electron's

TRIODE OPERATION

of

AUDIO and RF MODULATOR

POWER TUBES

Readers, please note this page is presented for your education, information and guidance only.

This paper refers only to the characteristics and performance of push-pull tube audio amplifiers without negative feedback.

For reasons detailed elsewhere in my website I have no interest whatsoever in either single-ended amplifiers or trans-stage negative feedback.

For full ratings and applications of specific tube types in which you are interested please refer to the manufacturer's catalogue.

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1. TRIODE OPERATION OF POWER TUBES

1.1 TRIODE TONAL CHARACTERISTICS

It is well established that many listeners prefer the "soft" and certainly pleasant tonal characteristics of triodes.

However triodes suitable for audio power operation are becoming extremely scarce in the world market and aftermarket prices for popular types have increased astronomically in recent years.

So it is often more convenient to use tetrodes, pentodes or beam power tubes because of availability, cost or convenience.

An often overlooked design feature is that most popular audio power triodes have directly heated filaments, thus creating a potential for problems in dealing with hum, reliability and power supply - whereas most popular tetrodes, pentodes and beam power tubes incorporate indirectly heated cathodes - ie use separate heaters.

Most tetrodes, pentodes and beam power tubes can be successfully operated as triodes in either voltage amplifier or power tube applications, by connecting Grid #2 directly to the Plate.

In the case of triode operation of pentodes and beam power tubes, Grid #3 or the electron beam shield respectively, are still usually connected to the cathode or filament, as is the case for normal tetrode or pentode connection.

The characteristics of a pentode/ beam tetrode as a triode are largely determined by the Grid#1/Grid#2 amplification factor which is dependant not on the Anode/Cathode spacing but the Grid#1/ Cathode and Grid#2/Cathode spacings.

The function of the Plate in a triode connected multi-grid tube is merely to collect all the electrons that have been attracted by the Screen-Grid acting as an ANODE which, because of its open structure, will collect relatively few electrons - which probably accounts for the increased allowable screen voltage when so connected.

My personal view is that to ensure tube operation - including Cathode Current, Plate Dissipation and Screen-Grid Dissipation - is maintained within design limits, the applied DC Plate and Screen voltages should never be greater than the rated Screen-Grid Voltage.

1.2 SUITABLE TUBES

The Radiotron Designers Handbook 4th Edition 1953 says:

(i) Triode operation of pentodes

Any pentode may be operated as a triode, provided that none of the maximum ratings is exceeded, and the characteristics may readily be calculated if not otherwise available.

When the cathode current of a valve is shared by two collecting electrodes (e.g. plate and screen) the mutual conductance of the whole cathode stream (i.e. the "triode g_m") is shared in the same proportion as is the current.

Let I_k = cathode current
I_{c2} = screen current
I_b = plate current
g_m = pentode transconductance (to the plate)
g_t = triode transconductance (with screen and plate tied together)
and g_s = screen transconductance (with pentode operation).

Then $I_k = I_{c2} + I_b$ (1)

$g_t = g_m + g_s$ (by definition) (2)

and $g_m/g_t = I_b/I_k$ (3)

If it is desired to find the screen transconductance, this can be derived from the expression

$g_s/g_m = I_{c2}/I_b$ (4)

or $g_s/g_t = I_{c2}/I_k$ (5)

Manufacturer's data is available for triode operation of some popular types of tetrode, pentode and beam power tubes such as EL34/6CA7, 6V6GT, KT66, KT88, 807, 6146. However, typically they are pragmatically assigned a significantly higher Grid #2 rating than for either tetrode or pentode connection.

The higher *triode connected* manufacturer's rating should only be used with great caution as it increases the risk of thermal problems and parasitics.

When tetrodes and pentodes are connected as triodes care must be taken to ensure the Plate and Screen Voltages are not too low, to prevent the Screen-Grid from becoming the primary anode and thus attracting too many electrons, thus exceeding Screen Dissipation rating and fusing the Screen-Grid.

For efficient and reliable operation, a minimum Plate and Screen B+ Voltage of at least half the rated Plate Voltage is therefore recommended. This obviously limits the choice of tubes to those tubes having an adequately high Screen-Grid Voltage rating.

In my opinion, the most likely candidates for triode connection are the:

6AQ5	**(275 VDC)**	**7 pin**
6V6GT	**(275 VDC)**	**Octal**
6CZ5/6973	**(285 VDC)**	**9 pin**
5881/6L6GC/7027A	**(400 VDC)**	**Octal**
KT88	**(550 VDC)**	**Octal**
813	**(1100 VDC)**	**Giant 7 pin**

All are well proven fine quality beam power tubes, each famous in its own right.

However with more careful selection and operating conditions, there are many other fine tetrodes and pentodes that are capable of excellent triode operation - such as the **EL34/6CA7 (425 VDC)** (Octal) and **EL84/6BQ5 (300 VDC)** (9 pin) pentodes.

1.3 OTHER OPTIONS

STC BRIMAR, in their ***Valve and Teletube Manual #8 (1959)*** state:

"Where Pentodes are connected as Triodes, the Suppressor Grid should be connected to the Cathode, unless otherwise stated" (end quote)

However as far back as 1940, RCA state that the Suppressor Grid (Grid #3) in Pentodes may be connected to the Screen Grid (Grid #2) to operate Pentodes as Tetrodes. It follows that in Triode operation of Pentodes, Grids #2 and #3 can be strapped to the Plate if preferred.

Unfortunately, it will be noted that many of the popular Pentodes, such as the 6BM8, 6BQ5/EL84, 6GW8 and 6M5, have their Grid #3 internally connected to the Cathode, leaving the designer only Grid #2 available to connect to the Plate for triode operation.

It may well be however that in those Pentode tubes (other than Beam Power Tubes described as "Pentodes" in British and European catalogues) having a separate pin connection for Grid #3 - eg EL34/6CA7, 803 and 837 - some benefit might be achieved by connecting Grid #3 to both Grid #2 and the Plate to form a composite equi-potential tube element for triode operation.

This option would certainly ensure a smooth flow of electrons through and beyond the Screen-Grid. Any electrons reflected from the Plate (Secondary Emission) should get caught up in the main electron stream and not present a problem.

No data sheets are available for this class of operation so some degree of experimentation would be essential.

I have no direct applications experience or information to verify this option.

1.4 Triode Operation - Audio Signal Output:

Of fundamental importance in audio amplifier design, is that when tetrodes, pentodes and beam power tubes are configured in triode connection, the Screen Grid SIGNAL voltage will ALWAYS appear in the Plate circuit because the Screen Grid is connected directly to the Plate - ie the electrons collected and diverted by the Screen Grids will appear in the output of the amplifier under all conditions between zero signal and full signal input.

Thus any distortion and/or effects upon frequency response and linearity of the AC signal in the Screen Grid circuit of triode connected tetrodes and pentodes will appear in the output of the amplifier.

This phenomenon also happens in ultra-linear connection - but only under linear controlled conditions determined by the output transformer primary turns and impedance ratios - that are quite different to Screen Grid behaviour under triode connection.

However this phenomenon *does not* happen with conventional tetrode and pentode configurations because the Screen Grid signal is bypassed to ground and does not appear in the output signal at all - even with negative feedback from the loudspeaker. Consequently tube behaviour and amplifier performance are very different when a particular tube type is configured in each of tetrode/pentode, ultra-linear or triode connections.

However, one major bonus from triode operation is that the changes in relative portions of Plate Current and Screen-Grid Current - ie signal output power - that occur with changes in Grid #1 Voltage - as illustrated in Fig. 2 above - will not have material effect on the output signal because the Plate and Screen Currents are mixed together.

In other words, triode operation will provide a more linear output stage than tetrode or pentode configurations.

NOTE: Triode operation of tetrodes, pentodes and beam power tubes produces substantially less power output than when used in their design configuration - ie for any given Plate voltage, the power output from a triode will be substantially less than that for a tetrode, pentode or beam power tube.

It should also be noted that Grid #1 bias voltage will be proportionately higher for triode connection, hence driving voltage will be also proportionately higher. For most applications this increase could be substantial, necessitating a more complex driving stage arrangement than would otherwise be the case.

The tube manufacturer's data sheets should be consulted before proceeding with an amplifier design commitment.

1.5 Triode Operation - Grid Stopper Resistor:

It is important to retain the grid stopper resistor between Plate and Screen Grid, to prevent parasitic-oscillation in the tube. The grid stopper resistor must be mounted as closely to the tube socket pin as practicable to minimise RF signal pickup and minimise inductance in the wiring.

The usually recommended value is around 100 to 500 ohms (although many commercial amps connect directly, with no Grid stopper at all) however an empirical approach derived from the manufacturers' data described on my *ultra-linear* operation page suggests a value of around at least one half the Plate to Plate load impedance presented by the output transformer.

A value (per-tube) of half the Plate to Plate load impedance might be a good starting point to give the electrons sufficient incentive to travel the further journey to the Plates instead of taking the easy path home. More resistance may be required though to achieve the desired effect - after all, **electrons are lazy critters and *always* take the easiest route they can,** even if it means increasing density - ie crowding into a small area of a conductor or electron beam. For those mechanically minded, electron flow behaves like a fluid.

Even if the Grid Stopper resistor has a value equal to the Plate load impedance, the current flow in Grid #2 will still be significant.

Unfortunately, the tube handbooks tell us that the Screen to ground return path must be of low AC low impedance. One way out of this is to shunt the Grid-stopper with a suitable value of capacitor so that the Screen is grounded via the Plate which is, of course, connected to ground through the load, but doing this will also reduce the AC separation sought between Screen Grid and Plate - taking us back to conventional triode connection and the less than ideal Screen Grid operating parameters.

A useful addition is a small bypass capacitor (say 100 pF) shunting the Screen Grid voltage dropping resistor to eliminate any stray RF.

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2. TRIODE OPERATION WITH SILICON DIODES

A significant practical improvement may be gained by installing a silicon diode between the Plate and Screen-Grid in the manner described in my **OPTIMISED ELECTRON STREAM © TECHNOLOGY** page - ie with the arrow pointing towards the Screen-Grid - instead of connecting the Screen Grid directly to the Plate, as is the conventional practice.

It offers the same benefits as in tetrode/pentode connection by removing Screen Grid output signal from the Plate circuit - ie the Tetrode or Pentode in Triode connection behaves like a real Triode, with electron flow direct from Cathode to Plate, as if the Screen Grid did not exist.

This configuration enables us to use beam power tubes, with all their benefits, as straight triodes, thereby attaining all the benefits of beam power tube operation but with the tonal and distortion qualitites of triode operation.

The Grid Stopper resistor and/or Screen Grid voltage dropping resistor must still be kept in the circuit to control DC voltage behaviour because in triode connection there is far too much DC on the Screen Grids than is needed to do their job. In this case, less is thus better than more.

Some adjustment may need to be made to the Grid #1 bias voltage to limit Plate current to the design value.

Experiments I have undertaken in this area have resulted in substantially improved high-frequency performance, more natural sound and superior tonal characteristics compared with the conventional approach.

In my opinion, the most likely candidates for *triode connection with silicon diodes feeding the Screens* are the:

6AQ5	**(275 VDC)**	**7 pin**
6V6GT	**(275 VDC)**	**Octal**
6CZ5/6973	**(285 VDC)**	**9 pin**
5881/6L6GC/7027A	**(400 VDC)**	**Octal**
KT88	**(550 VDC)**	**Octal**
813	**(1100 VDC)**	**Giant 7 pin**

All are well proven fine quality beam power tubes, each famous in its own right.

Most other tetrodes, pentodes and beam power tubes have too low a Screen-Grid voltage rating to be suitable for triode operation at full rated Plate voltage.

There are many fine tetrode, pentode and beam power tubes that can be used in triode operation, however care is necessary to avoid applying excessive voltage to the Screen-Grids - such as the **EL34/6CA7 (425 VDC)** (Octal) and **EL84/6BQ5 (300 VDC)** (9 pin) pentodes.

Note: In high power applications - ie more than 100W RMS, transmitting **triode** tubes such as 805, 809, 810, 811, 812, 833, 845, 8000, 8005, etc may be a more economical and practical solution than pursuing a triode connection configuration with tetrodes or pentodes because of a wider choice of suitable tube types and characteristics, simplified wiring and power supply requirements. Most large tetrodes and pentodes have a relatively low rated Screen-grid operating voltage, indicating a high risk of problems when connected as triodes.

At the present time, large NOS triodes generally cost about the same as large NOS tetrodes or pentodes offering equivalent power output.

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3. TRIODE OPERATION USING THE SCREEN GRIDS AS THE CONTROL GRID

This mode of operation offers yet another alternative for the application of Pentodes, Tetrodes or Beam Power Tubes as Triodes.

The method is simple.

Connect the Control Grid #1 to the Cathode

Use Grid #2 as the Control Grid.

This approach requires substantially higher DC negative bias voltage and considerable AC drive signal input voltage than as per the standard configuration, but offers the benefit of allowing full rated Plate Voltage to be applied.

This is because the Screen Grid does not attract electrons - in fact it is negatively charged so cannot.

Power output should thus be similar to that obtainable in Tetrode or Pentode mode - but with the tonal characteristics of Triodes. This is because the tube is now a real triode - ie only 3 effective elements (Cathode, Control Grid and Plate).

I am unable to provide details of typical operating conditions but this method has been used in professional broadcast standard equipment and in theory should be more reliable than the standard approach.

Class AB2 or B with fixed bias is essential for high Plate circuit efficiency and dynamic performance.

If you have experience with this configuration please advise your results.

Please let me know if you can add to this body of new knowledge and I will add it to this commentary.

Of course the smart thing to do here is to use tubes that are already triodes - instead of messing about with compromises - but then none of the triodes are beam tubes and thus do not offer the benefits of beam tube technology.

Also most of us have a junkbox stock of perfectly good Tetrodes, Pentodes or Beam Power Tubes just waiting to be used - so it is a tough call.

REMEMBER:

- ALWAYS TAKE CARE WHEN WORKING WITH HIGH-VOLTAGE -

DEATH IS PERMANENT!!

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