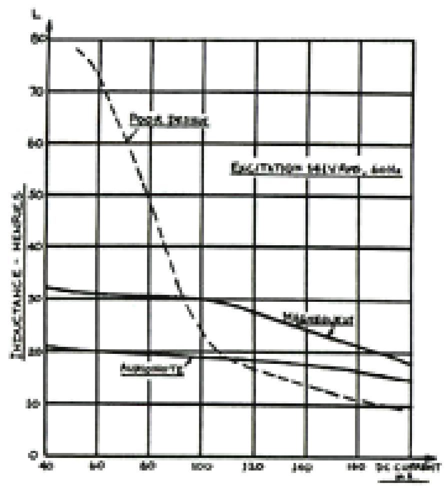



Figure 6. Inductance measurements for given 60Hz excitation volts vs. dc current

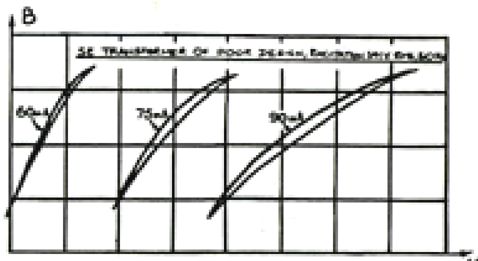



Figure 7. BH curves for different dc currents
Cost = $80  Z = 3kohm  Wt = 8.6 lbs  $I_{DC}$ = 75mA  Core size = 1.5" x 1.5"  Primary L = 54H