

J.C. Morrison on Phase Splitters

Note: This article originally appeared as a post by J.C. to the Joenet mailing list. HTML and minor editing for typos by [me](#), years of insight by J.C. Enjoy!

Date: Wed, 15 Jul 1998 03:14:00 -0700
 From: jc morrison <jcm@eclipse.net>
 To: joenet <sound@deliverator.io.com>
 Subject: was "Newer 300B's", now phase splitters

Johari Yip wrote:

> What other option do we have other than interstage X-former phase
 > splitters?

Allright, I'll try. Please respect that this takes time and effort, don't bombard me with dumb nonsense about tranny/resistor/capacitor types or other weird tweaky bullshit that will never make or break any approach. What we are concerned with here are the big things, namely, driving pp grids (or bases or gates).

a. What is the job of a "phase splitter"?

-To convert an unbalanced voltage into two balanced voltages 180 degrees out of phase.

b. What are the important features that determine the effectiveness of a "phase splitter"?

-As a first approximation, one would say that the output voltages are equivalent in amplitude and that the nonlinearities added by the circuit are as minimal as possible. in addition, it may also be of interest to some that the demands of the *devices to be driven* be satisfied as far as their own job is concerned.

Now, obviously there are a number of things that need to be addressed that are interconnected. but, the main issue is the job of the phase splitter and the job of the stage which the phase splitter drives. Johari asked: "what other option... other than a transformer"?

The options: the basic choices...

1. transformer
2. split load inverter: also known as P/K or "cathodyne" phase splitter.
3. "paraphase" inverter
4. differential amplifier

and the "mixed" combo splitters:

5. Williamson: cathodyne + differential amp (also known as a "long tailed pair)
6. Mullard: direct coupled SE to balanced floating diff amp.
7. "extended diff amp": a diff amp with an extra tube coupled to the non-inverting output so as to achieve two symmetrical output impedances...

In terms of the initial understanding of the job of "phase splitter", all of these can deliver two balanced equal amplitude out of phase voltages for one unbalanced input voltage. *(I am not going to go through this part of it with you, look at pages 521-527 of the 4th edition radiotron for the basics, all of these circuits can readily provide balanced voltages within 1% or 2%. this is better balance than any "matched" output tube is capable of, by the way. If we are talking about class A operation of the following stage, better balance is not significant distortion-wise until clipping. a cathodyne splitter with precision resistors can do 0.1% balance, for example. equal or better than any transformer. transformers will be only as balanced as the skill of the manufacturer allows.)*

If that was all there was to it, we could use any of these circuits and get equal performance! But as it turns out, from our initial job description, there is one more demand upon our arrangement that we have not examined. that is the **load** which is driven by our phase splitter, namely pp grids (bases, gates). What is the load we expect our circuit to drive? In the case of a triode, it is a very high variable impedance (What is the resistance between a grid and a plate? 10 megohms, 20 megohms?), a variable capacitance (Miller Effect) that will require charging, that will draw additional grid current above a certain range and will require a swing on the order of 30 to 60 vrms for most receiving power tube types (transmitting types will require more like 50 to 100 vrms). If it is a power tube we are driving, all of a sudden, our list of options becomes a confusing palette of imperfect choices. Let me go through them one by one.

1. **transformer:** As previously mentioned, balance in trannies depends upon balanced windings, balanced parasitic C + L, and identical termination. One really great thing about an interstage transformer is that its AC impedance and its DC resistance are two distinctly different things. Even in a step-up arrangement, the secondary DCR will be an order of magnitude less than the equivalent grid resistance necessary to properly terminate a coupling cap. this has an important benefit when looking into a grid that can abruptly draw current (as in clipping): as the current draw across the secondary increases, the bias shifts MUCH less than, say, a 100k resistor. This means a very stable grid parameter with a short time constant and low stored energy. On the other hand, transformers limit bandwidth, shift phase, and have quirky parasitic losses, not to mention that a really balanced tranny is EXPENSIVE. all those complaints about Tango NC-21s, ask any manufacturer how much fun it is to do balanced fine wire work! They honestly should cost more than any output tranny. and as I have harped on before (and no one listened...), if there are additional inductances prior to or following the interstage, the total lumped response of the system will be the summed number of poles. for example, an amp with two trannies between in and out will have a 2nd order response with the attendant phase shift, lag and ringing. this could be largely circumvented in the audio range by using an interstage with a bandwidth at least two octaves greater that of the output transformer. this **can** be done.
2. **split load inverter:** Arguably the best balanced of all phase splitters (in terms of unloaded voltage balance), it has two serious difficulties, namely that the output impedance of the two voltages is radically different, and it has NO gain. in a split load, the plate and cathode loads are identical resistors, and output is taken from the plate and cathode. the bottom part is functionally a cathode follower, and the top part is a grounded cathode circuit with a large unbypassed cathode resistor. i.e., low z out in the K circuit and high z out of the P circuit. If the high Z signal is looking at the starving mouth a power triode grid represents, you can easily imagine that it will be *really* easy to load it down. A typical power triode might have 15pf of grid to plate C, plus the socket stray (5pf), times the Miller number (μ times 20pf times the driver Miller, which might easily be 20pf by the time you're swinging 30-60 vrms, if you are not using a cathode follower...). All in all, it could typically shift from 60pf at 0 signal to about 400 pf at full output. If the driving Z is 50k (approximately 1/2 a 6SN7 with 20k p+k resistors), the top tube will load down by 8khz at full swing. The bottom tube will not load down until 80khz or thereabouts. Additionally, you will need about 400 volts B+ to swing 40 top and bottom, not to mention that the tube in front will have to provide 40 volts to the phase inverter! Weird! This is why Williamson used a combo cathodyne and a diff amp. It's a good solution. The cathodyne splits phase with near perfect balance, but it drives the much easier grids of a small dual medium μ voltage amp (2 or 3 pf instead of 15 or 20), which in turn have the same output z and easily drive pp grids. One further consideration that few have considered is using a power triode as a P/K inverter. An EL-34 wired in triode, with 4k P+K resistors could have an output z low enough to avoid problems in the audio range. The same 400v B+ would still apply...
3. **"paraphase" inverter:** You don't see this one much anymore, but it was popular in the early days because it provided balanced swings with gain. In this case, a sample of the out of phase output of a standard grounded cathode stage is attenuated and used to drive another tube which delivers in-phase output at the same amplitude. The difficulty here is that there is phase shift

between the two outputs because of the small difference in transit time: output one is added to output two. This is a problem mainly as frequency increases. The thing is that we actually *need* a clean bandwidth far in excess of what we hear, and especially far in excess of the tranny(ies). This is because harmonics need to decay naturally in order to sound natural. If I were to reproduce a continuous 40kHz tone at the same time as a 41kHz tone in a room full of people, what would they hear? If you said 1kHz, you would have gotten all the cash and prizes. This is in answer to the bozos that maintain that a 19.6 kHz (CD) bandwidth ought to be enough for anyone. A snare drum rim shot has every frequency from 12Hz to 125kHz, roughly (depends on the drummer and the snare). Have you ever heard a CD with natural sounding drums (or piano...)? I'll bet you haven't. (As a side note, new LP's are flat to 60 or 70kHz, no brick wall filter either, and the pilot tone for quad LPs was on the records, it was 40-something kHz...)

4. **differential amplifier:** The basic diff SE to Bal converter drives one grid of a difference amp and grounds the other. A difference amp amplifies only the difference between the two inputs. Diff amps have two outputs as well as two inputs: a non-inverting and an inverting output. Seems perfect? Actually, a subtle problem exists. One tube is operating as a grounded grid amp, and the other a grounded cathode. This means that the input admittance of the two halves are different. The grounded grid tube is neutralized for miller effect until a much higher frequency than the grounded cathode side. The gains are then different! Especially as frequency rises. However, there is an additional quirk in that the balance of the two gain wise is also controlled by the common cathode impedance. If the K_z is really big (as in constant current source...), the balance is near perfect, If it is small, it can vary by as much as 10%, assuming equal plate resistors. Big and small are dependent upon R_p (plate resistance). Or, this can be adjusted by using unequal plate resistors (ACRO UL-2, for example) or a pot of roughly 10% of the plate resistor value (telsonix instrumentation amps). If these things are addressed, the diff amp inverter can both provide gain and split phase. The complexity of the circuit is significantly more than a tranny or a split load inverter, in that a bipolar power supply is needed to really get the best performance. The "Mullard" inverter is a sensible compromise, as seen in Altec and Marantz amps from the US, it combines a DC SE stage to a floating diff with both grids driven but one held down with an RC. This is justifiably popular in that it doesn't need a complex power supply to swing a lot of volts and it can have excellent balance and symmetrical drive Z .

Now, if you are not directly coupling these splitters to grids, then chances are you are using a capacitor to block the dc. As many of you say, "Blech"! What does that really mean?

Unlike trannies, caps work poorly at the lowest levels. They get better as the swing increases. The bigger the cap, the bigger the problem. This is because of the dielectric properties of cap materials. Leakage and absorption problems cause smearing of the signal. Trannies get weirder and weirder as the swing increases. This is because of the iron. Both are affected by fields. I wonder why? The energy storage of $L+C$ is in fields surrounding the conductors, electrostatic and magnetic. It's easy to mess with it, all you need is more fields moving in different phase and magnitude... Of course, if you are using polystyrene or teflon caps, the dielectric stuff is minimized (paper is worst in terms of absorption, although it can be improved a bit with the addition of certain impregnations), but obviously, choice of caps can be a factor in getting the best out of an RC coupled stage. And interstage trannies with **good shielding** and no potting material (!) (dielectrics again...) and fancy high perm materials can make a big difference in the quality of bigger swings...

So, I hope that this answers your request for options. As you can see, there are several workable things here. There are combinations that can enhance certain things but there is also a point of diminishing returns. Try to remember that driving a power triode is NOT a trivial thing. If you want extraordinary results, you have to employ extraordinary measures. Mostly this just means looking at every stage and figuring out what is and isn't happening. Be aware of the source impedance of every stage and how the following stage loads it. If you pay attention, any of these methods can bring about excellent results.