Developing the Albert W. Hull Memorial Dynatron Receiver

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What is a Dynatron?

This is an interesting path not taken in the history of early electron tube development. In the 19th century, electrical experiments with evacuated glass tubes were underway in the work of Geissler and Crookes.[1] Roentgen's well-known work with X-ray phenomena[2] and Tesla's well-publicized lecture/demonstrations[3] of tubes used for lighting (and his lesser-known, but rather thorough, development of X-ray tubes)[4] led the way into the 20th century bringing the more familiar tube types: diodes, triodes, tetrodes, then the higher "-odes." (I am not forgetting to honor the better-known efforts of other colleagues such as Edison, Fleming, or deForest.) At the time of these developments, Dr. Albert W. Hull,[5] a leading scientist at the General Electric Laboratories in Schenectady, NY, experimented with some fascinating alternative internal tube structures, among which was the Dynatron that he disclosed in 1918[6]. Hull produced a number of working models, but I have not found any commercial production of the type.

The triode electron tube has three elements inside its strong vacuum: a hot filament/cathode, a grid between cathode and the next-placed element, the plate (or anode). In a triode, a positive voltage is connected to the plate while the negative goes to the hot cathode. A current of electrons (the plate current) flows through the vacuum from cathode to plate – as the voltage difference increases between cathode and plate, the flow of electrons that make up the plate current will increase, up to a limit imposed by physics principles. If a small voltage that is negative relative to the cathode potential is placed on the grid, that smaller voltage can be used to control the relatively stronger plate current. As we apply more voltage to the plate, the resistance to the flow of electrons from cathode to plate increases. In that setting, a small signal

Dr. Albert Hull (April 19, 1880 to January 22, 1966) was an inportant physicist and electrical engineer who made many contributions to vacuum tube development. He also invented the magnetron and was a member of the National Academy of Sciences.

entering the grid of a triode can be used to control a larger, but now similarly patterned plate current, as an output. If one speaks a quiet "HEY" into the grid circuit, a similar but louder "HEY" comes out through the plate circuit. Hence, we have an amplifier. If we make an arrangement for some part of this amplified output from the plate to re-enter the grid, we get feedback, and the triode becomes an oscillator. Amplifiers and oscillators are kissin' cousins.

Hull's prototype Dynatron was also a three-element vacuum tube, the internal structure of which is rather similar to a standard triode – a hot cathode, a porous dynode, and a flat anode (plate) in that sequence. But these resources are used differently. The positive lead from a voltage source is taken to the grid-like dynode while the negative of that source is placed on the hot cathode. The anode is made less positive than the dynode. With the dynode voltage at a particular fixed value, and the anode voltage made to start at nothing, then slowly grow, at first we will see the familiar increase in resistance to the flow of plate current as in the case of a standard triode. We can call this "positive resistance," which increases with a small increase in plate voltage. But in a Dynatron, at a particular value of anode voltage less than the dynode voltage, we suddenly see a reverse, or decreasing plate current as the anode voltage increases – this Hull called this effect "negative resistance" – more on why that happens in a moment.

Ordinary resistance consumes energy, but negative resistance is, for a localized part of the circuit, a source of energy. It can function, in other words, like feedback in an Armstrong regenerative oscillator. (However, it is important to remember that negative resistance is not "free" energy; there is no violation of the principle of conservation of energy for the entire system – the entire circuit in this case.) If this localized negative resistance is connected across a parallel inductor (L)/capacitor (C) combination, the Dynatron will oscillate at the resonant frequency of the LC component. So, a Dynatron can accomplish internally in the tube what a triode will accomplish with added external components – for example, the "tickler" coil in the Armstrong regenerative circuit, or the capacitors of a Colpitts oscillator.

Fine and dandy – I want a Dynatron for tinkering purposes. Alas and woe, as far as I can determine, no one mass-produced them – apparently they were only available as laboratory prototypes or special builds.

But There Are No Dynatrons In The Tube Catalogs!

At this point, I wanted to try to build a Dynatron regenerative receiver. They regenerate don't they, so shouldn't they receive? Where can we obtain one of these beauties for playing with homemade tube radios?

Where there is a will and some ingenuity, there may be a way. Other homebrewers of the 1930s – particularly the British master technician M.G. Scroggie[7] – following Hull's research, were faced with the same supply problem; they came to realize that some commercially available tetrodes such as the US type '22 or '24, or the British tetrode AC/S2, could easily be rewired to operate as a Dynatron instead of as a typical triode-with-an-additional-screen grid, AKA a tetrode. The working of a Dynatron is well illustrated by the methods employed by Scroggie and others using re-configured common tetrodes of the day (see Scroggie: Handbook, as cited in note 7, pp. 47-50).

Here we find an interesting side story. The phenomenon of secondary electron emission from the plate in tetrodes came to be regarded within commercial usage as a difficulty for the type, which was to be conquered by the addition of another element, a suppressor grid, a step that is documented in many good discussions of tetrode evolution into pentode.[8] In the literature there were often comments about a dreaded phenomenon to be avoided: for example, the *RCA Transmitting Tube Manual* number TT-4 of 1956, page 8, warns against unwanted "Dynatron Action" between plates and screen grids. Indeed, secondary emission occurs when, at particular levels of voltage, electrons arriving from the cathode hit the plate so strongly that they "knock loose" – cause secondary emission – of some electrons on the surface of the plate. In a triode this causes problems; in a Dynatron, this phenomenon "makes it work."[9]

Scroggie, taking a cue from Hull's prototype Dynatrons, realized that this phenomenon of secondary plate emission that "ruined" tetrodes in some hook-ups, was the feature that could be turned to useful work if the tetrode were re-configured as a Dynatron, using a technique similar to that now often employed when a pentode (for example) is re-wired as a triode. It was secondary emission of electrons from the plate that produced the negative resistance phenomenon in Hull's original prototype. The typical tetrode is operated as an amplifier with a slightly negative control grid, while the screen grid is positive, with the plate (or anode) usually set as still more positive. At particular higher levels of voltage, tetrode secondary plate emission went away, and one saw a rather familiar set of amplifier performance configurations if the tube was pushed past the "dip," or secondary emission zone. Following Hull, Scroggie reasoned that secondary plate emission in tetrodes could be used to operate some commercially available tubes of that type as Dynatrons, by making the screen grid – now Dynode – very positive and the plate somewhat less positive; this arrangement took advantage of the "tetrode dip" instead of eliminating it with a suppressor grid (as in pentodes). The tetrode dip was in effect the same phenomenon of negative resistance Hull found in the original Dynatron.

A closer look at the tetrode dip reveals that secondary plate emission creates the Dynatron negative resistance pattern in a tetrode performance envelope – a strange idea, this weirdly resistance with a minus sign. But it is familiar to we regenerative radio fans under the name of feedback. Armstrong's famous regenerative and super-regenerative circuits return some energy from an amplifier output to raise energy levels in an LC tank circuit such that the circuit can sustain continuous oscillations at its resonant frequency. Others, such as Colpitts, Hartley, and Pierce, developed alternative methods of feedback.[10] Feedback provides additional localized energy that can be focused into some circuit subsystem. (Remember, neither feedback nor negative resistance provide entirely new energy over and above the total energy input into the complete circuit; Mother Nature does not cook free lunches.) Since positive resistance dissipates energy, we can think of a negative resistance as adding local energy, which is exactly what happens during the dreaded tetrode dip. By using it instead of losing it, we get the Dynatron method of obtaining feedback – that is negative resistance – into an LC tank circuit. And the advantage is that fewer parts external to the tube are needed; moreover, in the case of a Dynatron, many parallel tank circuits can be made to oscillate by simply connecting the tank to the Dynatron negative resistance dual port; and furthermore, just single coils so connected will oscillate at their self-resonant frequency[11] (in parallel with their distributed or self-capacity). In effect, many of the Armstrong, Colpitts, Hartley, and Pierce feedback arrangements done with parts external to the tube, can be supplied by the phenomena occurring internally in a properly connected Dynatron.

OK, so what? – You ask with insightful logic!

My thought was that a regenerative receiver is, roughly speaking, an oscillating amplifier, or at least one that is about to oscillate – remember kissin' cousins. A Dynatron can oscillate, but can it be set up so that at the edge of its oscillation it will act as a regenerative detector and amplifier, much like the circuits of Armstrong and colleagues? Hull (in his various publications) and others reported amplifier, oscillator, as well as receiver configurations for Dynatrons, so there was hope. But where is one to get a good Dynatron these days?

Some Common Pentodes Are Dynatrons In Disguise.

Inspired by Scroggie who made Dynatrons from tetrodes – and thinking of pentodes as Dynatrons also with too many extra internal pieces – I thought it might be possible to reverse-configure a currently available common pentode. The early tetrodes used by Scroggie were not at my handy radio experimental supply warehouse; some persons, in an unnecessarily condescending way, refer to this scientific equipment resource as a "junk box." The suppressor grid in a candidate tube must not be internally tied to the cathode, because that is the pentode method of killing secondary emission, which a Dynatron needs. Sure enough, several pentodes common today in octal or peanut-tube types, have a suppressor grid that is not internally connected to the cathode – the 6SJ7GT seemed to be a particularly good candidate. Perhaps with a little fooling around, it might be possible to have an easily obtained contemporary tube functioning as a Dynatron by connecting the free suppressor grid to the plate while using the pentode's screen grid as the Dynode. It looked good in theory, but would it work? Following Scroggie's discussion (page 189-201) of a broadly useful Dynatron laboratory oscillator, I lashed up a test board using a 6SJ7GT with a plate-tied suppressor grid.[12] It is propelled by my Heathkit IP-32 bench power supply providing variable tube-strength A (filament), B (plate) and C (negative for control grid bias) voltages. I used the Dynatron test board (see **schematic 1**, next page), with an old crystal set broadcast band tank circuit (photo 1) connected to oscillation ports X1 and X2 on the test board. See **photo 1**, next page.

With 40 volts on the screen grid (Dynode), and -1 volts on the control grid[13] (tying the control grid G1 to the cathode works also), and a potentiometer providing a few volts on the plate, my oscilloscope showed oscillation at various settings of the plate voltage.[14] I think Scroggie's full lab instrument could be replicated with a 6SJ7 or other appropriate contemporary pentode; he outlined many useful lab applications of his Dynatron oscillator in his book, some

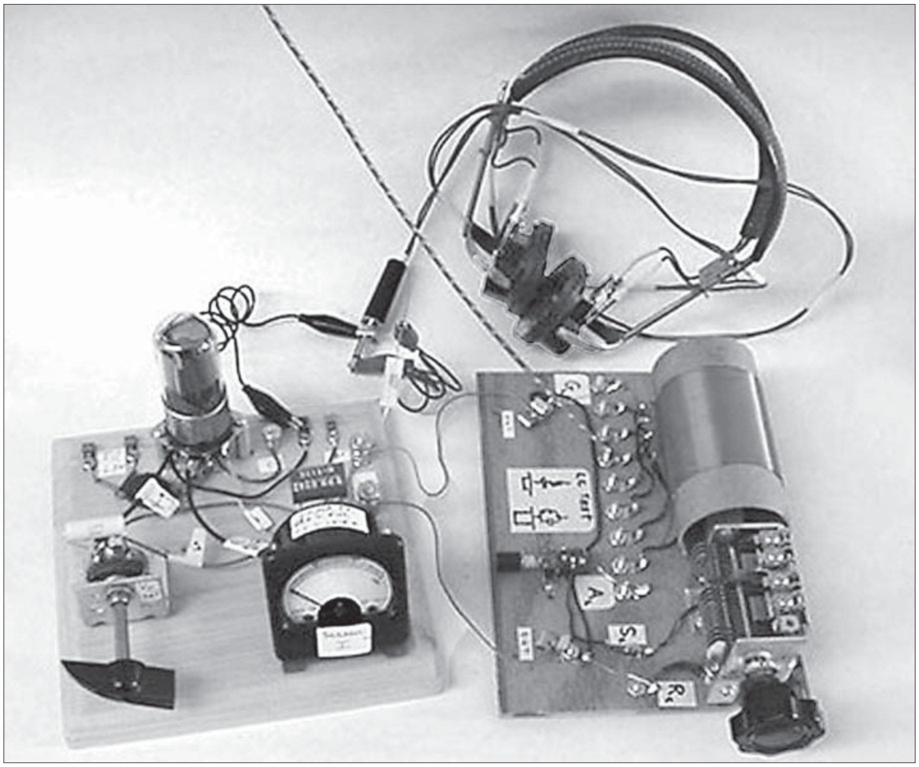
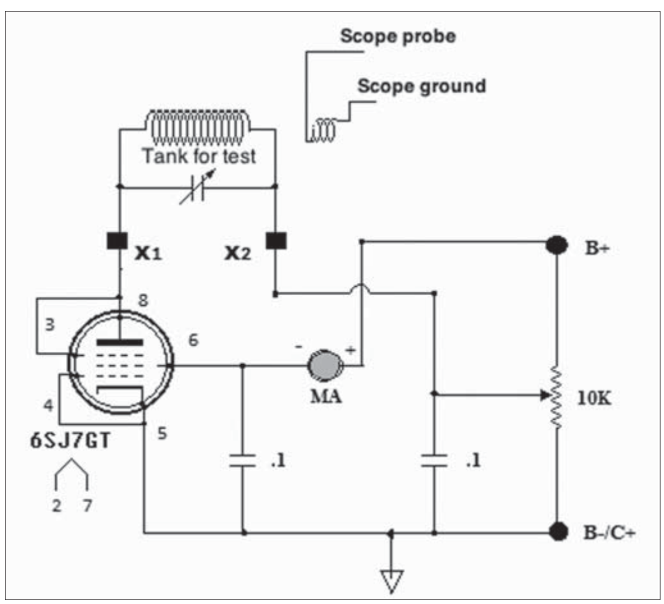


Photo 1, Above: Dynatron oscillator 6SJ7 test board, BC tank, sound-powered headphones, as BC receiver. Schematic 1, Below: Dyunatron Oscillator Test Board



of which involve using the control grid G1. Hull had perceived that trick in his original Dynatron work – he named such a four-element tube a "PlioDynatron;" its four elements were cathode, control grid, dynode, and anode. However, my purpose for the moment was only to obtain a bare-bones Dynatron oscillator as a possible route toward a constructing a receiver.

Now I had a working oscillator, a very useful one. For instance, I could tie my Miller model 90605 absorption wavemeter (a hand-held parallel LC circuit calibrated for 3-10 Mc) into terminals X1 and X2 and have HF oscillations, or I could tie in an audio frequency LC tank and have AF. Yet, it was not a receiver.

How to get a receiver?

After a lot of frustration, it was deceptively simple. Tap a wire antenna (mine is about 80 feet) at a few turns on the coil (readily available on the re-purposed crystal set LC tank board), using no external RF ground. Or, a better method is to use an antenna link coil (which does need an RF ground) loose-coupled to the tank tuning coil.

Where is the audio?

After the frustration, success came with connection of my sound-powered earphones through a .1 mfd capacitor stuck on the plate side at X1, with the other lead of the phones going to B minus. (There may be better AF takeoff points or methods, but I was sufficiently flabbergasted by this one to simply enjoy it for the moment.) With these two features in place, the potentiometer acts like a regeneration control, and I got some strong local AM BC stations at two points on the control potentiometer. With careful adjustment, good resolution of the AM signal was achieved, but with

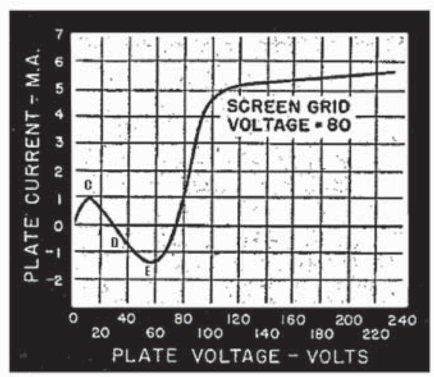


Figure 1: Dynatron Dip in a '24 Tetrode (From *Radio-Craft*, V. 1V, 1945, p.419)

some hum (I suspected this was due to my haywire breadboard layout of this preliminary lashup). I tried the AF output with 5k earphones, and with my Radio Shack mini-amplifier. Sound-powered phones were solid, and standard 2k or 5k earphones worked at a lesser but functional level; with little amplification from the RS unit, I had good volume from my 8-inch test speaker.

I noticed on my scope (and in the audio), while swinging the potentiometer from one end to the other, that a receiver performance pattern could be seen.

If one views the prototypical Dynatron/Tetrode negative resistance curve in the example curve[15] of **figure 1**, it begins with an upper peak (at plate current 1 mA, call this point C), then descends more-or-less in a linear fashion to a lower "inverse peak" (in this example at minus 1.3 mA, call this point E). (The standard tetrode amplifier circuit would use the part of this curve to the right of E, to avoid unwanted oscillation.) The Dynatron reception zones are near points C or E. This detector action is probably due to the nonlinear nature of the curve at those points. One of the zones of reception was a little stronger than the other, but I haven't tried to pursue the finer details so far. Those two peaks, located at "almost into oscillation" and at "almost out of oscillation," are zones where I found both detection of AM and amplification. Of course, if you want your Dynatron to be an oscillator, arrange the control potentiometer midway between C and E somewhere near D.

In the receiver function there is demodulation and amplification enough to support phones on these strong local BC stations. Just as in an Armstrong regenerative receiver, I suspected that resolution of CW or SSB could be present on the oscillatory side of the receiving zones. The present potentiometer is a one-turn 10k; a ten-turn unit might give better control of settings. Following Scroggie's advice to incorporate a milliammeter in the Dynode supply to avoid exceeding 5 mA (thought to be courting tube destruction), I included a 15 mA meter. When reception is well-tuned in the test board circuit, this meter runs at about 1.5 mA. These reception results were quite striking for me; but I am no engineer, just a tinkerer.

The Albert W. Hull Memorial Dynatron Receiver

I felt sufficiently confident at this point to proceed toward a nicely built receiver with a single stage of AF amplification. Thus was born the Hull Memorial Dynatron Receiver, see **photo 2**.

The circuit is given in **schematic 2**.

The chassis is a recycled and pretty-fied 1940's cheese box (wood works well in this case). Circuit improvements that were incorporated include use of a 6AK6 (at the left) as a Dynatron, a 6AU6 (at the right) as AF amplifier, an AF volume control, a BC band feri-loopstick as the tuning inductor (behind the tuning capacitor) with a hand adjustable antenna link coil and a 3-turn coil connected when monitoring with a scope, a 365 pF variable capacitor (VC) with internal reduction drive coupled to an additional external reduction drive and bushing assembly to give *slloooow* tuning action, and a small vernier rheostat in series with the wiper of the control potentiometer to give more precise fine control of the negative resistance. This vernier rheostat

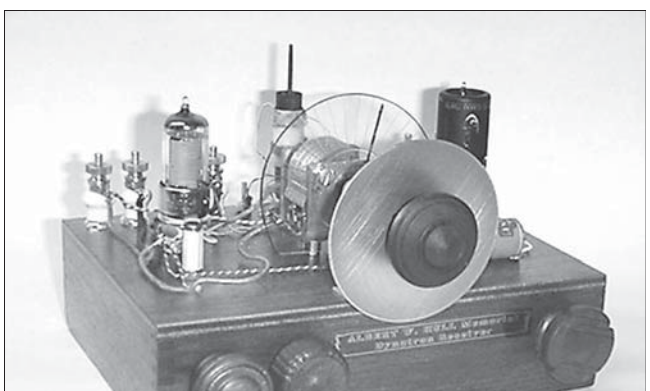
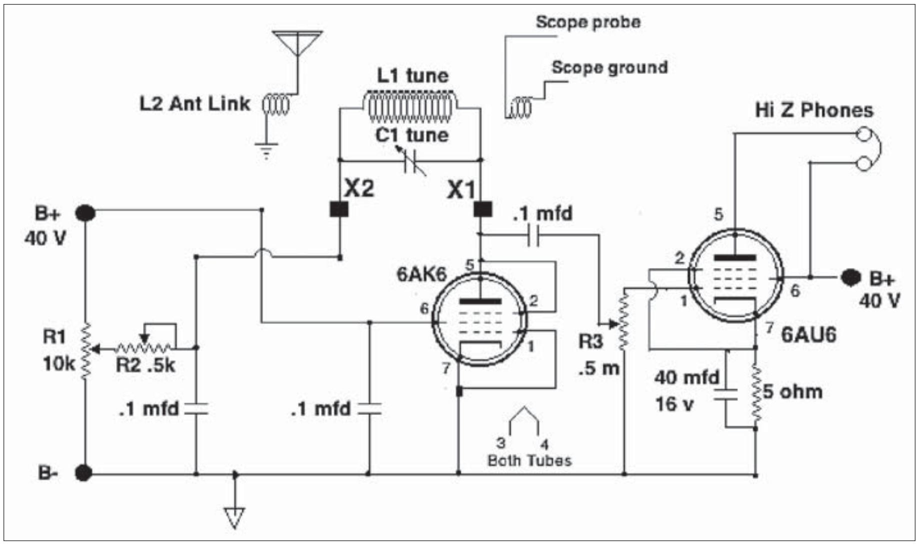


Photo 2: The Albert W. Hull Memorial Dynatron Receiver: The controls are left-to-right; Coarse Regen, Fine Regen, Tuning, and AF Volume.



Schematic 2: The Hull Memorial Dynatron Receiver

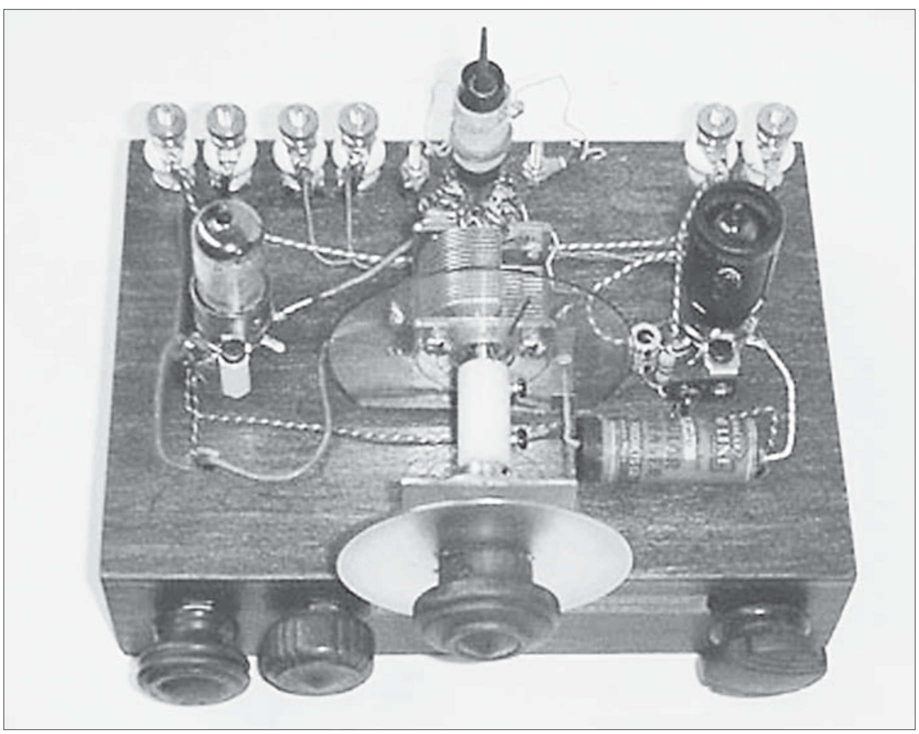


Photo 3, The Albert W. Hull Memorial Dynatron Receiver top view: Terminals left-to-right are B+, B-, F1 & F2 6 volt filament, Antenna then Ground for the antenna link coil, X1 then X2.

came into its own in fine tuning the feedback for best audio. The mechanical tuning indicator is a piece of music wire lashed onto the rotor shaft of the VC. The logging scale is a recycled CD screwed to the VC front plate.

This is a much stronger receiver than the previous clip-lead special. I notice no hum. The antenna loose-coupler coil can be set on the feri-loopstick at the strongest reception point while good selectivity is retained. I wanted to keep the maximum voltage for the entire rig at 40, so the AF amplifier is rather weak. When well-tuned to a local BC station I hear no distortion. If the slug in the loopstick is adjusted so that the minimum capacity point on the VC is at 4 Mc, then one can tune down (increase capacity in the variable) over the 80 meter band and into the top of the BC band. In 80 meters I could clearly hear CW and SSB as well as AM signals. As with a typical regenerative receiver, getting the regeneration control – which is to say, the Dynatron negative-resistance control potentiometer – slightly into the zone where oscillation is just starting, will yield conditions for CW and SSB. Above the BC band, as equipped, the AWH Memorial Receiver in this less than optimum HF embodiment becomes touchy to tune, both in settings of the frequency VC and the control potentiometer. A design for HF use might overcome these issues.

Alignment

Connect the antenna and ground to the link coil on the tuning inductor form. With a scope probe connected to the scope coil on the tuning inductor form, the plate voltage potentiometer set to provide the lowest voltage to the plate, light the tube filaments, count to 20 then place 40 volts B+ on the Dynode (four nine-volt transistor batteries will also work). Watch the scope trace while increasing the plate voltage slowly. The Dynatron should start to oscillate around plate voltage of 8 volts (Figure 1, point C). As the plate voltage is increased, the oscillation will cease at a somewhat higher voltages, around 13 volts (point E). The zone between points C and E – call its middle point D – is the region for oscillation. The AM reception zone will be just as one is entering point C from a lower voltage or as one is leaving point E toward a higher plate voltage. Possible zones for CW or SSB are in the reception zone a tad toward the middle point D. Here is where the fine (vernier) rheostat on the potentiometer wiper and the double reduction tuning drive begin to earn their pay.

I hope some persons more knowledgeable than me will try this rig. It works well as a broadcast band receiver. I wonder if the approach can be improved to produce a functional shortwave AM/CW/SSB receiver with a power amplifier to drive a loudspeaker. As I review the results so far, I can imagine a single tube CW transceiver: a Dynatron could receive, then easily be switched to its best oscillation point for transmit... perhaps.

Concluding Thoughts

While early screen grid tubes often could be drafted for Dynatron service, the progressive development of the standard screen grid idea brought carbonized plates and other factors as a way to knock down secondary plate emissions. So, the evolution of tube design moved away from the Dynatron idea. It should be possible to design a plate that would be a good secondary emitter, but apparently it didn't happen in receiving tubes except maybe in a laboratory. However, Crosley did use some of the early tetrodes in dynatron configuration in a few mass-produced receivers.

During the era when standard uncarbonized early tetrodes still could be arranged as dynatrons, the dynatron oscillator and amplifier was quite popular because among the oscillators available at the time, it could be used as a reliable home-built frequency standard. *The Radio Amateur's Handbook* for 1932 featured a dynatron frequency meter (pages 79-82) using a '22 or '32 tube. Scroggie's book also describes a number of other test-bench uses for his tetrode Dynatron circuit. Also, the Gernsback publications – *Radio Craft* and *Short Wave Craft* – in the early 1930s featured a number of articles on dynatrons and their possible uses. One can easily search for them through the excellent Americanradiohistory.com web site. Why use a dynatron circuit for amateur frequency checking? The 1932 ARRL handbook explained it this way (page 81):

"A frequency meter which is capable of all the accuracy needed in amateur work is shown in the photographs. A screen-grid tube is used as the oscillator, and when connected up in the fashion shown is said to be operating as a 'pliodynatron' or, more simply, 'dynatron' oscillator. A frequency meter of this type is known as a dynatron frequency meter… the best type of oscillator available for frequency meter work *at the present time*… [italics added]."

This theme of reliability for Dynatron oscillators – at that time (early 1930s) – is echoed in the work of Scroggie and in a number of Dynatron articles in the Gernsback magazines of the era. Thus, the Dynatron did have a run of functionality in the amateur and experimenter world of that day even though there were no purpose-built Dynatrons or Pliodynatrons produced by tube manufacturers. Here I have shown that if the circuit of a Dynatron frequency meter (oscillator) is slightly modified by adding an antenna coupling – as well as at the top of the tank circuit – a capacitor and some headphones, one has a regenerative receiver.

I am not an engineer by profession, merely a historian of science, so I cannot maximize this interesting receiver circuit. I hope there are some qualified electrical expert readers of this article who might want to refine it. What is presented here is only a rough outline of possibilities.

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End Notes:

1. For a good account of Geissler and Crookes see Wikipedia.

2. On Roentgen see: http://www.nobelprize.org/nobel_prizes/physics/laureates/1901/rontgen-bio.html

3. Tesla's various lectures in New York City, for example: online see http://teslasociety.com/columbia.pdf .

4. Maja Hrabak et al. "Nikola Tesla and the Discovery of X-rays." RadioGraphics, vol. 28, No. 4: published online 2008 – see https://pubs.rsna.org/doi/full/10.1148/rg.284075206 .

5. Hull's National Academy of Sciences biography may be found at: http://www.nasonline.org/publications/biographical-memoirs/memoir-pdfs/hull-albert.pdf .

6. A. W. Hull, The Dynatron, a Vacuum Tube Possessing Negative Electric Resistance, Proc. I. R. E., February 1918. See also, Negative Resistance, US Patent Office, number 1,387,984 (16 August 1921), available for download from Google Patents.

7. M.G. Scroggie, Radio Laboratory Handbook, London: Wireless World,

1943. This very useful but somewhat scarce book may be viewed or downloaded at:

https://www.dropbox.com/s/v31ac8um5mvd3s8/Radio%20Laboratory%20Handbook.pdf?dl=0

8. For example, J. F. Rider, Inside the Vacuum Tube, New York: Rider Publications, 1945, reprinted 2002 by Audio Amateur Inc., Peterborough, NH.

9. A nice study of secondary emission obtainable in common tubes may be retrieved at https://www.frostburg.edu/personal/latta/ee/2ndemission/generaltube.htm . This study examines secondary emission in a few common tubes; note the results for the 5763 tube, which appears to be a good candidate for Dynatron operation. A Google search using "vacuum tube secondary emission shows current research on tubes with plates specifically designed to have high secondary emission. Could one find such a commercial tube nowadays and adapt it for Super-Dynatron service?

10. An excellent account of a number of oscillator types, including Dynatrons and other negative resistance oscillators (beginning on page 75), is found in I. M. Gottlieb, Practical Oscillator Handbook, Oxford: Newnes, 1997. Another masterful work, especially for understanding negative resistance, is Herbert J. Reich, Functional Circuits and Oscillators, Boston: Boston Technical Publishers, reprinted 1965.

11. This suggests a technique for finding the self-resonant frequency of many coils in the .5-30 Megahertz region: place the coil alone across Dynatron oscillator ports (X1 and X2 in the circuits given here), then read the self-resonant frequency with a loose coupled frequency meter. Such a coil provides both L (its inductance) and C (its distributed capacity) at one frequency – its self-resonant point.

12. A number of octal-based tubes show a basing diagram with no internal suppressor grid (G3) connection, and are thus candidates for Pentode-wired-as-Dynatron: for example, those with base diagram 8N. In the 7-pin "peanut" tubes, the 6AK6 worked well (base 7BK shows a number of similar candidates). As an oscillator, the Russian 4P1L Loctal pentode is strong, but weaker as a Dynatron detector/amplifier. I have tried a couple of tiny 7587 Nuvistor tetrodes as Dynatrons, with good oscillation and detection. using these approximate voltages: B+ at 35, C at -1.5, vary plate voltage for setting. Determining the characteristics of the best Dynatron candidates would be a subject for another series of experiments. Note that a good internet source for tube data on an international scale is www.radiomuseum.org.

13. Some pentodes configured as Dynatrons will work with the control grid G1 tied to the cathode; others didn't like that condition and seem to need about -1.5 volt bias on G1. Changing the G1 bias requires other settings to be adjusted.

14. I found that wrapping a turn or two of junk wire around the tank coil, then connecting the junk ends to the scope probe and its ground provided a helpful scope view of both oscillation and of received audio.

15. Figure 1 shows voltages used in testing the Dynatron action of a type 24 tube. Voltages on this graph do not apply to the tubes in the circuits constructed here; however, the form of the curve is the same.

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