DESIGN AND CONSTRUCTION

OF A SUPER HETERODYNE RECEIVER

THESIS FOR DEGREE OF B. S.

W. A. FITCH A. J. SIMPSON

1926

Radio

** T H E S I S **

DESIGN AND CONSTRUCTION
OF A SUPER HETERODYNE
RECEIVER

A Thesis Submitted to

The Faculty of

MICHIGAN STATE COLLEGE

By

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A. J. Simpson

Candidates for the Degree

of

Bachelor of Science.

June 1926.

THESIS

** DEDICATION **

* TO *

The Electrical Engineering Department of the

Michigan State College for

Increasing and Bettering

the Laboratory

Equipment

and the Benefit

to the Course therefrom

this Work is heartily Dedicated

by the Authors.

** PREFACE **

This book is a collection of notes and details for the design and construction of super heterodyne receiver.

We selected the design and construction of this apparatus in view of the fact that it is a very useful instrument and is much needed to better the equipment of the Electrical Engineering Department. Also we considered the benefit to ourselves derived from the working out of the design and details of construction, the pleasure of seeing it materialize and work out under test after completion.

In the course of our work we received much help from various departments and persons connected thereto and we wish here to express our deep indebtedness to;

Mr. Burr K. Osborne for advice on design, construction, general information and supervision.

The Detroit Electric Co. for the loan of apparatus.

Mr. Fields for helping with the drawings and blue prints.

EVERYBODY with whom we came in contact for general good-will, readiness to help, and interest in the work.

We feel that we are well repaid for our efforts to make this work a success, and hope that the instrument that we have constructed will be of use and value to the Department. We will be glad if these notes as a benefit of our experience may be of use to anyone considering the same or a similar project.

W. A. Fitch

A. J. Simpson

M. S. C. June 1926

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INTRODUCTION

The Super-Heterodyne method of reception is a product of the ingenuity of Mr. E. H. Armstrong and represents his solution of the important and difficult problem of amplifying signals of short wave length. The performance of cascaded radio frequencies represented by wave lengths of the order of 100-600 meters is considerably poorer than their performance at lower frequencies, due to the comparatively high electrostatic capacity of the tubes and wiring used to connect up the amplifier.

THEORY OF SUPER-HETERODYNE RECEIVER

Briefly the theory of the Super-heterodyne is to beat the incoming frequency with a local oscillator producing a beat frequency which is amplified in an amplifier designed for this, and only this, frequency. After amplification it is then changed to audio frequencies by means of a detector. There are several advantages to this scheme. There are only two dials to control, one for the oscillator and the other for the loop tuning. The set is extremely selective due to the sharpness of tuning of the intermediate frequency amplifier. And due to the fact that the amplifier is designed for this one frequency, very high amplication may be obtained.

Figure 1 is meant to represent a modulated carrier wave such as are produced by a broadcasting station. The variations occur at voice frequencies. The mathematical expression for such a train of oscillations may be written as follows:

$$\left[V + V_1 \text{Sin}(pt + \theta_1) + V_2 \text{ Sin}(2\,pt + \theta_2) + V_3 \text{Sin}(3pt + \theta_3) + V_n \text{Sin}(n\,pt + \theta_n) \text{Sin}\, \omega_1 t \cdots\cdots \right]. \qquad (1)$$

Wherein the bracketed expression is the equation of the envelope curve bounding the amplitude of the radio frequency oscillations, expressed in the form of a Fourier's series, and the last term, Sin $\omega_1 t$, refers to the radio frequency oscillation of periodicity ,, which is to be

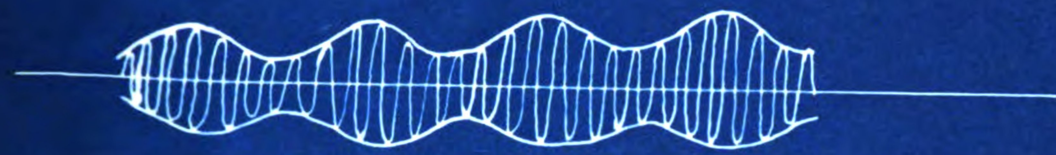


Fig. 1.
Illustrating a voice modulated carrier frequency.

considered as an oscillation modulated at audible frequency according to the envelope curve just mentioned. The envelope contains a fundamental frequency corresponding to p and all the harmonics 2 p, 3 p, 4 p, ...n p characteristic of the voice frequency. Thus the periodicity p would correspond to the fundamental voice frequency and the harmonics may run to the 10th or 20th before their amplitudes are small enough to make them negligible. V_1, V_2, V_3,....V_n designate respectively the amplitudes of the fundamental and the various harmonics. θ_1, θ_2,......θ_n represent their phases.

The voltage produced by the local oscillator for heterdyning is $V \cos(\omega_2 t + \theta)$.......................(2)

The total or resultant voltage acting on the first detector at every instant is therefore given by the sum of expressions (1) and (2). This can be written in the following form:

$$
\begin{aligned}
&V_1\Bigg[\frac{\mathrm{Cos}(\omega_1 - \omega_2 - p)t + (\theta_1 - \theta)}{2} \times \frac{\mathrm{Cos}(\omega_1 + \omega_2 - p)t + (\theta_1 + \theta)}{2} - \\
&\frac{\mathrm{Sin}(\omega_1 - \omega_2 + p)t + (\theta_1 - \theta)}{2} \times \frac{\mathrm{Sin}(\omega_1 + \omega_2 + p)t + (\theta_1 + \theta)}{2}\Bigg] + \\
&V_2\Bigg[\frac{\mathrm{Cos}(\omega_1 - \omega_2 + 2p)t + (\theta_2 - \theta)}{2} \times \frac{\mathrm{Cos}(\omega_1 + \omega_2 - 2p)t + (\theta_2 + \theta)}{2} - \\
&\frac{\mathrm{Sin}(\omega_1 - \omega_2 + 2p)t + (\theta_2 - \theta)}{2} \times \frac{\mathrm{Sin}(\omega_1 + \omega_2 + 2p)t + (\theta_2 + \theta)}{2}\Bigg] + \\
&V_3\Bigg[\frac{\mathrm{Cos}(\omega_1 - \omega_2 + 3p)t + (\theta_3 - \theta)}{2} \times \frac{\mathrm{Cos}(\omega_1 + \omega_2 - 3p)t + (\theta_3 + \theta)}{2} - \\
&\frac{\mathrm{Sin}(\omega_1 - \omega_2 + 3p)t + (\theta_3 - \theta)}{2} \times \frac{\mathrm{Sin}(\omega_1 + \omega_2 + 3p)t + (\theta_3 + \theta)}{2}\Bigg] + \\
&\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots + \\
&V_n\Bigg[\frac{\mathrm{Cos}(\omega_1 - \omega_2 - np)t + (\theta_n - \theta)}{2} \times \frac{\mathrm{Cos}(\omega_1 + \omega_2 - np)t + (\theta_n + \theta)}{2} - \\
&\frac{\mathrm{Sin}(\omega_1 - \omega_2 + np)t + (\theta_n - \theta)}{2} \times \frac{\mathrm{Sin}(\omega_1 - \omega_2 \pm np)t + (\theta_n + \theta)}{2}\Bigg] + \\
&V\,\mathrm{Sin}\,\omega_1 t. \qquad (3)
\end{aligned}
$$

In each of the bracketed terms four different frequencies appear, namely:--

$$\frac{\omega_1 - \omega_2 - kp}{4\pi} \qquad \frac{\omega_1 - \omega_2 + kp}{4\pi}$$

$$\frac{\omega_1 + \omega_2 - kp}{4\pi} \qquad \frac{\omega_1 + \omega_2 + kp}{4\pi}$$

k having different values 1, 2, 3, 4, ...n corresponding to the 1st, 2nd, 3rd, 4th or nth bracket involving the 1st, 2nd, 3rd, 4th or nth harmonic.

The explicit values of these frequencies depend principally upon the values ω_1 and ω_2 of the incoming and local radio frequencies.

When considering short waves, of the order of 500 to 200 meters ω_1 and ω_2 are both very large and of the four frequencies mentioned, the two involving the differences $\omega_1 - \omega_2$ are considerably smaller than the two comprising the sums $\omega_1 + \omega_2$. Thus the two trigonometric products which appear in each of the bracket terms of (3) indicate a radio frequency voltage of frequency $\frac{\omega_1 + \omega_2 \pm kp}{4}$ modulated by a considerably lower, though still super audible frequency of value $\frac{\omega_1 - \omega_2 \pm kp}{4\pi}$. The transformers of the intermediate amplifier are designed for frequencies of their order of magnitude and are not, thereaffected by the radio frequencies $\frac{\omega_1 + \omega_2 \pm kp}{4\pi}$. No energy of these latter frequencies passes through the amplifier. Neither does energy of the incoming signal radio frequency ω_1 represented by the last term of (3), particularly if the transformer stages are sharply tuned as they should be. It is only the beat or difference frequencies $\frac{\omega_1 - \omega_2 + kp}{4\pi}$ that have to be considered in designing the transformers and circuits. All of these frequencies lie in the neighborhood of the value $\frac{\omega_1 - \omega_2}{4\pi}$ which is the fundamental or basic beat frequency produced by the incoming R. F. and the local oscillations.

The transformers are fundamentally designed for the basic or mean frequency $\frac{\omega_1 - \omega_2}{4\pi}$. This can be adjusted by regulating the local oscillation but its proper value is by no means immaterial.

DESIGN AND TESTING OF I. F. TRANSFORMERS.

The intermediate frequency amplifier may be said to be the heart of the Super-Heterodyne. It is here that the feeble signals picked up from the loop are amplified to an audibility level.

The choice of intermediate frequency is important. It is limited in the lower ranges by the fact that it must be above audibility, and thus about 20,000 cycles is as low as is permissible. The limitations in the other direction are the difficulties usually encountered in amplifications of high frequencies, such as oscillation due to feed back between stages so a value of about 150,000 cycles is about as high ascan be used effectively.

The transformers should be as sharply tuned as possible to permit the building up of high voltages and avoid losses in resistance. A second requirement is that there shall be no distortion in the tonal quality of the received signal as it passes through the amplifier. This means that essentially all of the harmonics contained in the envelope curve of the arriving modulated oscillations must appear in the telephone current of the last detector. Thus, it is necessary to transmit equally through the coupling transformers of the amplifier all of the frequencies,

$$\frac{\omega_1 - \omega_2 + kp}{4\pi} \quad \text{and} \quad \frac{\omega_1 - \omega_2 - kp}{4\pi}$$

and while designing the transformers for the basic frequendy $(\frac{\omega_1 - \omega_2}{4})$, the tuning must be broad enough so that the response is practically uniform over all the frequencies up to $\frac{np}{4}$ on either side of this basic value. For radio phone reception $\frac{np}{4}$ should be at least 5,000 cycles. This allows a 10,000 cycle audio band that is uniformly amplified.

There are several disadvantages of the use of low intermediate frequencies. In the first place the closer the intermediate frequency to the audio range the greater the tube noise, as this is an inverse function of the frequency. Then also if a certain type of transformer will amplify equally frequencies 10% above and below its best frequency the frequency band will be wider for higher frequencies. For instance with this transformer the responsive range at 30,000 cycles would be 6,000 cycles which is not wide enough to retain all of the speech frequencies, with the result that it will sound unnatural. Whereas this same type transformer at 50,000 cycles would give a responseve range of 10,000 cycles.

There is another circumstance which favors the use of high beat frequencies. The reason may be best explained by an example which will illustrate the fundamental weakness of the Super-Heterodyne--its complete lack of high selectivity under certain conditions. Suppose that the intermediate frequency is 30 K. C. and we desire to receive a station having a carrier frequency of 680 K. C. Let us further suppose that there are other stations on the air having carrier frequencies of 620 and 740 K. C. Now one setting of the beating oscillator to receive the desired station is 650 K. C. and the other is 710 K. C. But it will be noted that each of these oscillator settings is exactly right also for the reception of one of the interfering stations, so that without changing the oscillator setting we can change from one station to the other by merely changing the tuning of the loop. In other words the only protection against the undesired station is the selectivity of the loop circuit. Obviously if we double the intermediate frequency the selectivity will be enormously greater, as the stations to produce this type of interference will have their carriers separated from that of the desired signal by 120 K C. instead of 60 K C. and the loop circuit would be sharp enough to eliminate the undesired signal if properly designed. The proper design of the loop circuit will be taken up later. Another type of interference is also present. Suppose we want 680 K. C. as before and have interference at 650 and 710 C. C. This interference will also give us a 50 K. C. beat note which will come through the amplifier. For this reason the intermediate frequency should not be any multiple of 5 K. C. or half the spacing between stations and less trouble from beat notes will result if the intermediate frequency is a prime number.

In view of the numerous advantages of high frequencies it seems wisest to have the intermediate frequency at least 50 K. C. and preferably higher.

The choice of the intermediate transformer was decided only after considerable testing and experimentation. Altogether 6 commercial transformers were tested. A photograph of the apparatus used for testing is shown. The important parts of the set up are the oscillator, wavemeter, vacuum tube voltmeter, intermediate frequency amplifier, intermediate frequency transformer, detector and galvanometer.

The idea of the set up is to test different transformers for amplification when operating under conditions approximatingas nearly aspossible the actual conditions in the receiving set.

The peak voltage in the pick up coil, which receives this energy from the oscillator, is measured by the vacuum tube voltmeter. This voltage is adjusted to one volt by varying the distance from pick up coil to oscillator. Then by a potentiometer arrangement 1/100 of this voltage is fed into the input of an amplifier consisting of a tube and transformer under test. The alternating voltage is again measured by the detector and galvanometer. An explanation for the different parts of the set up will now be given.

The oscillator uses the simple Hartley circuit and is calibrated from 30 to 100 K. C. by means of the wavemeter. The tube used in this oscillator is a 7.5 watt type U. V. 210.

The pick up coil was about 9" in diameter and had about 100 turns. It was always kept at least two feet from the oscillator to eliminate the effects of mutual induction.

The vacuum tube voltmeter is a device that measures A C peak voltage without causing any load to be put on the potential to be measured. The operation of measuring the voltage consists of biasing the tube negative till the milliameter in the plate circuit just ~~reads~~ zero, with the oscillator turned off. We are now operating on point (a) of the characteristic curve of the vacuum tube and the milliameter reads zero.

If now the oscillator is turned on the milliameter will show an increase in plate current. If now the grid bias is made more gegative by varying the potentiometer, when it reaches C the plate current will again be zero and the difference between the two voltmeter readings will be the A C peak voltage induced in the pick up coil.

In the test, point (a) need be measured only once. Then the potentiometer is adjusted until it reads one more volt than at (a). Then the oscillator is turned on and the distance from coil to oscillator adjusted till the milliameter just reads zero. The induced voltage is then one volt and can be maintained at this value throughout the test by adjusting the distance. It is necessary to do this because the output of the oscillator varies somewhat with the frequency it generates.

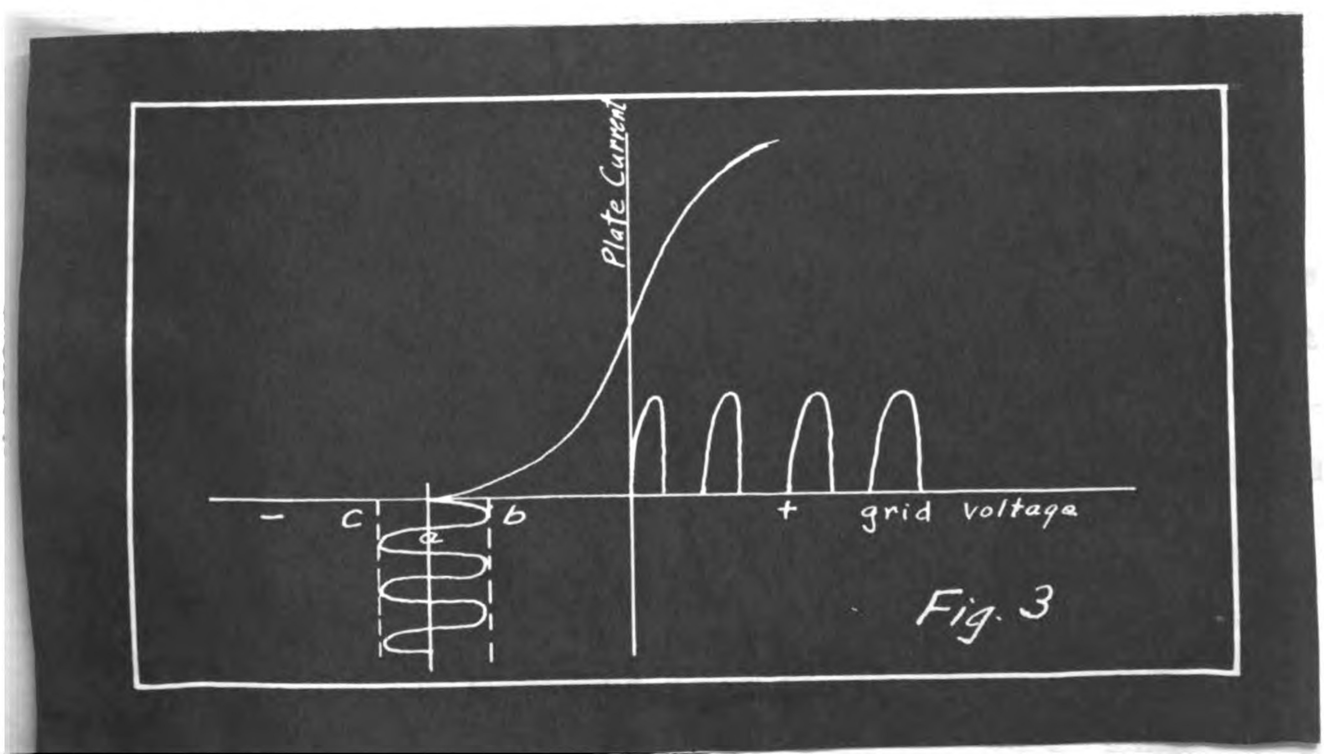


Fig. 3

The reason for using the 100 to 1 ratio potentiometer ahead of the amplifier is to cut down the input voltage to a value that would occur in an actual set. In most Super-Heterodynes probably the voltage input to the last intermediate stage would be .01 volt. If excessive voltages were used it might not give the iron transformers a fair test due to the possibility of saturating the iron.

The amplifier used the same type of tube that was to be in the set namely, U X 199. This tube has many advantages over other types. In the first place its filiament consumption is very low being only .06 amps at 3 volts. The inter-electrode capacity is also smaller than most other tubes. Its amplification constant is not quite as high as the U X 201 A but this disadvantage is slight.

The actual curves for the transformers tested are shown on curve sheet number 1. For good quality reception the peak should be at least 7 kilocycles wide. In order to make the sampon transformers broad enough it was found necessary to put a half megohm grid leak across the secondary. Of course this cut down the amplification considerably but even then the amplification was higher than the other transformers. For this reason it was decided to use these transformers in the set. Possibly the other transformers would have given a better account of themselves if the larger tubes were used. Following is a description of the Sampson Transformers by the Sampson Electric Co.

The Samson HW-R1 Long Wave Radio Frequency Transformers have Helical Windings in both primary and secondary. The effectiveness of this unique winding method has been demonstrated in our Audio Frequency Transformers, and is found to be of even greater value in Radio Frequency. These Transformers are made for three wave lengths; 3,000, 5,000, and 10,000 metres.

Minimum Leakage: Owing to the use of the helical winding with the small voltage between adjacent turns, the primary and secondary coils are exceedlingly compact, which results in more self-inductance for a given number of turns, and therefore in a minimum of magnetic leakage.

Coupling: In the helical method of winding it is possible to carefully govern the coupling between the primary and secondary windings without disturbing either of the windings, and this is one of the factors which makes it possible to accurately determine the best coupling for the finished product, and to maintain this standard accurately in manufacturing.

Windings: In the arrangment of the primary and secondary windings, the dispostion of the setions is such as to provide the necessary coupling without the use of a large iron core which is usually necessary where the magnetic leakage in the windings is large. The obviates the need of depending almost entirely upon iron for the coupling where its use always involves a variable element which may widely differ in different lots. It is impossible to reproduce the sectional winding of the Samson Radio Frequency Long Wave Transformers by the ordinary layer winding method.

DESIGN AND TESTING OF AUDIO FREQUENCY TRANSFORMERS

The purpose of the audio frequency amplifier is to amplify without distorsion the output of the second detector to such a volume that it will operate a loud speaker.

That one clause, amplify without distortion, might be called the whole problem in a nutshell, because if the music or voice is to sound right it must not be distorted in any way when passing through the set. In order to accomplish this amplification without distortion there are two main requirements to be met. First, the tubes used must be large enough to deliver to the loud speaker as high an output as is desirable without being overloaded. (If the grid swing exceeds the straight line portion of the tube characteristic a tube is said to be over loaded.) It is easily seen that the last tube in the set would be the one that would be most likely to be over loaded because it is the final step in the process of amplification. This limitation then, may be completely removed by the use of a higher power tube in the last stage, such as the U X 120. This tube is designed for a grid swing of 22½ volts which is not likely to be exceeded. It also has a low output impedence which matches the loudspeaker, thereby giving greatest efficiency.

The second possible source of distortion lies in the coupling device used between the tubes. The different methods of coupling may use either impedence, resistance or transformers. The principle reason for choosing the latter type for the set is that there is considerable amplification in the transformer itself due to the stepping up of the voltages in the transformer. The most common cause of distortion in the transformers is the failure to amplify the low frequencies due to their having insufficient impedence at the low frequencies. Also some transformers have a resonant frequency at which they amplify much more than at other frequencies. So in order to determine what transformer was best it was decided to take several commercial transformers and measure the voltage output over the complete musical scale for a constant voltage input. It was also decided that in order to test the transformer fairly it should be operated under the same conditions it would be in a set, with an amplifier tube connected aheah of it and another tube connected onto the secondary. This amplifier tube should have the same plate, filiamentand grid voltages it is designed for. Now then, the problem is to maintain a constant voltage input between filiament and grid of the amplifier tube over a wide range of frequencies and measure the alternating voltage output. This can be done with a set up similar to the one used for testing the intermediate frequency.transformers with the exception that we are interested in the output voltages, so a vacuum tube voltmeter is connected onte the secondary of the transformer as shown in diagram N. 2. Of course an audio oscillator is used in place of the radio frequency oscillator. The audio oscillator is calibrated and is capable of generating frequencies from 186 to 7,000 cycles.

On another page is shown a photograph of the set up as used for testing the transformers. A diagram is shown of the connections of the testing apparatus. The purpose of the 2 m f condenser in the grid lead of the amplifier is to keep the bias from the voltmeter tube from affecting the amplifier. The impedenne of this condenser is so low that its effect on the A C may be neglected.

In running a test on a transformer first the bias on the two voltmeter tubes are made more negative until the galvanometers G_1 and G_2 just read zero. The voltmeter V_1 and V_2 are read. The readings will be called E_1 and E_3 respectively. Then the bias on this tube is made more negative by adjusting potentiometer p_2 until the voltmeter V_1 indicates two volts higher than before, this reading is called E_2. Then the oscillator is started and the voltage raised by means of potentiometer P_1 until the galvanometer G_1 just starts to indicate. Now there is two volts maximum value fed on the input of the amplifier. P_3 is then adjusted until the galvanometer G_2 just begins to indicate. The voltmeter V_2 is then read. This reading is called E_4. The voltage amplification of the transformer and tube combined is then $K = \frac{E_4 - E_3}{E_2 - E_1}$. Since E_3 and E_1 are constant they need not be measured again.

Six commercial transformers were tested in this way over the complete musical scale and a band of frequencies from 60 to over 6,500 cycles. For the 60 cycle source the college supply was used by first cutting down the voltage. The results were then plotted and the transformer chosen that had the flattest curve. Of the transformers tested the Rauland Lyric proved to be the best. It not only had a fairly high amplification but held this amplification practically constant even down to 60 cycles where all other transformers fell off to a marked degree.

DESIGN OF OSCILLATOR COIL

It was originally proposed to design the Super-Heterodyne to tune from 70 to 550 meter. In order to have the oscillatior to respond to this wide range of wave lengths it would be necessary to have an arrangement whereby defferent size coils could be plugged in. On account of lack of time only one coil was made. This was designed from a chart on page 587 of the March issue of Radio Broadcast. This chart is based on Nagaoka's formula. It was found that with a 10005 mf. condenset across both grid and plate coils, the number of turns on both grid and plate coils should be 49 when wound on a $2\frac{1}{2}$ inch tube. This coil has a range of from 250 to 550 meters.

DESIGN OF LOOP.

In order to reduce the distributed capacity of the loop as much as possible it was decided to wind it as shown in Fig. 2.

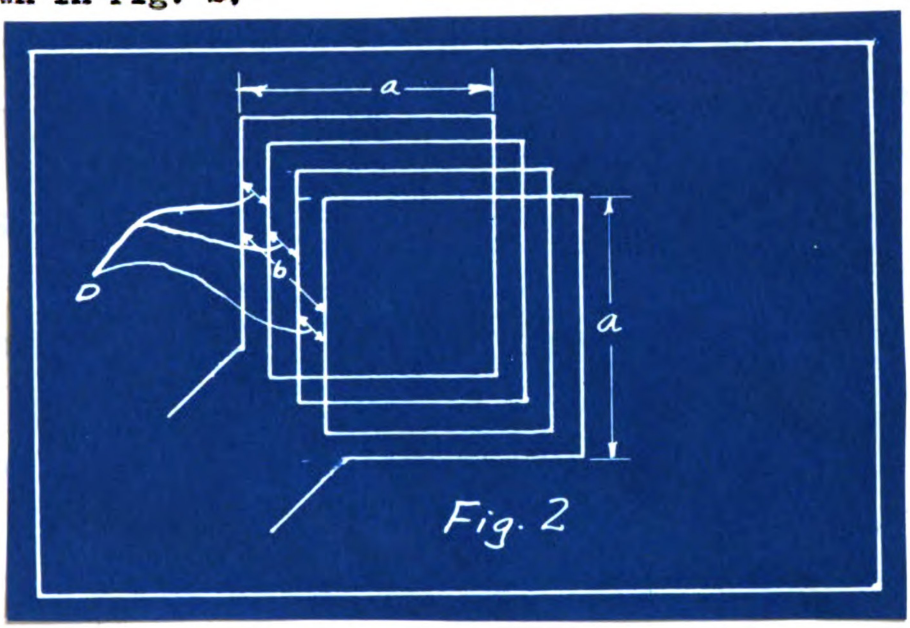


Fig. 2

This permits of a wider range of tuning than could otherwise be had. The number of turns was determined from formula 165 in Bureau of Standards Circular #74, which is;

$$L_o = .008\, an^2 \left[2.303 \log_{10} \frac{a}{b} + .726 + .2231 \frac{b}{a} \right] - .008an \left[A+B \right] \quad (5).$$

In which

L_o = the inductance of loop in microhenries.

a = the side of the square, measured to the center of the wire.

n = number of turns.

D = pitch of the winding, that is, the distance between the center of one wiree and the wenter of the next.

b = nD.

A and B are constants depending on the spacing and the number of turns.

The constants a, D and d are arbitary and were chosen as follows:

a = 18" or 45.75 cm.

b = 6" or 15.25 cm.

d = size of the wire or 1 mm.

Since the loop is to be designed to tune to 550 meters or 545 KC, the loop should have enough inductance L_o to tune to 545 KC with the .0005 M.F. condenser all in.

Then from the formula for resonacne;

$$L_o = \frac{1}{4\pi^2 f^2 C} = \frac{1}{4\pi^2 x (545x\ 10^3)^2\ x\ .0005x10^{-6}}$$

L_o = 170 x 10^{-6} hen. or 170 Microhenenries.

This value of L_o is then substituted in equation (5) and the number of turns required found to be 16.

DETAILS OF CONSTRUCTION.

The details of construction may be understood more clearly from the various photographs of the set than can be told by words. The copper box on the left hand side of the set contains the oscillator. The purpose of building the shield is to prevent the oscillations from tthe oscillator interacting with the rest of the set, It also adds to the selectivity in cutting out nearby stations by keeping keeping the coils that would be likely to pick up the interference shielded. This box is closed on all sides and soldered. It has a tight fitting cover on top and small holes in the bottom for the wiring.

Most Super Heterodynes use a potentiometer across the filiament battery and connect the grid return of the Intermediate Frequency amplifier tubes to the slider. The purpose of course being to prevent oscillations. By making the grid of the tubes positve with respect to the filiament, a curfent is caused to flow in the grid ciruit similarly to the space current in the plate circuit when the plate is made positve with respect to the filiament. This current in the grid circuit is not only due to the battery potential but also due to the alternating E. M. F. superimposed on the grid. This results in a loss in the grid circuit which stops oscillations and of course reduces ampligication. We were prejudiced to the use of this lesser method of control and not to use it if possible for two reasons. First it causes a reduction in amplification as explained above and second, by making the grid positive, the plate battery consumption is increased considerably. So in building the super heterodyne the transformers were kept separated as far as possible so as to prevent as much as possible, reaction tending to cause oscillation. Also the tube sockets were placed in such a postion as to make the grid and plate leads as short as possible for the same reason.

However in spite of these precautions the set oscillated strongly when first tried out. It was thought that possibly the oscillations couls be eliminated by mounting the transformers all at different angles. (Originally they had all been nounted up right in a straight line, separated six inches). Then also the wiring came in for its share of or criticism. The set was wired up bird cage fashion, that is, using bare wire, spearating the wires sufficiently so as not to touch. It was thought that some of the feed bake might be eliminated if the battery wiring was bunched together. Both of these schemes were tried and perhaps consitions were better. However it still persisted in oscillating. It was finally decided to put resistance on the secondary of the transformers. This accomplishes the same result as the potentiometer only it does not increase the B battery consumption. It was found that 125,000 ohms across each secondary except the filter transformers which is left unloaded was sufficient to stabilze the set. Of course this cuts down the overall ampligication but the results seemed to indicate that the amplification was sufficient. Time was not had to make exhaustive DX. tests on this set. We spent one evening tuning in stations up to 1000 miles radius with loud speaker volume.

This is good reception considering the fact that only a 18 inch loop was used and that it is in the summer when the static is heavy. The set is very sharp in tuning. Usually a station can be tuned out with one division on the dials.

The tonal qualities of the set are very good. This no doubt is due to the choice of audio frequency transformers and to the fact that the detectors use a C battery to bias them negative in place of grid leaks and condensers.

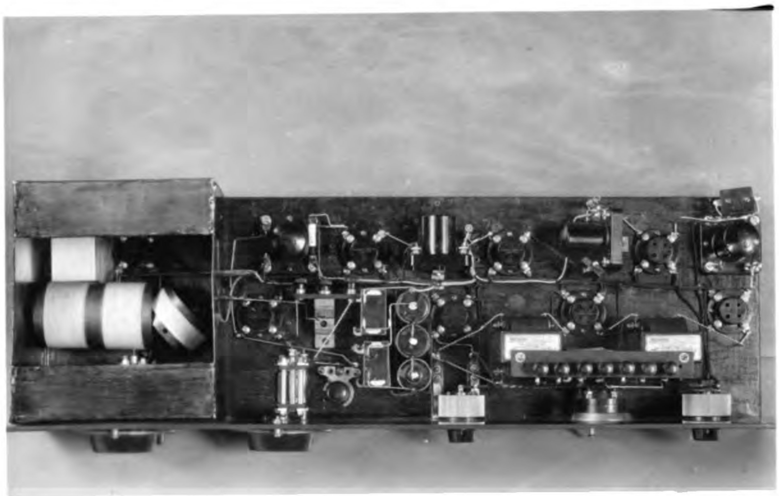
An attempt eas made to neutralize by putting small capacity between the grids of adjacent tubes. Time was not available for accurately balancing these condensers but results seemed to indicate that more amplification may be had if it is possible to properly neutralize and thereby eliminate some of the resistor load on the transformers. This is we believe a new idea as regards super heterodynes and would like ~~to~~ see this successfully carried out in the future.

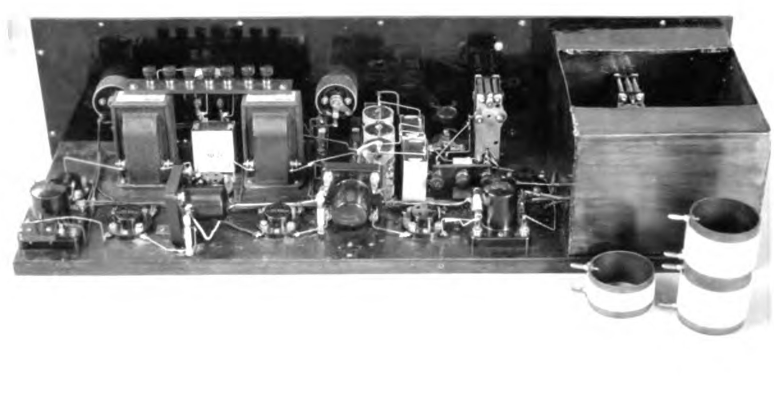
Pictures of Apparatus Used.

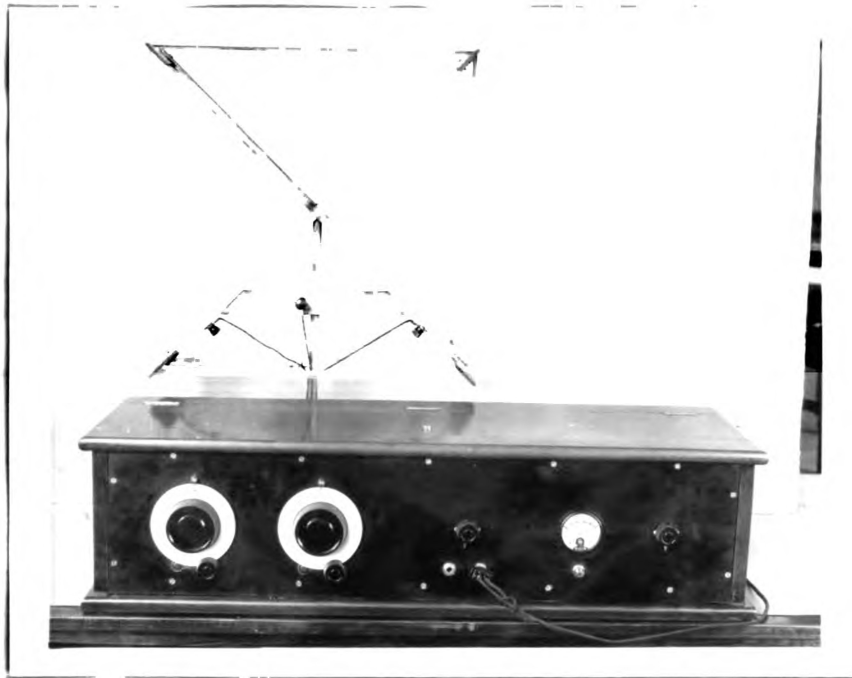
Apparatus Used for testing I. F. T.

Apparatus Used for testing Audio F. T.

PICTURES OF SUPER HETERODYNE RECEIVER.







APPENDIX

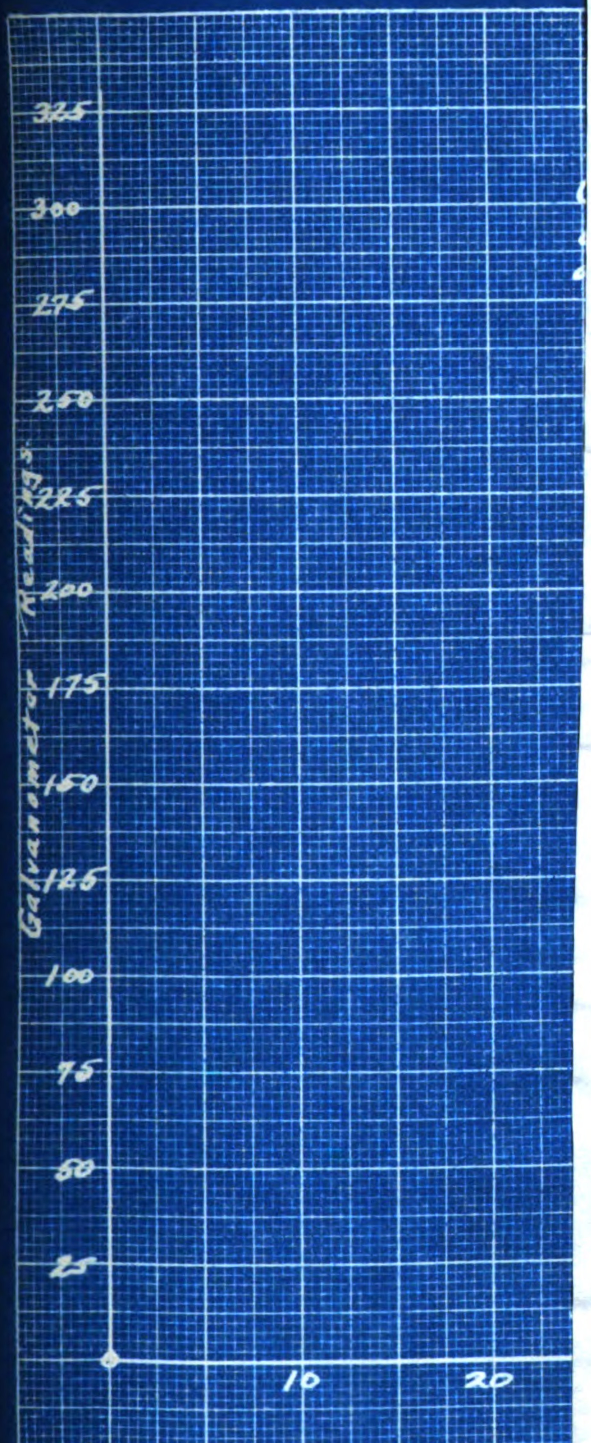
Detailed Cost Of Set

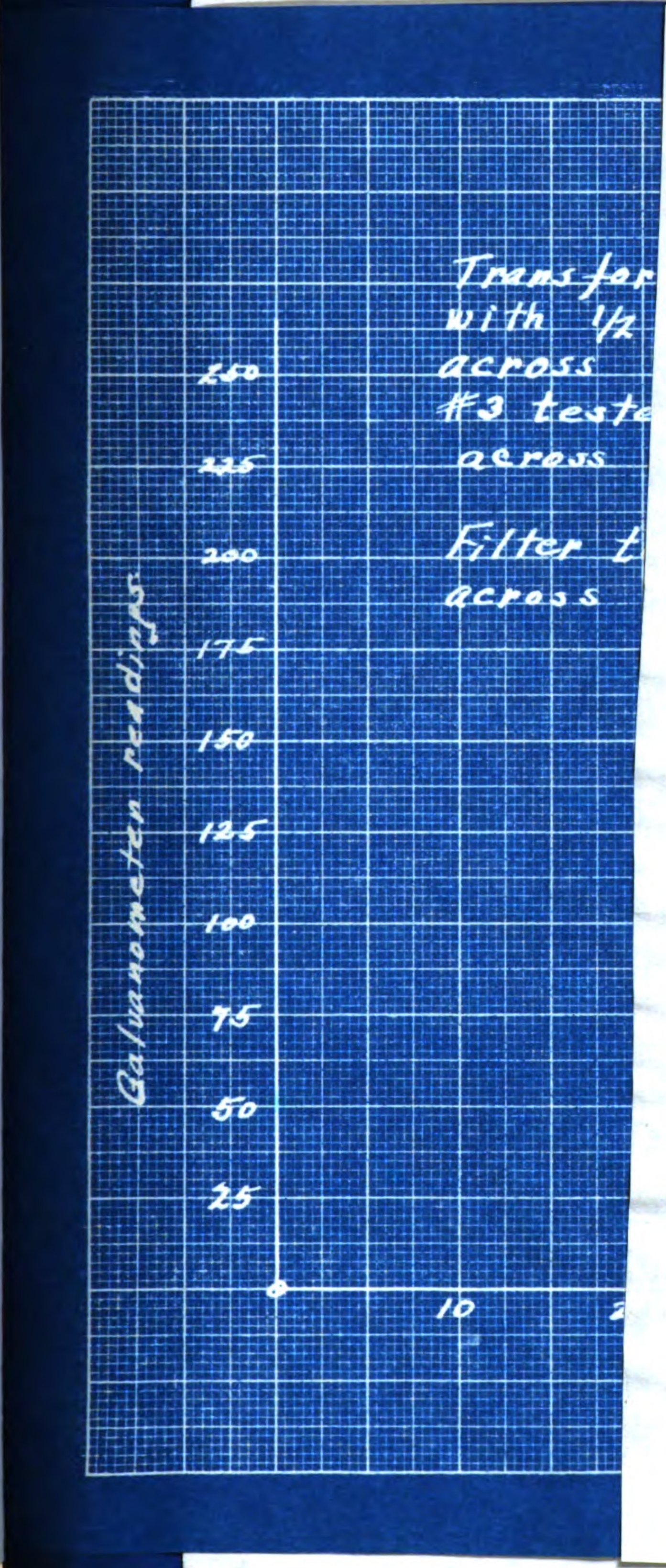
The following are the prevailing list prices of materials used in the construction of the set.

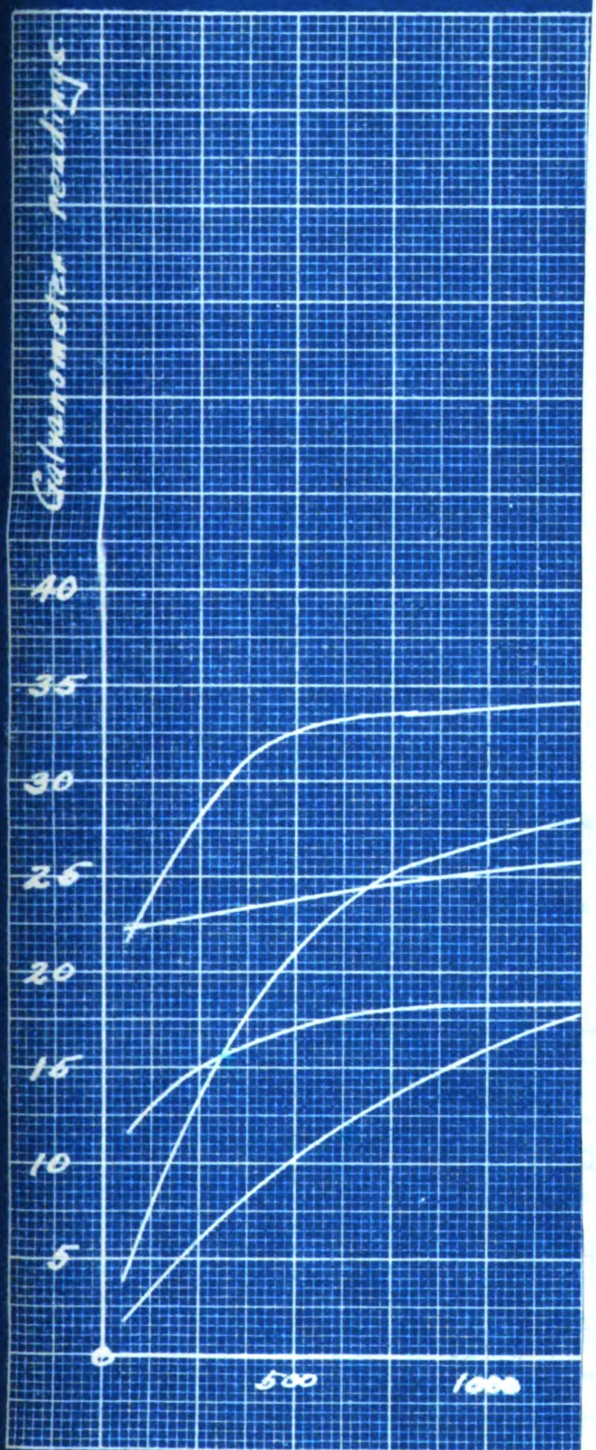
Quanity	Part and Type	Reference Number	Price Each	Price Total.
8	UX 199 Tubes		$2.25	$18.00
1	Panel 7"X 30"X 3/16"		4.92	4.92
8	General Radio X Soxkets		.50	4.00
2	Rauland Lyric Audio Transformers	13	9.00	18.00
1	Sampson Filter Transformer	7	4.50	4.50
3	Sampson Intermediate Transformers	11	4.50	13.50
1	Weston Voltmeter 0 - 5 Volts	24	7.00	7.00
1	General Radio Rheostat 6 Ohms	8	1.25	1.25
1	General Radio Rheostat 25 Ohms	8	1.25	1.25
2	General Radio Dials		2.00	4.00
2	Double Circuit Jacks	17&18	.50	1.00
4	1 M.F. Condensers	19	.90	3.60
1	Kresge Straight Line Frequency Variable Air Condenser	20	1.61	1.61
1	Spool Litzendrat Loop wire		.90	.90

Quanity	Part And Type	Ref.No.	PRICE EACH	TOTAL
1	$2\frac{1}{2}$ X $4\frac{1}{2}$ Fiber Tube	2 21&23	$ .15	$ .15
1	$2\frac{1}{2}$ X $2\frac{1}{2}$ " "	3	.15	.15
1	Kresge Straight Line Frequency			
	Variable Air Condenser	2	1.61	1.61
1	Chelton Midgit Condenser .000045 f	5	.75	.75
1	Filter Condenser .001 m.f.	6	.40	.40
1	C Battery $4\frac{1}{2}$ Volt	15	.40	.40
1	Mahogany Cabinet 7 X 30		7.50	7.50
1	Subpanel $\frac{3}{4}$"X 9"X 29"		.50	.50
1	Cutler Hammer Snap Switch		.60	.60
1	Binding post strip		.25	.25
6	Binding Posts For Loop			.25

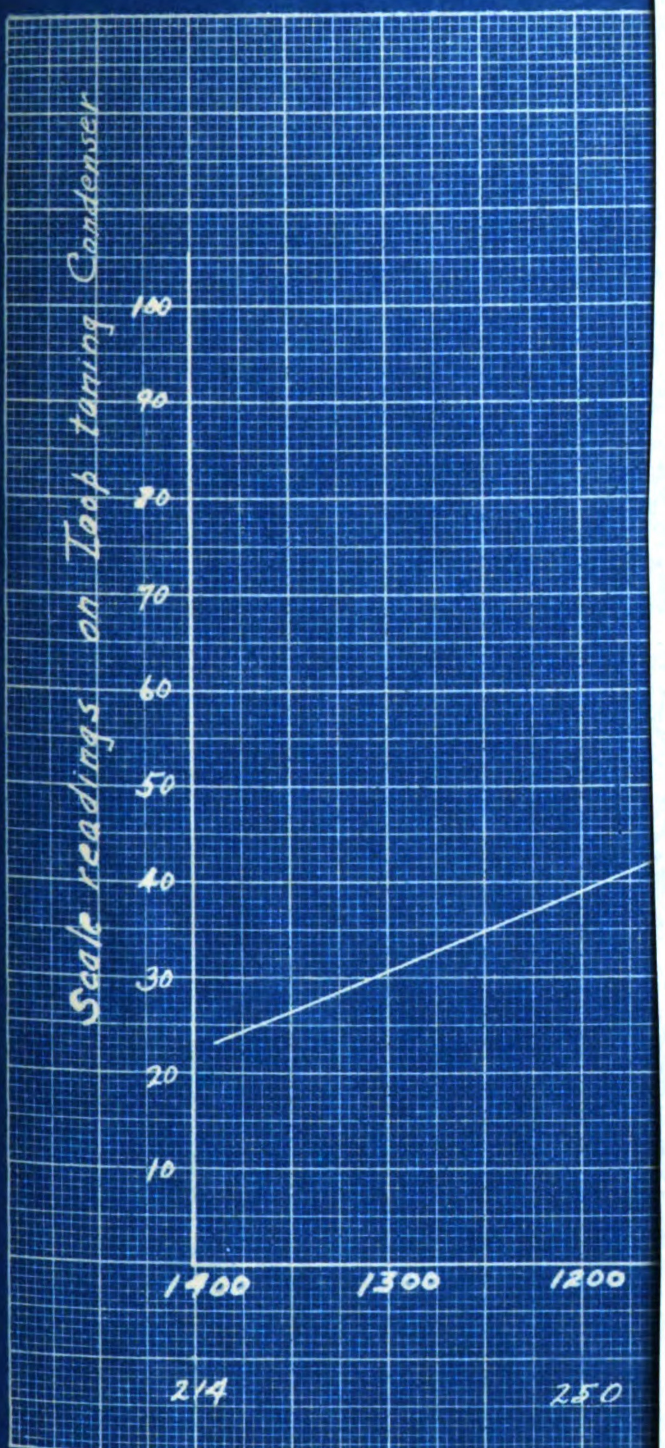
Total Cost Of Super Heterodyne ----------------$96.09


Galvanometer Readings
325
300
275
250
225
200
175
150
125
100
75
50
25
10
20


Transfor
with 1/2
across
#3 teste
across
Filter t
across
Galvanometer readings
250
225
200
175
150
125
100
75
50
25
0
10



Galvanometer readings
40
35
30
25
20
15
10
5
0
500
1000


Scale readings on Loop tuning Condenser
100
90
80
70
60
50
40
30
20
10
1400
1300
1200
214
250