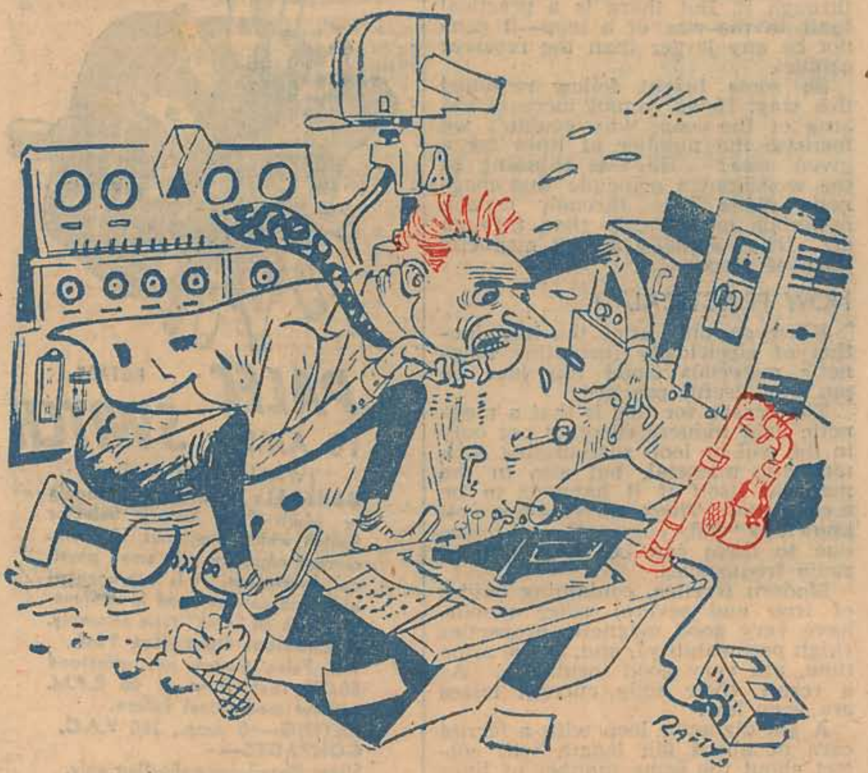


real genius in their choice of the name "Ultra-Linear". Applied in the commercial field, such genius would lift an obscure radio or refrigerator to the top of the market. As a name it's a real "beaut". No amplifier can be expected to sell, these days, unless it contains this modern wonder.

Unfortunately, the name is so palpably extravagant and meaningless that I doubt it will ever take its place in technical literature along with traditional terms. On a permanent basis I mean. I can't see learned writers and engineers adopting a term which describes a linearity curve as being straighter than straight!

WANTED: A NAME

Consequently all and sundry are busily engaged, just now, in the popular pastime "Give It A Name". It isn't easy, either.

One English correspondent refers, in most dignified fashion, to "distributed load pentodes". As a term it's technically correct but rather a hazard for those who wear false teeth! It has the same mellifluous quality as Horatius Augustus Ramsbottom!

One might suggest, of course, a combination of words to produce something like "tripode" or "tritode".

Let's Buy An Argument

After having spent so long with traditional amplifiers of the triode and pentode variety, it is a refreshing change to have something new to think about. I refer, of course, to the "Ultra-Linear" circuit and all the problems which it poses.

BUT perhaps I should begin by qualifying the words "something new", because they are not strictly true!

About three years ago (February, 1952, to be precise) we reprinted an article on the subject which had appeared just previously in the American magazine "Audio Engineering". It was written by two worthy gentlemen, Messrs. Hafler and Keroes, who proclaimed the virtues of the circuit in no uncertain fashion.

PRIOR TO THAT . . .

Previous to that, however, in 1943, an English author had something to say on the subject and he is currently lamenting that the idea had to go to the US and back again before it received any real attention from English designers.

But it seems that the idea had already travelled a fair distance before that—all the way, in fact, from Australia! As far as I can gather, it was first conceived and put into print by Messrs. Rex Lackey and Bob Chilton, of the Australian Radio College. The date? Somewhere about 1932!

As the story goes, they had just received one of the wonderful new pentodes (or maybe penthodes) and, while impressed by its output and sensitivity, were anything but impressed by its "tone". Perhaps some kind of a compromise could be struck?

Suiting the thought to the deed, they picked out a push-pull output transformer, connected one side to plate, one side to B-plus and ran the screen to the centre top. This half-triode, half-pentode thing sounded so promising that students of the said college were officially advised to use their pentodes that way!

If one might repeat a well-worn phrase—"There is nothing new under the sun".

Apart from a well-phrased article, Messrs Hafler and Keroes showed

by Neville Williams

(Please accept my humble apology).

The best term I've heard to date is "partial triode", suggested by Mr. Langford-Smith. It's simple, factual and easy enough to say.

But enough of that. Let's get on with more technical business.

As you will doubtless appreciate by now, "Ultra-Linear" poses some tricky problems, partly by its nature and partly because it happens to come at a time when the whole conception of amplifier design is changing. Engineers are striving to evolve new criteria by which performance can be judged.

ROOM FOR RESEARCH

While the Ultra-Linear circuit certainly works very well in practice, its theoretical background is full of gaps—like some of Sydney's "shark-proof" nets. It may be 12 months or more before the full pattern of its operation begins to emerge.

Just how, for example, should the Ultra-Linear circuit be regarded? Is there something specially beneficial or mysterious about tapping the screen down the load or is it basically just a convenient method of applying feedback around the output stage? It's rather important to get this matter straight.

The idea of a feedback loop around the output stage is gaining favor anyway, these days. Such a loop is in the position where it can do most good and where, being confined to one stage, there is the least risk of it producing instability due to phase rotation. An additional loop (or loops) may still be used over several stages but they can afford to operate with more modest degrees of gain reduction.

INPUT IMPEDANCE

Care is necessary, however, because the traditional feedback circuit from plate to grid of an output stage severely lowers its input impedance and makes things difficult for the proceeding valve.

The Ultra-Linear arrangement overcomes this problem very neatly—or so it would seem. The grid input impedance does not appear to be drastically affected and the two active elements (plate and screen) are as intimately coupled as one could wish for. What is more, an overall feedback loop can embrace the stage as simply as it would a straight triode or pentode. All that is on the credit side.

However, this "feedback", as we have called it, tends in some cases to degrade power output —and that is something that feedback doesn't normally do!

Is this because we are applying the feedback to an element (the screen) which is often not too linear in its control characteristics? Some have suggested that, when the screen "overloads"—or runs into its non-linear region—the output of the stage goes awry.

Personally I doubt this line of reasoning, though it may contain a modicum of truth. I am more inclined to look for the solution of the power output problem in the fundamental difference between a triode and a pentode.

The pentode (or tetrode) gets its extra power and efficiency in no small measure from the ability of the screen to keep current flowing through the valve when the plate voltage swings to quite low values. It extends the load line into a region which a triode can only match by running the grid positive, as in class B.

TRIODE v. TETRODE

To see what I mean, have a look at figure 1, which compares the characteristics of a 6V6 operating alternatively as a tetrode and a triode.

Under ordinary tetrode conditions, with 250 volts on plate and screen and a bias of -12.5, the maximum signal grid swing is from zero to -25. These two bias lines are drawn solid, together with the relevant 5000-ohm load-line.

Note how the plate swing extends from over 400 volts down to less than 50, while the current swings on peaks from over 85 down to around 10 milliamps. Reduced to RMS values and multiplied out, the figures yield a power output rating of 4.5 watts.

For triode operation, the screen is connected to plate so that the screen

CURVES HAVE A STORY TO TELL

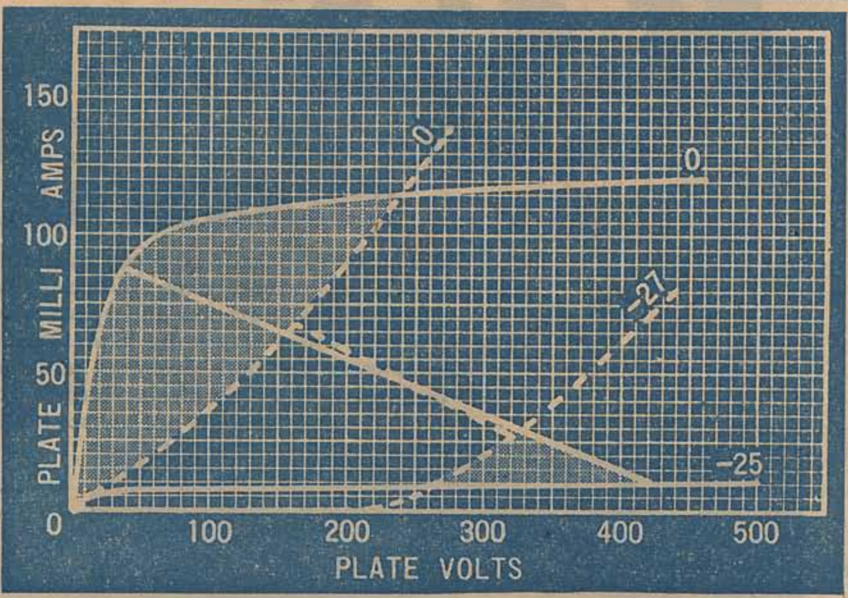


Figure 1: A comparison between the plate swing of a 6V6 as a pentode (solid lines) and as a triode (dotted). The shaded area represents the advantage the pentode has in power output. But what would the Ultra-Linear curves look like?

voltage must follow the plate voltage exactly. When the plate voltage swings downward, the screen voltage naturally follows suit.

The effect on characteristics is drastic as far as power output is concerned. Have a look at the triode curves, shown dotted and note how the peak voltage and peak current swings are reduced to about half those for the original tetrode connection. The whole of the shaded portion of the graph is virtually lost and power output reduced by over 4:1.

"IN BETWEEN" CHARACTERISTICS

In the ultra-linear arrangement, since the screen is tapped part way down the load, it seems logical to assume that characteristics will fall somewhere between the limits shown in figure 1. Peak plate excursions will not be as great as for the pentode connection, with a consequent loss of output power.

But why is the effect apparently more noticeable with some valves than with others. Some suffer a reduction of nearly 40 pc below

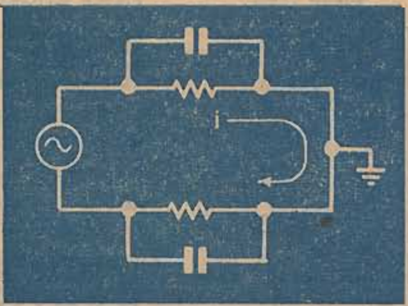


Figure 2: If the phase splitter can be represented as a generator in a series circuit, it must be self-balancing.

the pentode output power. Others, notably high transconductance types, suffer hardly any reduction at all!

It might be suggested that the plate current in such types is more sensitive to variations in grid voltage than in screen voltage.

Yet again, it may be the result of some "accidental" screen characteristic of a high-Gm tube. Something to do, perhaps, with grid-screen or screen-plate transconductance. Such figures are not normally extracted or published.

It might even be that the performance of an Ultra-Linear stage could be predicted from the kind of comparison envisaged in figure 1.

It would be an interesting field for investigation, if one didn't have to do other things in life than write these columns.

Some English designers have shown preference for an arrangement which often shares the name "ultra-linear" or "distributed load". I'm not trying to impugn the designers here, as much as to draw attention to a vague idea that seems to be abroad that the Ultra-Linear scheme can be achieved alternatively in the cathode circuit.

SCREEN SUPPLY

In this arrangement, the screens are returned to their normal B-plus feed point, which is a handy feature if the optimum screen voltage has to be less than the plate voltage. It saves the untidy business of having to string dropping resistors and bypass capacitors between each individual screen and its tapping point.

The difference is in the cathode circuit. Instead of returning to earth directly, the cathode returns pass through an additional winding on the output transformer.

The voltage injected into the cathode circuit thus appears as a potential difference between cathode and grid, and between cathode and screen.

Naturally enough, the feedback signal between cathode and grid has by far the greater influence on the valve's performance and, in fact, it becomes a half-baked cathode-loaded output stage. It recalls the work we did with these circuits a dozen years ago and the discussions as to whether the screen should be connected to B-plus, or decoupled and by-passed to cathode.

Without getting involved again in all the details, I can't see that the cathode feedback arrangement has much in common with the original "Ultra-Linear" or tapped screen circuit.

A BETTER CIRCUIT?

It operates primarily as plate-to-grid feedback, the screen feedback having only a very secondary effect. This being so, it should not show a marked degradation of power with any output valves. It may, in fact, be a better circuit on this count, though demanding a more complicated output transformer.

We shall see.

Returning now to the "Ultra-Linear" (or partial triode or screen feedback) arrangement, the editor made a few tentative remarks last month about the possible complex loading effects such a stage may have on the driver valve.

They were prompted by a higher-than-anticipated IM distortion reading when using a conventional plate-cathode phase splitter. Though there was no time to track it right down, it appeared to have some connection with the overall balance of the push-pull output system (note that I said "appeared to have").

At this stage, I can well imagine a particular section of audio enthusiasts leering in a most objectionable fashion and mouthing the words, "I told you so". However, such an attitude is scarcely justified.

All arguments we've ever had on the subject have been based on observations within or just above the audible spectrum and using conventional triode and pentode circuits. When tracked down, every condemnation of the phase splitter, thus far, has turned out to be due to error introduced by meter or CRO input impedance and its unequal loading effects on the two sections of the circuit.

INPUT IMPEDANCE

When we came up against the problem on this occasion, the natural reaction was to speculate about the input impedance to an Ultra-Linear stage. Was there anything unusual about it?

There seemed to be no reason why the input resistance should change but what of input capacitance? "Miller effect", for example?

When you come to think about it, imposing a signal voltage on the screen approximately equal to one half the instantaneous plate voltage, must re-introduce Miller effect as a significant quantity.

While the Miller effect formula is simplicity itself in its usual form, the Ultra-Linear circuit introduces some special complications. We could reduce the gain figure (m) by an appropriate amount but what of the grid-screen capacitance? It was not available for any of the valves with which we were concerned.

My guess was that the input capacitance to a typical Ultra-Linear stage would be 100 pf or more, depending on the construction of the valve and its transconductance. This value of capacitance would be shunted across each half of the phase splitter output.

But why the sudden interest? What of straight triodes? Wouldn't Miller effect be a lot worse than with Ultra-Linear?

Not necessarily. If you consider the popular 2A3, it has a stage gain of 3 and a grid-plate capacitance of 16.5 pf. This gives us a figure for input capacitance, all told, of no more than 70 pf.

My tip is that an Ultra-Linear

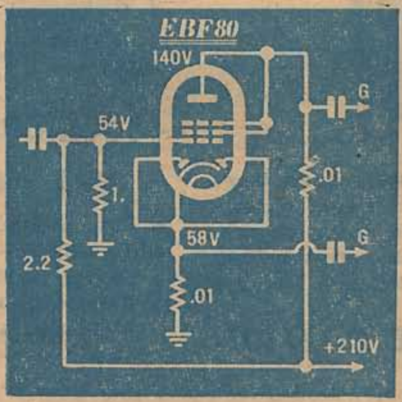


Fig. 3. From the magazine "TSF et TV" comes this rather unusual version of the phase-splitter. Whether it has any advantage to offer is doubtful.

stage, using a high gain valve, could double that figure.

Having thus "guesstimated" a figure of such proportions, one might be excused for assuming that the capacitive shunting would unbalance the phase-splitter at high frequencies, since it would presumably shunt the high impedance plate side more seriously than the low impedance cathode side. However, such is not the case.

SERIES CIRCUIT?

Reduced to fundamentals, the phase-splitter may be regarded as a generator with a load in each leg returning to a common "earthy" point. Each load is made up principally of a DC load resistor (usually about .05 meg), shunted by a following grid resistor (usually 0.5 meg.) and a virtual capacitor, as already discussed.

It is, in fact, a simple series circuit and, provided the two loads remain symmetrical, the circulating current around the series circuit must develop identical signal voltages across them.

Ordinary care in wiring should preserve the capacitive balance well enough while the resistors can be checked, one against the other, with nothing more elaborate than an ordinary ohmmeter. This is one of the big features of a phase splitter.

The difficulty arises when we try to attach any measuring equipment at all to the circuit to check what commonsense tells us must be correct.

In the supersonic region, the capacitance of a test lead, hung on the cathode side, can be quite sufficient to act as a partial bypass and increase output on the plate side. Conversely, such extra capacitance on the high impedance plate circuit markedly reduces the output, leading to an entirely false impression.

Just how important this point is became apparent from some further observations on phase splitter operation.

Examination of the behavior of a phase splitter in a typical Ultra-Linear amplifier showed the balance to be virtually perfect at 1000 cps and still perfect at 10 Kc—or so close that it didn't matter. But at 50 Kc the balance had deteriorated markedly.

Then I noticed that touching the VTVM lead on the respective grids had a slight reaction on the output of the amplifier, as shown on a separate meter. Touching the VTVM lead in he cathode side increased the output slightly, while touching it on the plate side had the opposite effect.

AFFECTING CIRCUIT

Very obviously, a perfectly respectable Vacuum-Tube Voltmeter was affecting the circuit, despite its apparently high input impedance.

Substitution of an RF probe for the normal audio test lead practically eliminated the effect and revealed that the balance was indeed very close to perfect.

If the phase splitter is indeed unsatisfactory with an Ultra-Linear stage, we will presumably have to invent another explanation for it. It is entirely possible that our queries were due to some other effect which escaped our notice.

The evidence was purely circumstantial.

Just in passing, I noticed recently in a French radio magazine, an interesting variation of the traditional phase-splitter circuit.

In an effort to reduce the overall impedance of the stage, the plate and cathode loads had been reduced to 10,000 ohms each.

In addition, instead of returning the grid resistor to a point on the cathode circuit, as is usual, the grid taps into a high impedance divider strung between B-plus and earth. The resistors are so proportioned that the grid assumes a potential slightly and suitably less positive than the cathode.

WHAT ADVANTAGES?

On the surface, the arrangement would not appear to have any special advantages. The assumption of correct operating conditions would not be quite as automatic as with the conventional arrangement and the stage would have a much lower input impedance.

The flow of signal current through the grid circuit would certainly be more or less direct to earth instead of via the cathode load, but this has never been considered as a significant factor in the practical operation of a phase-splitting stage.

However, there's the circuit, for what it's worth, in figure 3.

There is one difficulty about the phase splitter which is well known I refer to its poor overload characteristic on the plate side.

The moment the particular output

valve runs into grid current, the wave pattern flattens abruptly. While a good amplifier system should never have to be pushed anywhere near this extreme, the effect doesn't look nice on a CRO screen and a more gradual overload characteristic is to be preferred.

Various phase inversion circuits have been evolved which present a lower and reasonably balanced source impedance for the push-pull signals. Unfortunately, however, they lack the big feature of the phase splitter in not being self-balancing in terms of grid drive.

Some achieve an automatic and permanent degree of unbalance. Others achieve balance by a careful selection of circuit values. But they go out of balance if the valve sections should age differently in service.

Some use too many coupling components, leading to a "messy" circuit and a suspected source of phase rotation. Others are too easily upset by a flow of grid current in the output stage.

A NEW CIRCUIT?

Just before penning these sentiments, I succumbed to the urge to invent a phase inverter circuit all to myself that would be less prone to these difficulties. Well, I did invent one that's original as far as I'm concerned. It may or may not be so to readers.

Have a look at it, anyway, in figure 3.

It starts off with one section of a twin triode as a traditional phase splitter. The drive for the lower output valve comes off the cathode circuit, as usual.

The plate side of the phase splitter, however, is directly coupled to the grid of a second triode section acting as a cathode follower. The drive for the upper output valve is taken from this cathode circuit, thereby providing its grid with a low impedance signal source.

The whole arrangement can be made to look very simple by reason of a couple of happy accidents.

The lack of shunting on the plate side of the phase splitter triode increases slightly the signal voltage across this portion of the circuit. The increase is just sufficient to offset the slight loss in the cathode follower, resulting in an almost exact balance in drive to the two output grids.

WORKS OUT SIMPLY

Again, when using a general purpose twin triode, suitable operating conditions for the direct-coupled section are obtained by simply doubling the value of the cathode load.

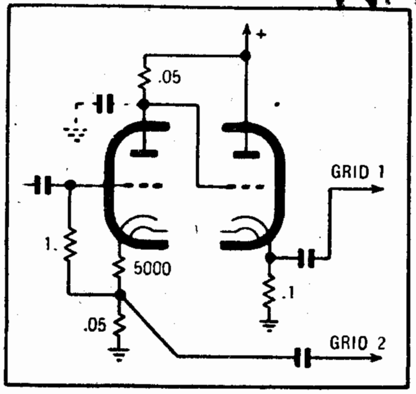
The direct coupling ensures a minimum of phase rotation while the nature of the circuit preserves it automatically from errors due to valve ageing, &c.

Is it perfect, then? What the world has been waiting for?

Unfortunately, no! The balance is excellent and automatic at all frequencies in the audible range, but it goes awry in the supersonic range —if that matters. The output valve driven from the plate side, gradually gets more and more drive, while its mate gradually starves.

The reason is found in what I've already had to say about input capacitance.

If the cathode side of the phase-splitter feeds a triode or an Ultra-



Another and perhaps original contribution to the list of phase splitters. Like all the others, it has good features and bad ones.

Linear grid directly, it finds itself shunted by a capacitance of about 100pf. This acts as a cathode bypass on the stage, gradually taking effect in the supersonic region.

As a result, the cathode drive falls away, the degenerative effect diminishes and the output on the plate side begins to rise.

There is nothing to limit this rise, either, because the plate side is shunted only by the small input capacitance of a cathode follower stage.

To restore the balance it is necessary to bypass the plate with a capacitor large enough to make up the difference between the input capacitance of the cathode follower and the output valve it drives.

For a 6BW6 output stage (Ultra-Linear) the balance capacitor turned out to be 68pf, which added to circuit strays, &c., would suggest a total effective input capacitance of 75 to 80pf. This for a relatively low Gm valve.

It isn't any hardship, of course, to add this capacitor, the only objection being that its value would have to be suited to the output stage. Once fixed, however, the balance should stay put at all frequencies and irrespective of valve ageing.

Like the phase-splitter it could be upset only by a variation in two resistors, the plate and cathode loads. The resistor in the cathode follower could vary all over the shop without upsetting things, because of the self-compensating nature of the circuit.

Anyhow, there it is — a new phase-splitter (or I think it's new) which may be forgotten henceforth or taken up and credited for the sake of prosperity to Yours Truly.

One more observation and I'm through. The curves we published last month showing the comparative performance of pentode and ultra-linear output stages did two things:

1) They demonstrated the superiority of the ultra-linear connection, all other things being equal.

(2) They showed the pentode to be surprisingly good, nevertheless.

SPEAKER LOAD?

But remember one very important thing. All curves thus far have been taken into a resistive load, for personal and social reasons. I don't know whether you've ever tried to conduct lengthy distortion tests, at full volume into speaker load. It isn't pleasant.

Only when such tests are taken, however, will the full story be told. I expect that the difference between the classes of operation will become greater. And how will the Ultra-Linear pan out when measured with a highly reactive load? Will it be nearly as good as a triode, or only half as good, or what?

And does it matter, anyway? Can one appreciate the difference, considering the limitations of the rest of the system? I'm not sure of that right now, but it isn't relevant. As long as there's a fragment of distortion to chase or a tiny decibel to pick up, the amplifier fans will be after it, whether they can hear the difference or not.

Now you must pardon me, I have to rewire my amplifier!

A further possible criticism of the circuit is that it contributes no more gain than the ordinary phase splitter, yet uses a twin triode.

Agreed! Whether it matters or not, however, depends on circumstances.

Plenty of amplifiers have been designed around the ordinary phase splitter, in which extra gain would only be an embarrassment. The amended arrangement could be substituted very easily, a twin triode replacing the present single valve.

But, of course, there are other cases where gain is at a premium.