# Vintage Radio

By Ian Batty

# A detailed look at the Grebe Synchrophase

**If you feel that you have already read about the Grebe Synchrophase, you are correct, as it was featured in the July 2016 issue. But this set is so exceptional that it warrants a detailed analysis, explaining why its performance rivaled some of the finest superheterodyne sets of the period.**

The first point to note is that it is not a superheterodyne circuit. Edwin Armstrong's famous patented circuit was well known at the time the Grebe was manufactured but the patent fees were expensive. So the Grebe Synchrophase is a Tuned Radio Frequency (TRF) set, using Hazeltine's Neutrodyne patent (www.google.com/patents/US1450080).

And while you have probably assumed that TRF sets are pretty basic stuff, with performance not much better than a crystal set and subject to unpleasant whistles and fluctuating volume from different stations, be prepared for some surprises.

While it may appear simple, the Grebe Synchrophase is a very well-engineered product that's one of the best examples of TRF design ever manufactured.

In the 1920s, radio pioneers must have been a persistent lot. The few stations that did exist were broadcasting at low power, and not always for 24 hours a day.

Still, the excitement of hearing the news before it arrived on your doorstep in the form of a newspaper, eavesdropping on the lives of movie stars, keeping up with the heroes and heroines of radio serials, hearing the latest weather reports and the most up-to-date doings of politicians... these were all just too good to miss out on.

But how to receive this avalanche of information? It was all well and good for Uncle Harry to teach Junior how to build a crystal set and tune into it instead of doing homework or playing in the yard but a family needed a family radio.

That meant a radio that would get more than just one station and play it over a loudspeaker, not the earphones of a crystal set that only one person could listen to.

And you could forget about putting up an aerial forty feet high and a hundred feet long like on Grandpa's


**The label inside the cabinet gives detailed information about the battery connections, the function of the dial controls and dial settings as well as descriptions of the tone and volume controls. The chain drive links the three tuning capacitors, one for each stage, since tuning gangs had not been developed yet.**

farm. City dwellers needed a good set that would work with just a few feet of wire.

## Gain, gain and more gain

Edwin H. Armstrong, studying at Columbia University, had heard of the "howling" problem encountered by Lee de Forest and other experimenters working with early Audion (triode) amplifiers.

Reasoning that this was a form of uncontrolled regeneration, Armstrong turned a curse into a blessing. Controlled regeneration could give astounding improvements in receiver sensitivity but a regenerative set was tricky to tune and use. Bursting into oscillation, it would blank out all other receivers in the vicinity.

Do-it-yourself articles describing Tuned Radio Frequency sets abounded but you would be hampered by the natural anode-grid feedback capacitance of triode valves with their pitiful gains – tetrodes and pentodes were still some years in the future.

Further work by Armstrong produced the superheterodyne which remains a widely used technology to this day. US giants General Electric, RCA and AT&T bought Armstrong's superhet patents and those of another significant contributor, Reginald Fessenden.

The Independent Radio Manufacturers' Association (IRMA), frozen out of the superhet world, contacted Louis Hazeltine's laboratory for some other method of building high-performing radios. Employee Harold Wheeler produced the Neutrodyne, with Hazeltine filing U.S. patents 1,450,080 (7/8/1919) and 1,489,228 (28/12/1920) and throwing the IRMA a lifeline.

The Neutrodyne is simple. If a triode's anode-grid capacitance could be cancelled out, you could get its maximum gain. So you "just" need to apply a neutralising feedback equal to the (undesired) anode-grid signal, but in opposition to it.

This cancels out the undesired anode-grid coupling and also (equally important at radio frequencies) removes the effect of lowered input impedance caused by anode-grid feedback.

A feedback capacitance of "a few" picofarads might seem trivial but the amplifier's gain magnifies the Miller effect: a gain of only 8 applied to a $C_{g\text{-}a}$ of 5pF gives an effective value of 40pF. At radio frequencies, that's a lot in anyone's terms.

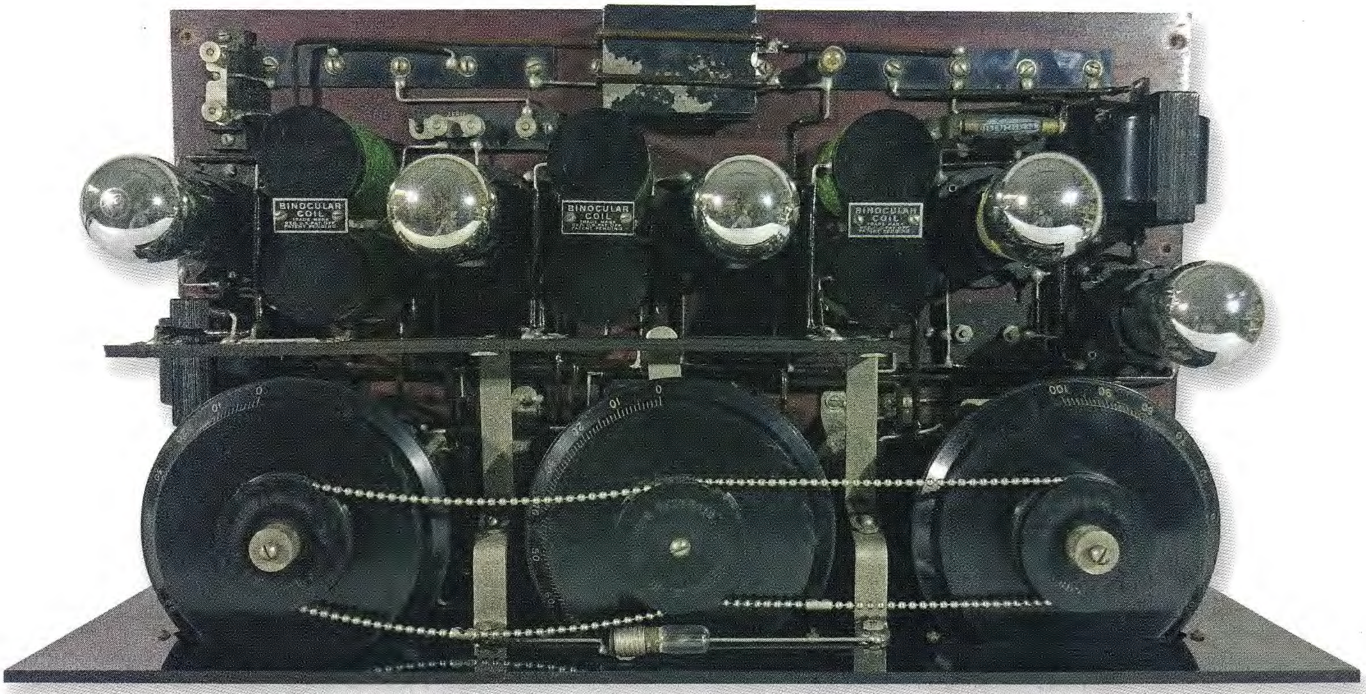
You can regard the Neutrodyne as a feedback circuit, but it's more useful to regard it as a balancing circuit. Now the concept of electrical balance had been understood for some 80 years in circuits such as the Wheatstone Bridge, first popularised in 1843.

Indeed, the Hazeltine patents describe their principles solely in terms of neutralising. And as noted below, our modern concept of feedback had not even been described at the time, let alone fully understood.

A neutralised triode circuit becomes a simple amplifier and the problems of feedback and oscillation are removed. We can go back to a straight TRF radio, where every RF stage works at the signal frequency, without Armstrong's novel and (in the early days) the troublesome complexity of the superhet. Even partly tech-savvy customers could grasp the Neutrodyne concept.

Enter George Grebe, born in 1895. Having built and supplied "submarine receivers" for the U.S. Navy during WWI, he viewed the burgeoning domestic radio market with anticipation. People wanted radios, radios and radios, of any kind.

Beginning with regenerative sets, Grebe moved on to the prestige end of the market. The Synchrophase was (and still is) widely recognised



**This Synchrophase has trademarked binocular coil plates which became a feature of sets produced after mid 1925. Another production change was the small lamp (actually made by Mazda) below the centre dial which was powered by the filament line and would light up when the radio was turned on.**

as the best non-superheterodyne set of its day.

Grebe's problem was that he was not a foundation member of the IRMA, so he was in breach of their ownership of the Hazeltine patents. A lawsuit reached court in 1927 but by then Grebe had sold some 150,000 sets and the growing acceptance of Superheterodynes meant that the Synchrophase (like all Neutrodynes) was reaching the end of its commercial life anyway.

## Design highlights

The Synchrophase was aimed squarely at the prestige market. Its luxurious mahogany cabinet, with dark Bakelite front panel and gold-plated trim, combines with Grebe's patented chain drive tuning to offer one-touch operation. Given the flip top and compact width, I guess this is a "mini-coffin" set.

It might have been all sizzle and no sausage but Grebe sensibly realised that a high-priced radio needed to offer superior performance. That implied two things: sensitivity and selectivity. Sensitivity was a major problem with TRFs, since they needed to optimise gain but somehow reduce undesired coupling between stages.

## Binocular coil design

P. D. Lowell, working for Grebe, designed the unusual "binocular" interstage coupling coils. As pointed out by Dr Hugo Holden in the July 2016 article on the Grebe, the two coils in each "binocular" are connected in series and are placed beside each other.

Because the windings run in opposite directions, this reduces their mutual coupling. Any signals (eg, from radio stations or due to interference) picked by this coil arrangement induces out-of phase signals in the two coil halves and so they cancel. There's also reduced unwanted signal pick-up from radio stations because of the parallel orientation of the coils.

The result was similar to that achieved with coil shielding but with no actual metal shield which always has the effect of lowering the circuit's Q. This physical design greatly reduced magnetic coupling effects between grid and anode circuits, allowing the coils to be assembled vertically onto the baseboard.

This was an elegant arrangement and an ingenious solution to preventing coupling between interstage coils. In fact, it seems similar to the thinking behind the design of today's common mode filter chokes which have two


**This photo shows the construction of the binocular coils which each comprise a pair of formers wound in opposite directions with green Litz wire. In front of the closest coil there is a small lamp that acts as a series fuse for the 90V B+ rail.**

windings on a common toroid core. Is this yet another case of "nothing new under the sun"?

This coil arrangement was devised in the early 1920s and the designer must have had a clever insight in to the problem.

Other designers, lacking this technique (and insight), were forced to reduce coupling by offsetting coils at different angles to each other. While such offsetting works, it just looks awkward and amateurish.

The Synchrophase's physical presentation is just what you'd expect from a set costing some 155 USD in 1924 or around $2750 in today's Australian currency.

So the Synchrophase exhibited good sensitivity, but what about selectivity?

Selectivity allows a radio to respond to a desired station while rejecting those nearby. Superhets, with their fixed-frequency IF amplifiers, can be designed for high selectivity that's constant across the tuning band.

Selectivity (Q) is controlled by (i) resistive losses (principally due to inductors) and (ii) the LC ratio. TRFs suffer from variations in Q as the LC ratio changes with tuning.

A high Q gives good selectivity but tuned circuit Q is mostly compromised by the RF resistance of inductors. It's mostly due to skin effect, where RF current flow is largely confined to the conductor's surface. The solution to this problem is to use multi-stranded Litz wire.

The bother of stripping and tinning every one of a bundle of 20 wires is well compensated for by their combined surface area: Lowell's 20/38 Litz has the surface area of single-strand of 28 AWG but the bundle is more flexible. In practice, Grebe engineers did laboriously tin each individual wire, then tested the actual RF resistance once assembled.

## Let's talk about feedback

An article in April 1925 QST, by Grebe engineer R. R. Batcher, asserts that it was component quality rather than use of the Neutrodyne principle that gave Grebe sets their performance edge. Well, yes and no.

It's true that the Synchrophase is superbly engineered by any standard. But the cancellation of feedback probably plays a larger role than Batcher (or anyone) probably realised back in 1925. Bell Labs' famous Harry Black did not lodge his patent for negative feedback (with its engineering description) until late 1928.

Feedback from output to input (whether positive or negative) modifies gain: that's why it's so widely used in analog circuitry. Negative feedback is overwhelmingly used, and it reduces gain.

But also, the anode-grid feedback in triodes (shunt voltage feedback) reduces input impedance. Indeed, this design is used with solid-state op amps to create a virtual ground node of (theoretically) zero impedance.

So un-neutralised triode amplifiers present a low impedance to their inputs at Broadcast frequencies, rather than the almost open-circuit that a valve should exhibit. Anode-grid feedback would create significant loading of the grid tuned circuit, thus reducing gain and compromising selectivity.

Selectivity is specifically addressed in Hazeltine's 1924 patent US1489228, and input circuit loading is specifically addressed (as "increased input conductance") in that patent (note that increased conductance means reduced resistance/impedance).

The third potential problem of oscillation could be (and was by some other manufacturers) overcome by circuit damping. But this also reduces both gain and selectivity – the two highly desirable characteristics that Grebe engineers were able to optimise and which set the Synchrophase apart.

So the Neutrodyne principle's balancing-out of anode-grid capacitance (ie, isolation of an amplifier's grid circuit from its anode circuit) was vital to the Synchrophase's performance, allowing its refined tuned circuits to operate at their peak of selectivity, and the amplifiers at their peak of sensitivity.

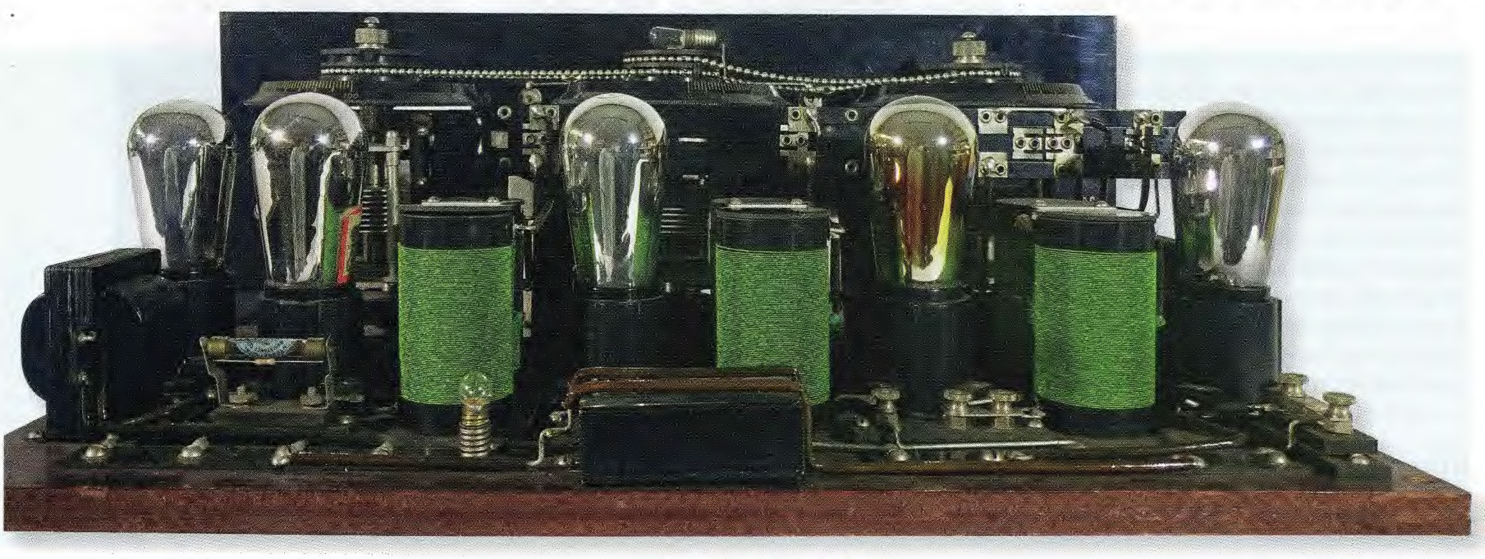
A final note: is the Neutrodyne a positive feedback circuit? Yes, you can describe it that way. Remember that the purpose was to achieve the theoretical maximum gain from a stage, not to increase it over that maximum (the purpose of regeneration).

Is it possible to increase the positive feedback beyond the point of balancing and get extra gain? Yes. I was able to push the Synchrophase into regeneration and ultimate violent oscillation by maladjustment. Is this cheating, against the purpose of the Neutrodyne principle and just plain wrong? Yes, yes, and yes.

But it is a TRF, after all.

So how does a sensitivity of 8 microvolts for 10 milliwatts output sound? And in the HF band?

The BC-AN-429 military aircraft receiver (kitted out with pentode RF am-



plifiers) managed this over its lowest HF range of 2.5-7MHz, rivalling that of its more famous superhet "Command" successors. Could the Synchrophase get anywhere near that benchmark?

## Circuit description

The Synchrophase, like other Neutrodyne designs, is simplicity itself, as can be seen in the circuit diagram overleaf. Like other sets of the era, its component count is "economical". LT (filament) power was commonly from a 6V lead-acid battery, regulated via one or more filament rheostats.

"Gasoline Alley", a comic of the day, shows the man of the house driving around and around the block: he's taken the radio battery for an outing to charge it!

HT batteries came in some multiple of 22.5V and were connected in series, the highest voltage for the output stage, lower voltages for the demodulator and RF stages. Bias was very often supplied via a tapped battery, with outputs at 1.5 or 3V.

Given the ready availability of battery-supplied voltages and the natural low impedance of such batteries, the Synchrophase has just two bypass capacitors, C3 and C12, both 1μF.

The set covers frequencies 545-1900kHz in two bands: 545-1250kHz and 1200-1900kHz. Turning the dial to either extremity of its range trips a lever that operates a 3-pole slider switch.

The switch cuts in (or out) part of each of the binocular coils and it's also possible to do this manually (as can be seen at the bottom of this page).

The aerial circuit, in common with many early sets, provides for "long" and "short" wire aerials or for a tuned loop aerial. If using a loop, it's important that it is of the correct inductance for proper tuning.

All valves in this set are UX201As, similar to the iconic '01, but with reduced filament current of only 0.25A.

Later sets used a UX112 in the final stage for greater audio output. V1 and V2 operate as common-cathode, tuned RF amplifiers.

The proprietary "binocular" coils are secondary-tuned by C2 and C4. Neutralisation is provided by C3 and C5. The bias battery supplies a common bias voltage of -4.5V while the HT supply is +90V.

Demodulator V3 operates with grid leak bias, returned to its filament, rather than to the -4.5V ground potential. C7, although similar to C3 and C5, does not neutralise; it's there to match the circuit capacitances of C3 and C5 so that V3's tuned grid circuit tracks those of V1 and V2.

The tuning capacitors use plates cut to give a straight line (linear) frequency calibration, preventing crowding of stations at the top ends of the bands. This is shown in the diagram directly below.

V3 feeds 1st audio V4 via driver transformer T1. This has a step-up ratio of around 4:1. The demodulator runs from a +45V supply.

All three RF stages are tuned together via Grebe's patented chain drive system that mechanically couples the three separate tuning capacitors. Note that the now commonly-used multi-gang capacitor did not appear until F. W. Dunmore's competing patent on the 23rd of March 1926.

First audio amplifier V4 uses another step-up transformer to drive output valve V5. Together, T1 and T2 give more gain than an extra UX201 without the cost of an actual valve and its power consumption.

Be aware that such transformers can have very high resistance windings. We're probably accustomed to conventional valve output transformers with primary resistances around 500Ω.

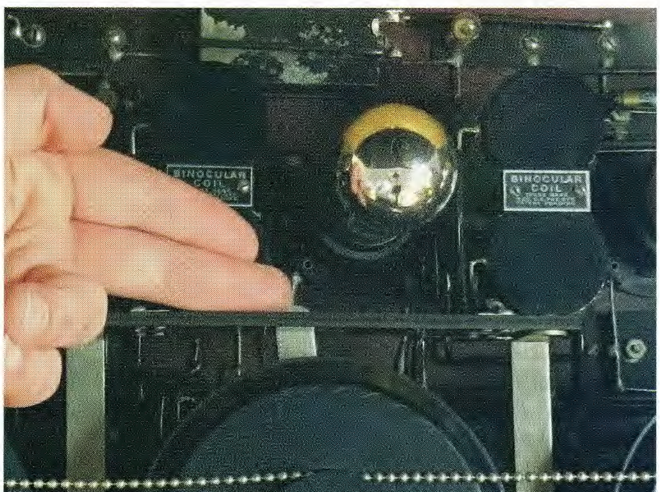
Because these are loaded (by loudspeakers), the natural combination of inductance and winding capacitance is well-damped and any peak exhibited by the winding is commonly damped by small shunt capacitor.

Interstage transformers, fed by a triode of some 10kΩ source impedance, matching into the following grid of near-infinite impedance, do exhibit significant resonance within the audio band.

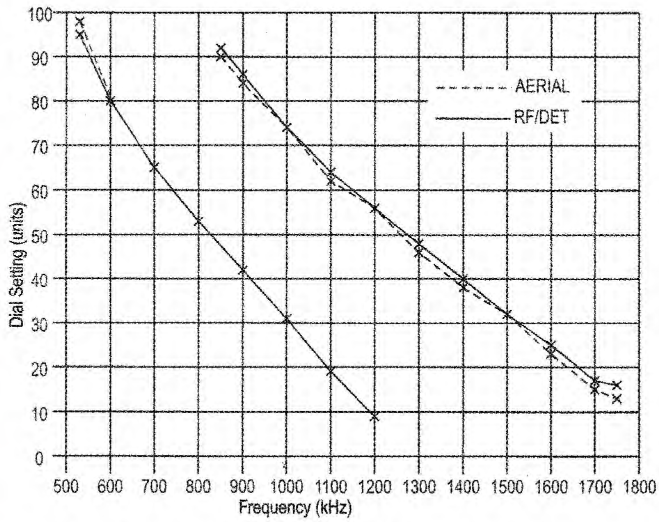
The solution was to use high-resistance wire for primary or secondary (or both) to damp out the resonant peak.

T1 and T2 both have primary resistances of 300Ω and secondaries of 6.6kΩ. So if you're working on one of these set, don't be misled into assuming an interstage transformer with high resistance has a faulty winding.

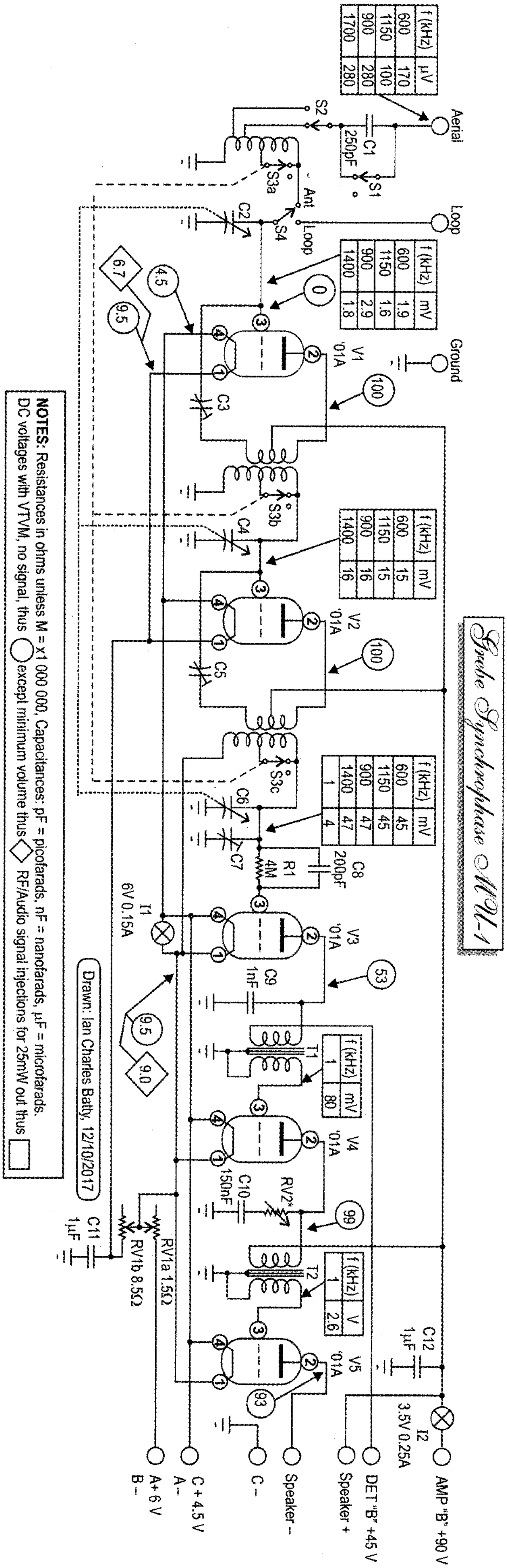
As this set uses a UX201A for output amplification, it shares the common -4.5V C supply and the common +90V HT. Sets using the UX112 need an extra bias voltage of -9V and use an HT supply of +135V.




**The three-pole slider switch shown the the centre of this photograph can be used to manually change the operating band.**




**This diagram shows the straight-line tuning characteristic of the Synchrophase.**




My set's volume is controlled by RV1a/RV1b, a dual rheostat that adjusts filament voltages of all valves, with greater effect on V1 and V2 than V3/4/5. This both compensates for falling A battery voltage and controls gain in the RF section.

While low heater voltage can be a recipe for disaster with oxide-coated cathodes, this method of controlling emission (and thus gain) works fine with "bright emitter" tungsten filaments (UX201) and with thoriated-tungsten (UX201A).

Later Grebe versions used a variable shunt rheostat across the first audio's anode connection to its driver transformer for volume and a common rheostat for all valves to compensate for falling A battery voltage.

Tone control, via switched resistor bank RV2 (ranging from 3.6kΩ to 120Ω) and 150nF capacitor C10, applies a variable top cut to the audio driver's anode circuit.

Such sets are designed for high-impedance speakers, either "earphone" types that use a flat diaphragm to drive a coupling horn or moving-iron types that drive a large diaphragm. When testing, I found two horn speakers to be less sensitive than my moving-iron example.

When it comes to the supply, the C supply's negative end connects to ground. This may seem odd but its positive end connects to the A supply's negative, putting all five filaments at 4.5V above ground and applying a -4.5V bias to V1, V2, V4 and V5.

This arrangement ties these grid returns ("cold" ends of transformer secondaries) to ground, eliminating valve-to-valve coupling that would otherwise need at least two bypass capacitors (one each in RF and Audio sections). Demodulator V3's grid returns to its filament.

Continuing the supply "totem pole", B- connects to A+ (a point some 10.5V above ground), thus counteracting a loss of some 10V if the B- were connected directly to ground.

## Cleanup

Online examples, and Dr Hugo Holden's version in the July 2016 issue, show the beautiful gold flashing on the escutcheons and the timber in new condition. In contrast, mine has a definite patina, with the escutcheons dulled off to a faded bronze colour.

It came with a modern power supply and the connecting cables in a modern reproduction woven cotton jacket. The valves were all ST ("stepped tubular") 01As. Some tested low so I bought a new kit of balloon envelope 01As from the HRSA valve bank at a good price.

Apart from noise in the volume pot, the set worked just fine. But on test, there were a few surprises. The 01A was only ever meant as a general-purpose triode, so its output power is modest. The set went into clipping at around 30mW, reaching 10% THD at 35mW. I decided to test at an output of 25mW, finding THD of about 7%.

That sounds high, and the 10mW figure was 6%. Everything seemed to be working, so I suspected the grid-leak detector's basic design. That was confirmed by a test which exhibited obvious non-linearity over its signal range, as shown in the diagram to the right.

This will create distortion in the demodulated envelope, and is probably typical of any rectifier/demodulator working with a low input voltage.

On the other hand, its RF performance was surprisingly good. A few metres of wire thrown out the door brought in local stations strongly, and extending that to about eight metres let me just pick up 3WV at Horsham, 200km away.

Using the standard dummy antenna, I needed 170µV at 600kHz, 100µV at 1150kHz and 280µV at 900kHz and 1700kHz. Signal-to-noise ratios well exceeded 20dB for all settings.

Audio bandwidth was surprising: I found -3dB bandwidths of ±1.2kHz at 600kHz, ±3.5kHz at 1150kHz, ±1.2kHz at 900kHz and ±8.5kHz at 1700kHz.

Frequency response from antenna to speaker terminals was around 350Hz to 2.5kHz for -3dB the points at the 1700kHz end, indicating that the audio transformers have limited low and high frequency performances.

If the figures sound pretty good, consider the detailed stage injections on the circuit. You'll see that, for my 100µV input at 1150kHz, I needed around 1.6mV at the 1st RF grid. This implies a circuit gain of some 16 times in the antenna coupling and its tuned circuit. It's a reminder of just how well good circuit design can contribute to a set's performance.

The difference in sensitivities between the two bands is probably due to the band-change mechanism, which appears to short out the unused sections of the RF coils. I had wondered about a "shorted turns" effect and figures seem to bear it out.

Volume control was pretty effective: turning down all the way demanded some 35mV at 1700kHz, implying a gain reduction of around 42dB.

## How good is it?

It's great. Grebe gave us a set with sizzle and sausage, and it hits both of my criteria for collecting: it's a visual treat that people find attractive and charming, and it's technically refined and a great performer.

Would I buy another? One is enough but you can still find them for sale at affordable prices. Given its great visual design, if you want a "real" radio, and one that's compact enough to fit most shelves, it's hard to pass by.

## Synchrophase versions

"A new set every week!" while it was not really a Grebe slogan, there were many versions. Model coding is mysterious and confusing but the "radioblvd" reference located under "Further Reading" has useful information.

## Special handling

In some sets, the 01 and 01A use a locking pin to secure the valve in the socket; the pin tips make contact against flat "leaves" at the bottom of the socket rather than sliding into socket contact sleeves used in later equipments.

The pin indexes the valve, so insertion requires matching the pin, pushing down and gently twisting clockwise a few degrees. Removal is the opposite but excessive twisting can detach the envelope from the valve's Bakelite base. Use care.

## Further Reading

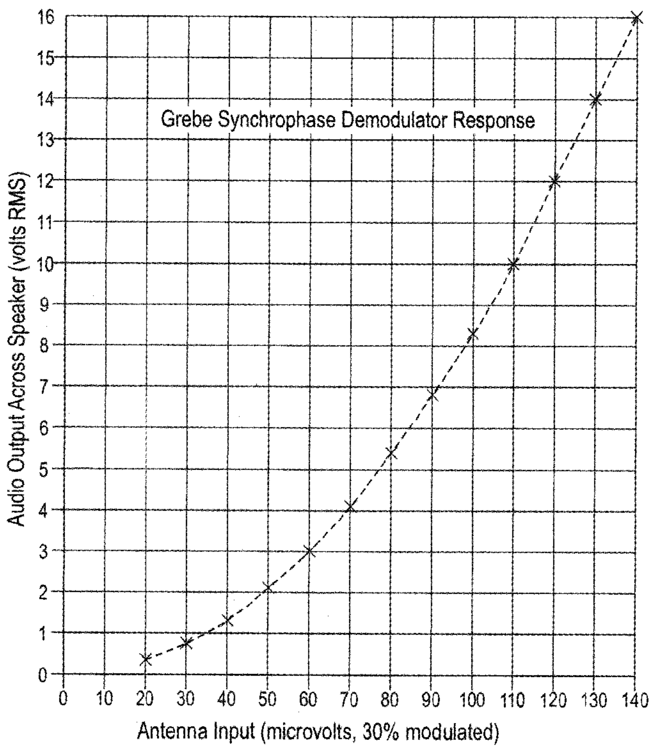
The 1924 review appears at: www.greberadio.com/?page_id=101

Batcher's QST review of 1925 (four scans) appears at: www.atwaterkent.info/grebe/Articles/QST2504.html

There's an excellent Synchrophase site at: www.radioblvd.com/Grebe%20Synchrophase.htm

Set manufacture: www.youtube.com/watch?v=2ovD5lX53Ck

And don't forget Ernst Erb's comprehensive site. It has the MU2 and many other Grebe sets at: www.radiomuseum.org/r/grebe_synchrophase_mu2_1.html **SC**




**This diagram shows the audio output versus the antenna input. Note that it is not a straight line and this is the reason for the relatively high harmonic distortion in the Grebe MU-1.**

### Thoriated-tungsten filaments

The first generation of valves used either tungsten or tantalum filaments, a natural consequence of their light bulb predecessors' technology.

These were also the only available metals that could give useful emission and stand the extremely high temperatures needed, around 2200°C. This was close to tantalum's melting point, so tungsten became the material of choice

It was known that thorium, for instance, would give improved emission at lower temperatures, but that it was incapable of being formed and used at the 1700°C required for useful emission.

The solution was to coat a tungsten filament with a very thin thorium coating, and to run the tungsten at the 1700°C needed. Where tungsten gave only about 5mA of emission per watt of heating power, thoriated-tungsten improved this to 100mA/watt.

Thoriated tungsten also offered much longer life than pure tungsten "bright emitters", but was still capable of the very high emission currents demanded in transmitting valves.

Further development led to oxide-coated cathodes used in receiving valves and low-power transmitting valves. These commonly use a combination of barium, calcium and strontium oxides, giving emission currents of 500mA/W and operating temperatures around 700°C.

Oxide-coated filaments are used in battery-powered octal, miniature and subminiature valves.