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A Manual of Instruction for the Successful Operation of The Servo System

by

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CONTENTS.

A Manual of Instruction for the Successful Operation of the Servo System

1. Introduction.

With a view to minimize the abrupt changes in zero level of the recorder caused by instability of the mixer crystal current which is in turn caused by drifts in the tuned circuits in the local oscillator chain, a servo system has been designed and constructed. The function of this system will be to effect automatic compensation for the arbitrary changes in crystal current. The principle of operation consists in sampling the crystal current for inequality during neighbouring half periods of switching and in readjusting the final tripler tank circuit by the right amount and in the right sense to restore equality. At the moment of going to press the last link in the chain is missing. A tripler capable of being steered by a motor is, at the moment, conspicious by its absence. Such a one is, however, in the process of being ably designed and will surely make its appearance in the very near future. The purpose of this manual is to provide the constructor with a picture of the rest of the chain in which the tripler is the most important link, and to help him in putting the whole into operation. In the event of occasional failure such as can overtake even well designed equipment, it is hoped that this guide will facilitate the work of whoever it is who will put it right with the efficiency and despatch that has been so typical of the 'Våtegång'.

2. Description of the Units.

A schematic diagram of the units comprising the servo system is seen in Fig. 1. They are namely:

1) The signal preamplifier.
2) The signal amplifier.
3) The suppressor unit.
4) The reference preamplifier.
5) The calibrator.
6) The servoscope.
7) The junction box.
8) The signal output stage.
9) The reference output stage.

Blockschema över servosystemet.

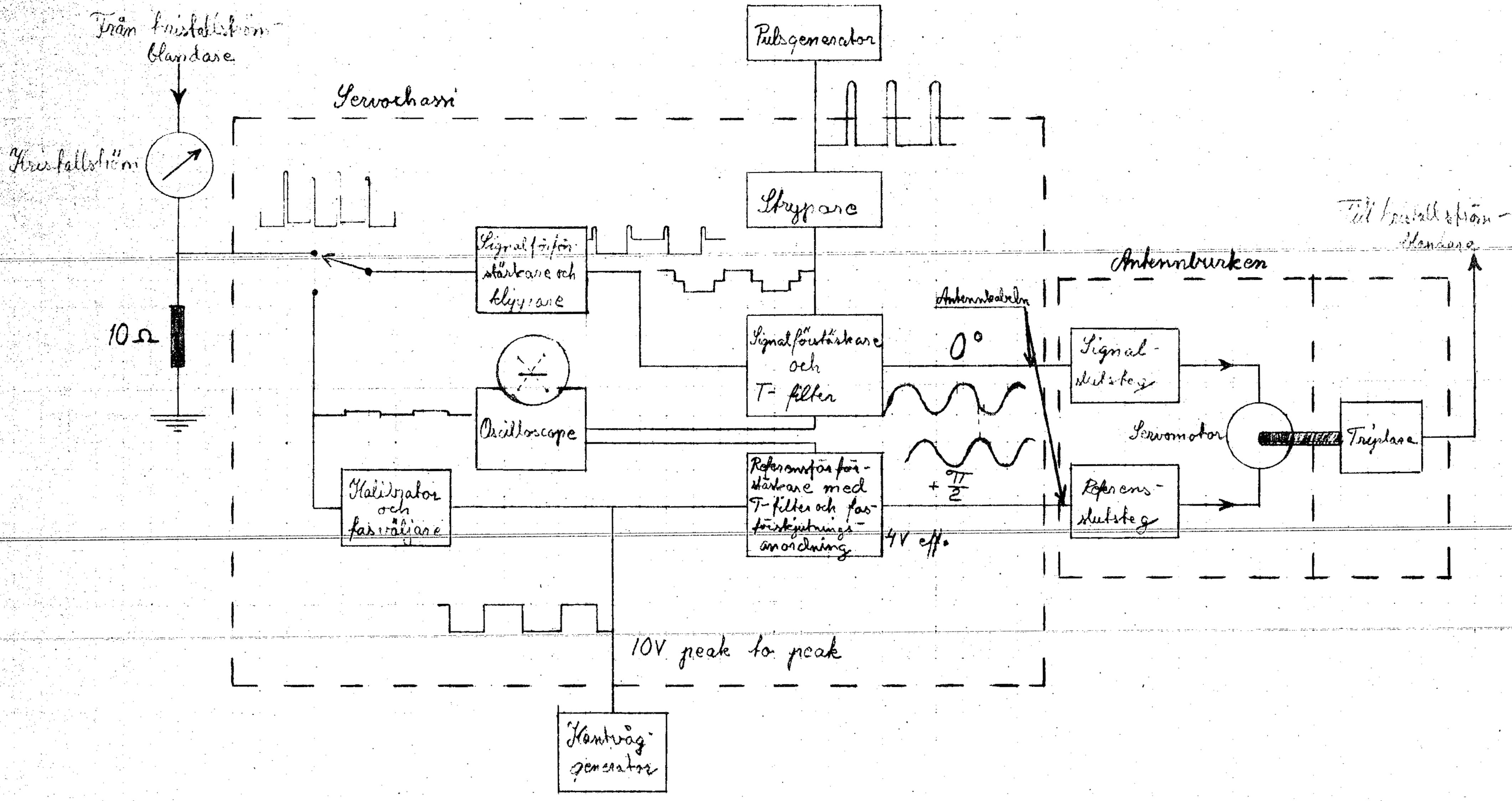

Fig. 1. Schematic diagram of the servo system.

10) The servo-motor.
11) The tripler.

All of which except the last are to hand. The first seven items are mounted on the 'servo chassis' which must be supplied by a Type E power supply. Items 8 to 10 will in course of time be located in the antenna box annexe. If the tripler is also placed in the annexe, the servo-motor could be mounted on the tripler; on the other hand, if the new tripler occupies the same position as the present one, provision must be made for mechanical coupling of the motor to the tripler through the partitioning wall. A length of thick rubber tubing would make a suitable transmission and also isolate the tripler from the high frequency mechanical vibrations that the motor is prone to cause under certain conditions.

Before going on to discuss the functions of the various units as parts of the system it might not be out of place to devote a little attention to each as independent entities.

1) The signal preamplifier consists of a single stage transistor voltage amplifier followed by a clipper stage. A transistor was chosen to avoid the excessive hum pick up that the use of an a.c.-heater-fed valve would have entailed. A transformer is used at the input end to enable isolation of both input terminals from the rack ground. The transistor is connected in a grounded emitter configuration. This is possible, in spite of the fact that the collector is grounded, thanks to the use of a transformer input. The voltage gain obtained in this stage is about 600 measured between the input to the transformer and socket No. 2. Mu-metal screening was found absolutely necessary for the transformer in order to reduce stray pick up. Through the use of double screening, the hum and random voltage components in the output have been reduced to a negligible value. At a signal input level of 10microvolts peak to peak, noise just becomes observable as modulation on the output.

A clipper stage follows and delivers clipped output through socket No.3. Various diode configurations were tried and the present one adopted as the least unsatisfactory of them all. At the low signal levels involved, the discontinuity in the diode characteristic tends to become a 'continuity'

Transistorförförstärkare till Servon.

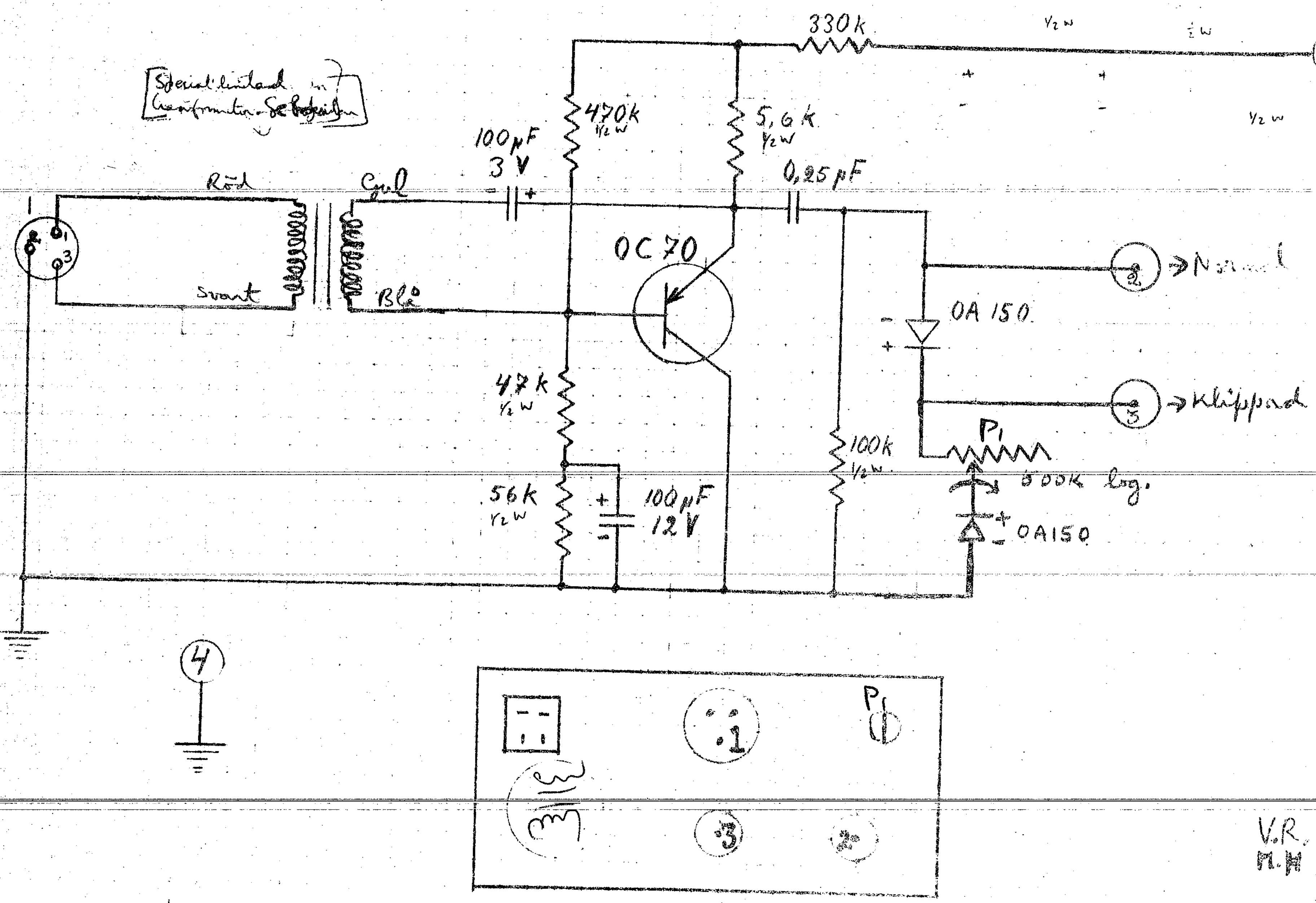

Fig. 2. The signal preamplifier.

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and the ratio of the back to the forward resistance is considerably less than at higher signal levels. In the arrangement used here the signal is fed in across two diodes connected back to back and the output is taken out across one of them. The ratio of their impedances is inverted with a change in polarity of the signal resulting in attenuation for negative signals and almost unattenuated transmission for positive ones.

2) <u>The signal amplifier</u> Fig.3 consists of two stages of pentode amplification and one of triode amplification. Two cathode follower stages are also incorporated, one before and one after the triode stage. Signals fed in at socket No. 1 are amplified about 250 times by the first pentode stage and then go on to the next stage through a gain control. The hot end of the potentiometer is accessible at socket No.2. When connected by a cable to the suppressor unit, this point is effectively grounded for the duration of the suppressing pulses, thus cutting off the rest of the amplifier during these periods. The next pentode stage, the following cathode follower and a twin T network between them together constitute a narrow band filter centred nominally at 400 c/s. A combination of this type usually introduces a phase shift at all but its exact center frequency. To correct for this, one of the resistance arms of the twin-T has been made variable. It is possible by adjusting this arm to obtain zero phase shift at any one frequency lying between 350 and 450 c/s. The corresponding amplification obtained varies with frequency and has a maximum around 400 c/s of about 180 times.

The last tube in the unit is a double triode one half of which provides further amplification (60 times). The other half is a cathode follower. The cathode resistor is a potentiometer which can be used to regulate the input voltage to the succeeding unit.

3) <u>The suppressor unit</u> Fig.4 had no place in the original scheme and was included to make up for the unsatisfactory operation of the clipper stage in the preamplifier. Four diodes are connected in the form of a bridge one corner of which is earthed. The opposite corner is connected to soc-

Servo-Signal-Förstärkare.

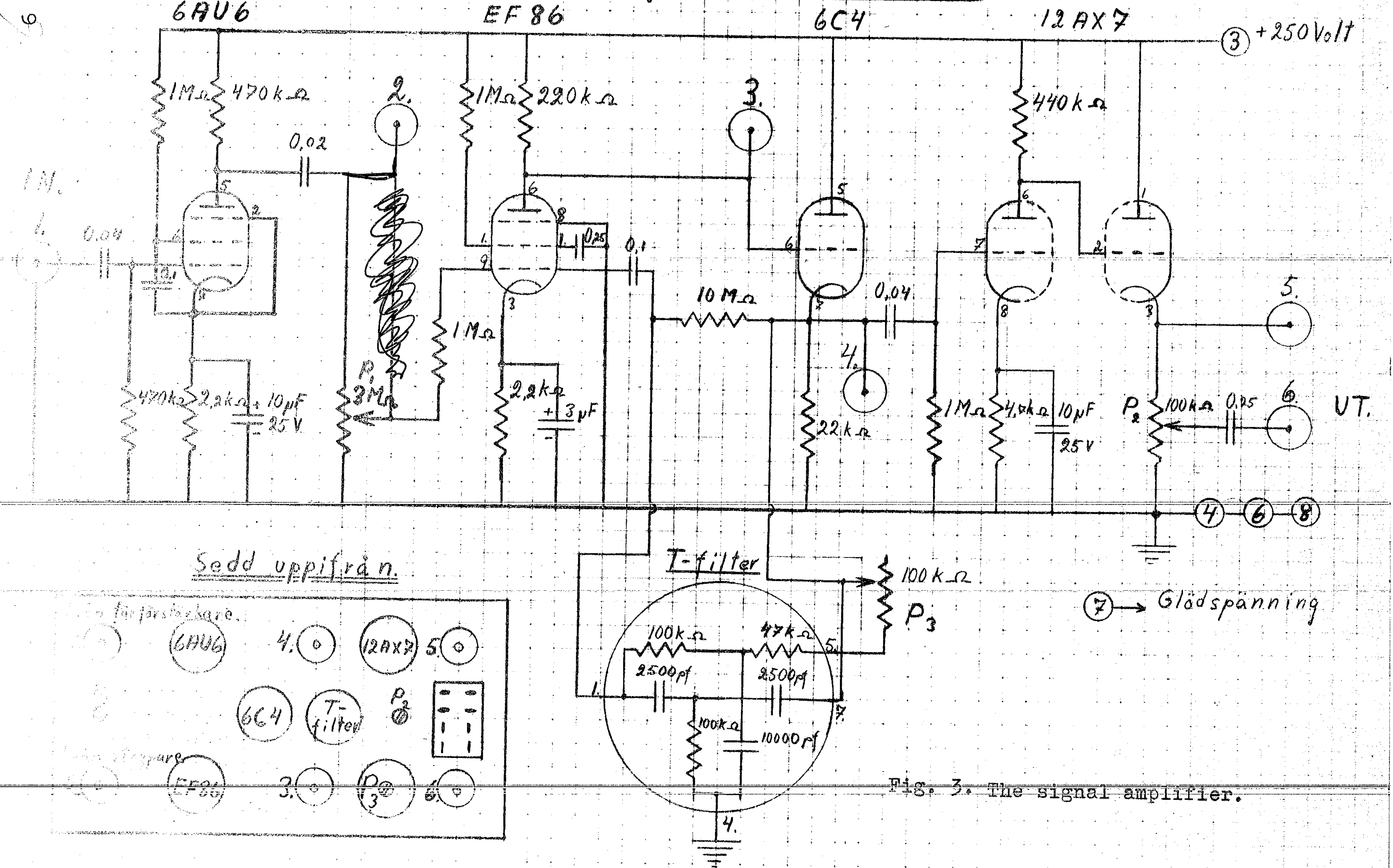
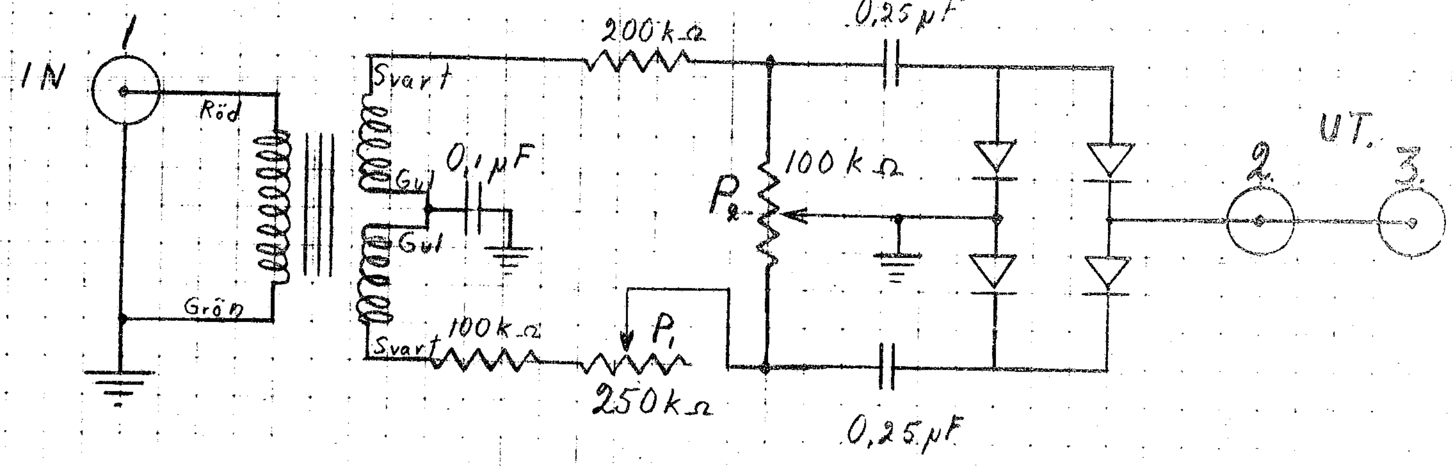


Fig. 3. The signal amplifier.

Strypare.



Sedd uppifrån.

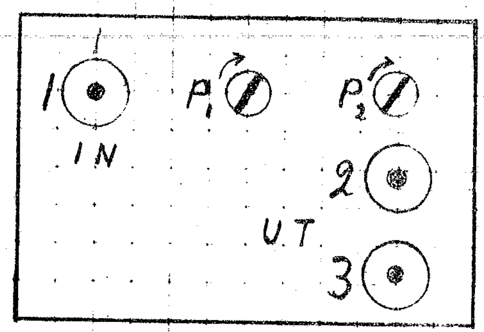


Fig.4. The Suppressor Unit.

kets 2 and 3 and has a very low impedance to ground if current is flowing through the diodes. If, however, the diodes are biased off, sockets 2 and 3 have high impedance to ground and behave as if they were isolated from the rest of the circuit.

A positive pulse fed to the input of the transformer causes a positive and a negative pulse to appear at the ends of the center-tapped secondary winding. These pulses go through the series condensers and cause a current to flow through the bridge. The resistors in series with the condensers limit the magnitude of the current and keep it flowing for the duration of the pulse. The discharging time-constant of the condensers is made larger than the interval between the successive pulses and this results in the diodes being biased backwards during this interval.

The net effect of pulsing the input is therefore to provide a short circuit to ground for terminals 2 and 3 during the pulse period and to isolate them between pulses.

4) <u>The reference preamplifier</u> Fig.5 consists of an amplifier, cathode follower and twin-T network combination followed by a phase-shifting network. A square-wave input at socket 1 yields a sine-wave output at socket 2. A potentiometer in one arm of the twin-T enables adjustment for zero phase shift in the process, and functions satisfactorily within a 50 c/s band centred approximately at 400 c/s. The network which follows, shifts the phase of the sine-wave by approximately 90 degrees. If exactitude is desired, the potentiometer referred to above can be adjusted to give a 90 degree phase shift between terminals 1 and 3 instead of zero degrees between 1 and 2.

5) <u>The calibrator</u> Fig.6 is merely a device to provide an input voltage to the system during alignment and testing. With it, one can simulate the exact source impedance and magnitude and phase of voltage that the input will see in actual operation.

A 10 volt square wave at terminal 1 provides at terminal 4, a continuously variable voltage from 0 to 10 microvolts having either zero or 180 degrees phase shift.

6) <u>The servoscope</u> Fig.7 is a tiny one-inch oscilloscope complete with focussing and intensity controls mounted on the

Servoreferensförförstärkare.

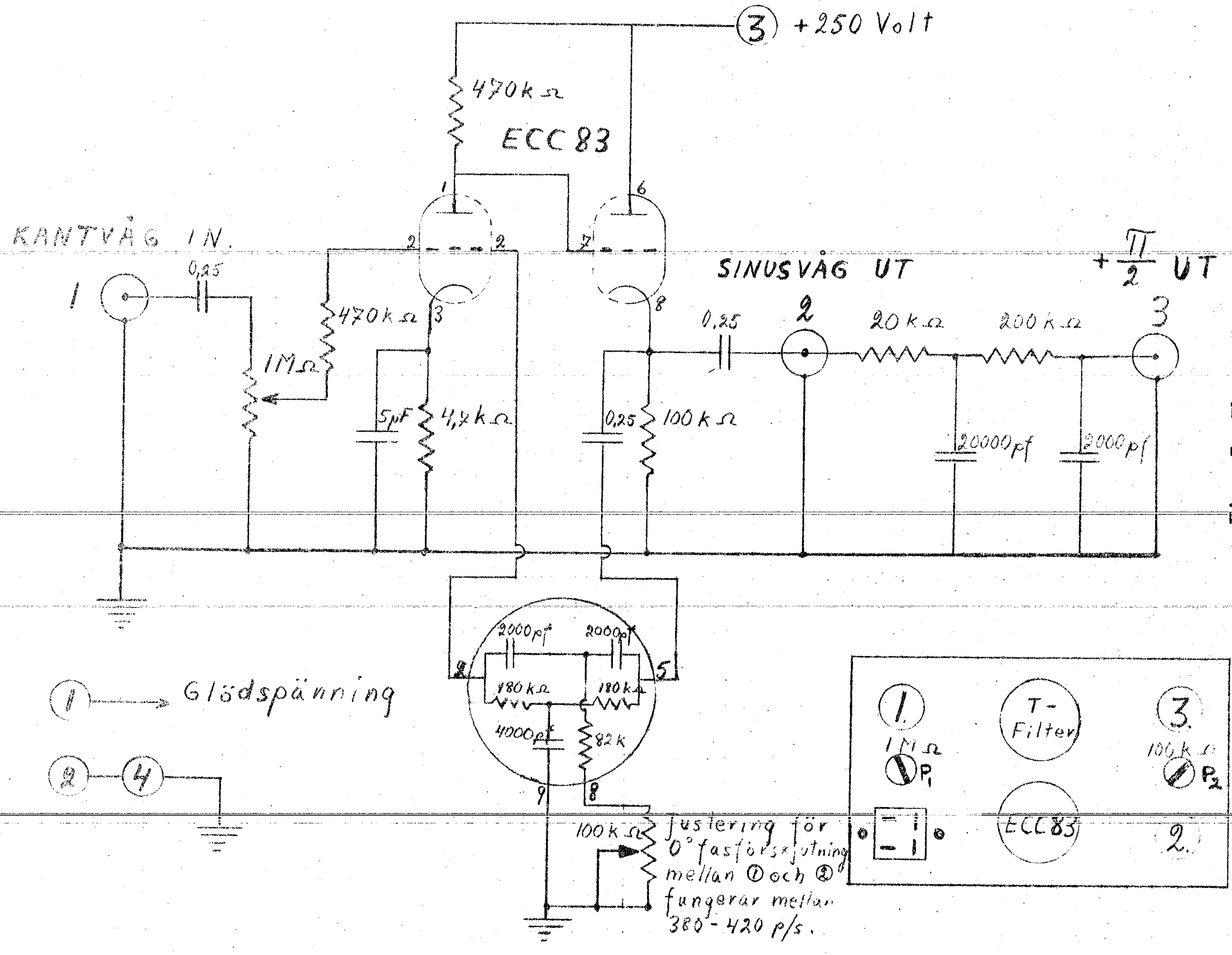
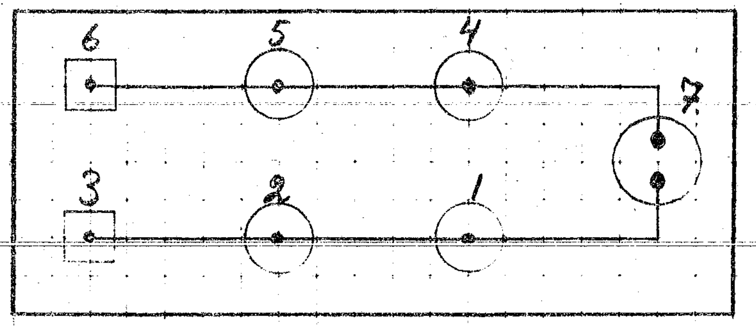
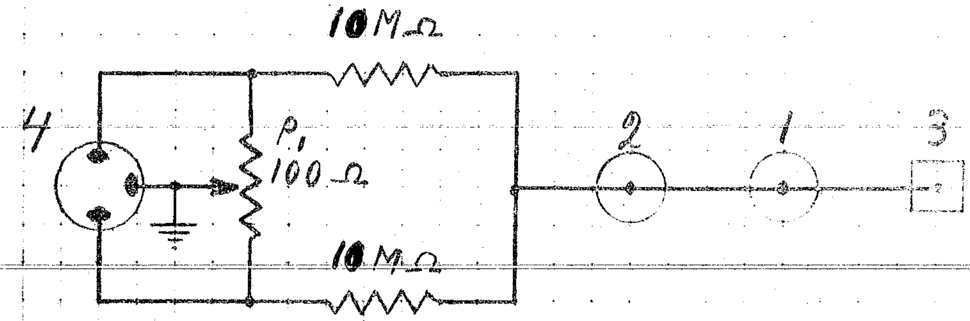


Fig. 5. The reference preamplifier.

Kopplingsburk.



Kalibrator och fasväljare.



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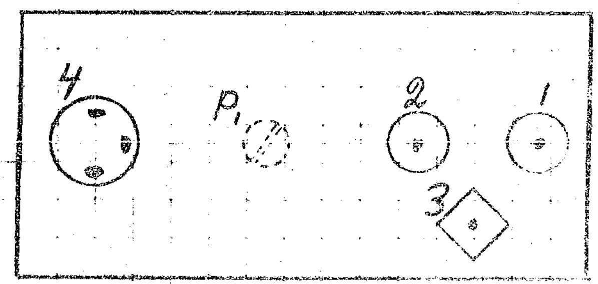


Fig.6. The Calibrator.

Oscilloscope.

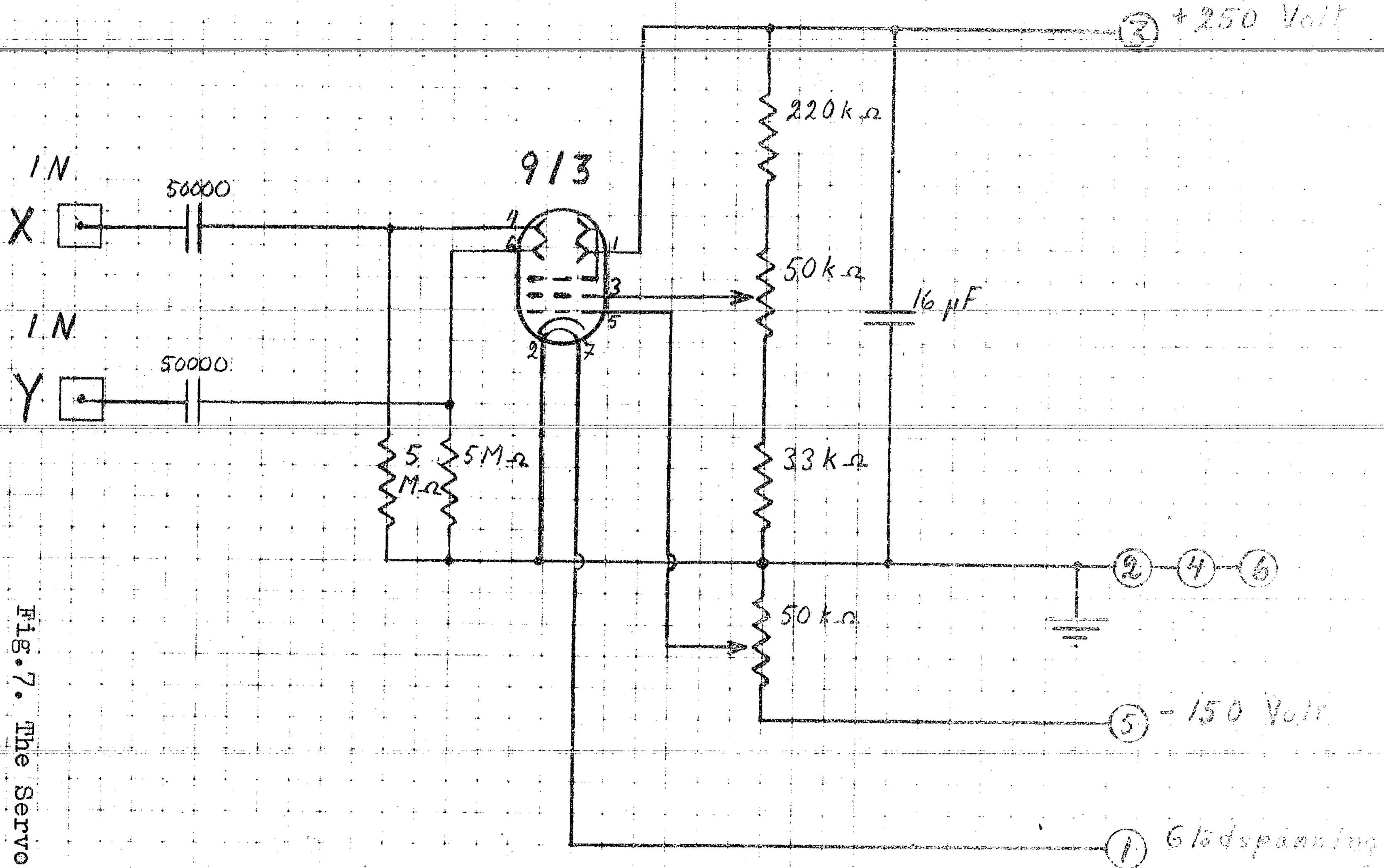


Fig.7. The Servoscope.

panel of the servo chassis. Limited, as is the accuracy obtainable on such a small instrument, it is yet possible to align the entire system with its help. In its absence, the use of an expensive double-beam oscilloscope would have had to be resorted to for even minor checks.

The X and Y inputs go directly to the pairs of deflecting electrodes as no amplifier is available in between. The lines in the reticule correspond to deflections that are obtained for certain standard voltages at certain check points. This will be dealt with in detail in the section on alignment.

7) The junction box is illustrated in Fig. 6 and needs no further comment.

8) The signal output stage Fig.8 is as its name aptly implies, a power pentode output stage for the signal amplifier. This has been separated from the rest of the amplifier to prevent oscillation that would have been practically inevitable if it had been part of the same. An additional advantage of housing it in the antenna box is the reduction of cross-talk in the antenna cable. The leads carrying the signal and reference voltages to the two amplifiers in the antenna box, terminate in the high input impedances to the tubes and have consequently negligible currents in them.

The tube is coupled to the high impedance winding on the servo motor (about 300 ohms) through a matching transformer housed in a mu-metal can. The condenser across the secondary winding is to tune out the reactances in the transformer motor combination. At frequencies around 400 c/s the current through the motor winding is in phase with the voltage input to the stage. With sufficient input voltage the stage is capable of supplying more than 30 volts of undistorted sine-wave to the motor.

9) The reference output stage Fig.9 is practically identical to the signal output stage. The only difference is in the transformer which matches down to a lower impedance (about 100 ohms) than in the previous case. The higher transformation ratio sets a limit to the undistorted voltage available at the motor end. Distortion begins to set in for inputs corresponding to more than 20V to the motor reference winding. At 22 volts it is just noticeable. At greater than 24 volts it is

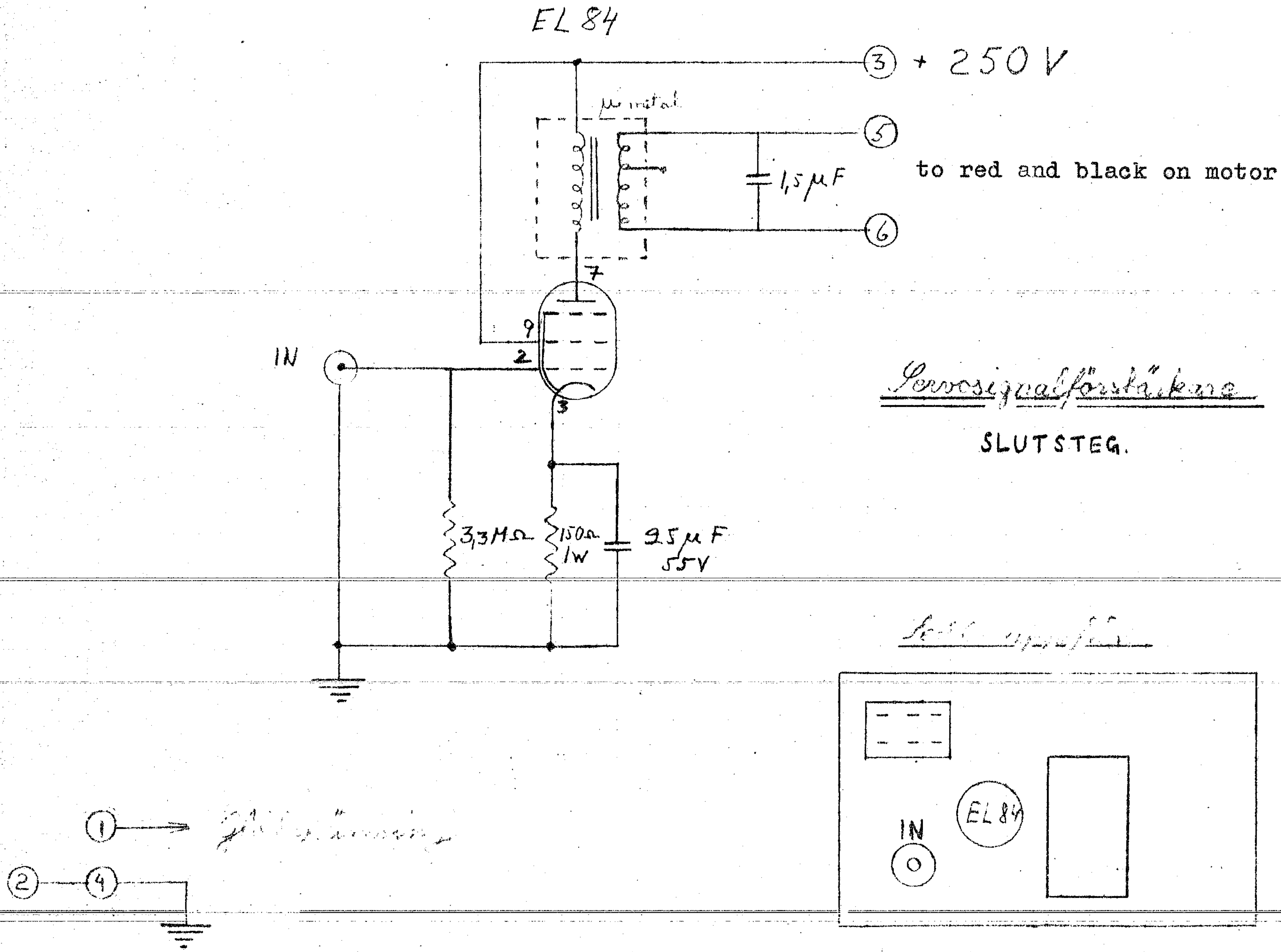


Fig. 8. The signal output stage

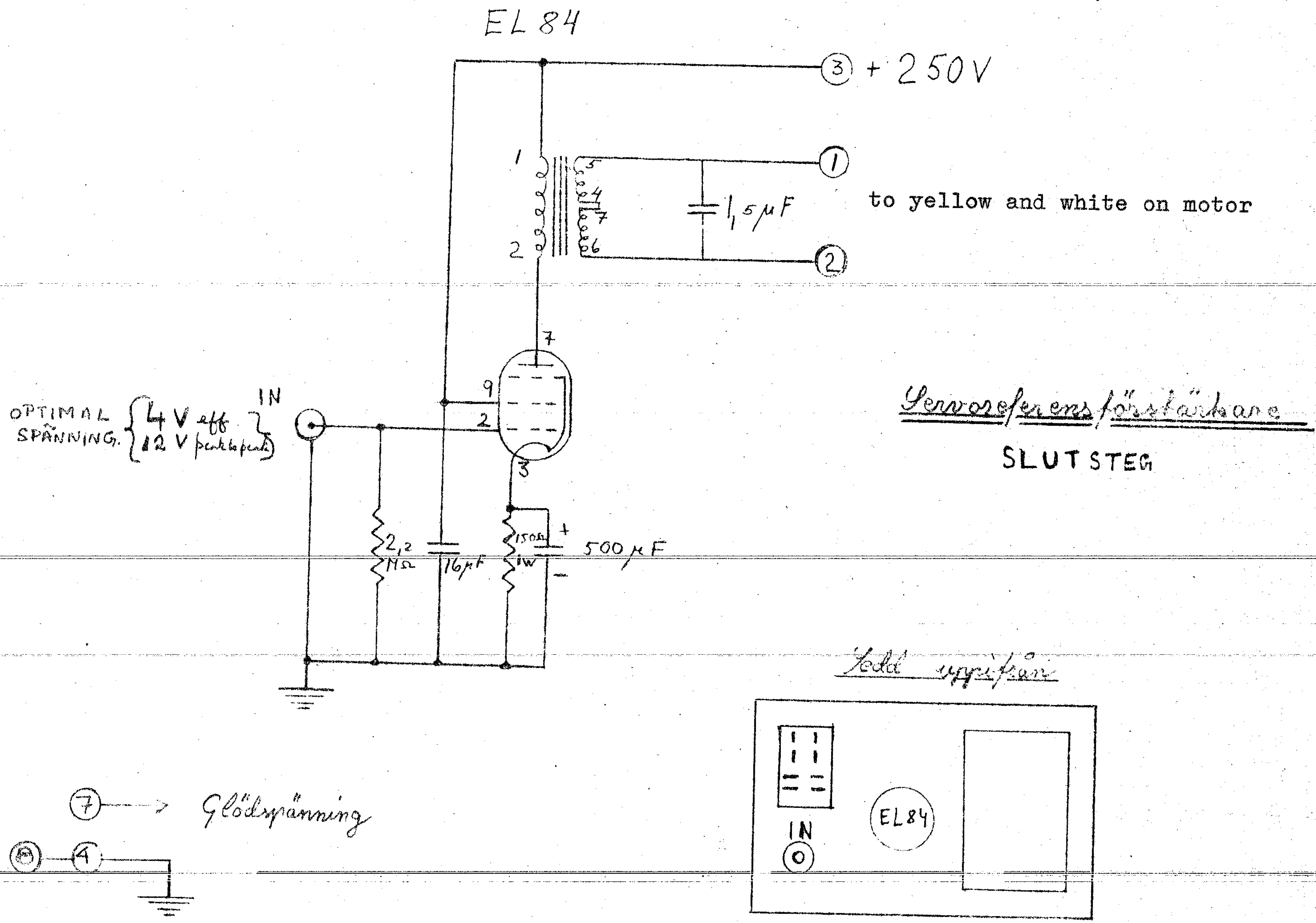


Fig. 9. The reference output stage.

excessive. The transformer used was not one specially ordered for the purpose and is believed to cause part of the distortion. For those who wish to make further refinements it is recommended that a power tube cathode follower stage be substituted for the present arrangement. It might then be possible to use a lower transformation ratio to match the cathode follower output impedance to the motor, for which a suitable transformer could be ordered. It is, however, certain that no improvement will be noticed in the actual performance of the servo as a result of this refinement.

10) The servo-motor is part of a war surplus torque unit. It is designed for 26 Volt 400 cycles operation and in its orignninal form is mounted on a framework with reduction gears in front and a selsyn unit behind. Three such units are available in the laboratory. The selsyn unit has been removed from one of them. It is possible, by leaving the selsyn unit on, and by connecting it to a similar free selsyn unit, to obtain remote indication of the movements of the servo-motor. The free selsyn unit could be mounted on the servo chassis or in some other suitable place in the shack and would provide a continuous check on the functioning of the servo-motor up in the antenna box. But this is not recommended as it would entail the use of five extra leads in the antenna cable - a luxury that we can hardly afford.

The motor proper has four leads. Red and black belong to the higher impedance winding, and yellow and white to the lower. Considerable experimentation has shown that the motor functions better if the lower impedance winding is supplied with the steady reference voltage, and the higher impedance winding used for the constantly changing signal voltage which can have large variations in magnitude. With a reference voltage of 22, the motor just begins to turn for 4 volts of signal voltage, reaches normal speed at 24 and has a maximum at about 40 volts. For higher inputs the core begins to saturate resulting in a drop in speed. These three voltages correspond respectively to 0.5V, 3.0V and 5.V input to the grid of the signal output stage. Operation at over the nominal voltage results in heating of the motor.

11) The tripler in its present stage can be seen in the full scale illustration of Fig. 10.

Fig. 10. The tripler.

Ha. Ha.
Well, when you do get down to making one it would be worth while to bear the following in mind.

The shaft on the tripler, rotation of which accomplishes retuning of the output stage, must have a gearing ratio such that about 2 to 4 seconds of normal speed rotation of the motor moves the bandpass by the same amount as its average drift in say a 10 second period. The latter can be determined by the simple method of watching the servo-motor in action when not connected to the tripler. The number of revolutions the motor shaft makes per second at normal speed can be determined by setting the signal voltage to the motor at 24. The amount the tripler shaft has to be turned to counteract the drift can be found by turning it manually till the motor stops completely even at the highest sensitivity of the system. With a knowledge of these three quantities it should be relatively easy to include the necessary amount of gearing-down to obtain operation corresponding to a time constant of a few seconds.

3. General principles of operation.

The current through the mixer crystal caused by the high frequency output from the tripler consists of rectangular pulses of about 1250 microseconds in duration separated by a few microseconds between them. All the odd pulses are caused by one of the two tripler frequencies and all the even ones by the other. The function of the servo is to hold the heights of these pulses equal to within about a thousandth part of the height of either. The method is to obtain a voltage proportional to the difference in the heights of these pulses and to use the voltage to retune the tripler output stage to decrease this difference.

If the voltage that actuates the retuning device (e.g. a motor) is dependent only on the magnitude of the difference between the tops, and independent of the sense, the motor would not know, so to speak, which way it should turn in order to restore equality between the pulses. The usual way to solve this problem is to include a phase detector in the scheme of things. If the phase detector were switched by the same source as caused the switching between the two tripler frequencies, then a d.c. output voltage would be obtained whose magnitude is proportional to the difference between the tops, and whose polarity would depend on whether the even tops were higher than the odd ones or vice versa.

A two phase motor is, in a sense, a phase detector and changes direction with a change of 180^{o} in the phase of one of its two input voltages. By a lucky coincidence three small two phase motors meant for operation at the same frequency as our switching system were available in the lab. It was therefore decided to simplify the arrangement by just amplifying the small difference between the tops of the pulses and feeding it directly to one of the windings on the motor. It is now necessary only to supply the other winding with a steady reference voltage of the same frequency shifted 90 degrees in phase from the voltage of the switching system in order to obtain a rotation of the motor whose speed is proportional to the magnitude of the first voltage and whose direction is dependent on the sense of the inequality of the pulses.

The two phase motor requires sinusoidal voltages and the switching system offers only rectangular voltages. The circuits in the servo system must therefore perform one additional function and that is to convert the rectangular voltage waveforms into sinusoidal ones. This is done by the twin-T networks which filter off all the higher components present in the rectangular waveforms leaving only the fundamental.

The reference preamplifier and reference output stage form one of the parallel arms of the system. They perform together the simple function of taking a square wave from the switching system, converting it into a sine wave, shifting it 90 degrees in phase, amplifying it and feeding it to the reference winding on the motor.

The signal preamplifier, amplifier and output stage form the other parallel arm of the system. They do the same things to the tiny square wave obtained from the difference in the heights of the pulses with the exception of the 90 degree phase shift. In this case it is seen to that no phase shift occurs at all.

The reason for the greater complexity of the signal amplifier chain is twofold. Firstly, the amplitude of the square wave is considerably less than in the reference case. About 1 microvolt as opposed to 10 Volts. Secondly, it is impossible to amplify the difference in the heights of two pulses without amplifying the pulses themselves. The sides of neighbouring pulses take on the form of long spikes going down to ground potential. In the arrangement obtaining for viewing the crystal current on an oscilloscope these spikes appear to go upwards. This is incidental and results from the fact that the polarity of the mixer crystal inverts the picture obtained by viewing the amplified voltage drop over a resistor included in the crystal current ground return.

These spikes must be removed if the odd microvolt is to be amplified to the magnitude of several volts without overloading the amplifier. The clipper stage in the signal preamplifier does this to a certain measure. Had the remaining waveform had been left with truncated spikes that were all exactly alike. No harm would have come of their presence. Passage through the twin-T filter would have left the outcoming waveform with no contribution from them as their periodicity is twice that of the square wave fundamental. However, a slight inequality between the odd and even spike stubs results in the appearance of a 400 c/s sine wave even when the pulses are equal. To counteract this, and to eliminate their influence altogether, the suppressor unit was added which accomplishes this by simply choking the amplifier for short periods beginning just before the appearance of a spike and ending just after.

4 Alignment.

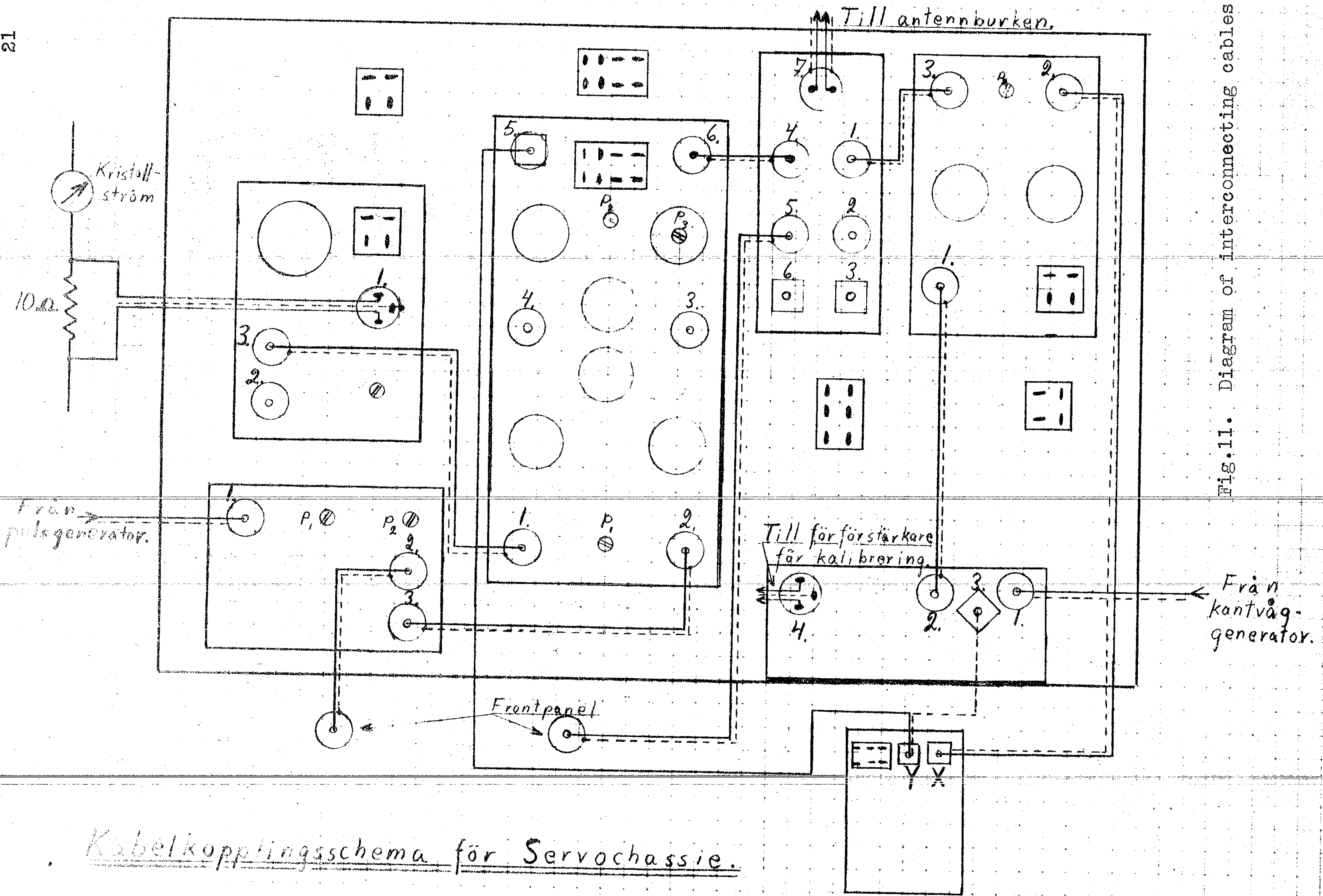
Alignment of the system can be done either with a proper double-beam calibrated oscilloscope or with the servoscope. The former is more thorough and hence more complicated. The latter is simple and although adequate a trifle inaccurate.

with a d.b. oscilloscope.

Connect all the unit interconnecting cables according to Fig.11, except the cable from the suppressor unit. Removing cables if and where necessary in order to introduce the oscilloscope and replacing them after, perform the following operations.

Adjust the output control on the square wave generator to provide exactly 10 volts peak to peak as measured at point 3 on the calibrator unit. Switch on the H.T. to the reference preamplifier and check the sine wave obtained at point 2. Adjust potentiometers 1 and 2 to obtain a sine wave of about 35 volts peak to peak and exactly in phase with the square wave. Check the sine wave at point 3. It ought to be about 12 volts peak to peak and 90 degrees out of phase with the square wave. Otherwise adjust P1 and P2 to obtain this. It may be necessary to wait a short while for the tube to warm up and settle down. This applies to all the phase adjustments on the system.

If point 3 on the reference preamplifier is connected to the input on the reference output stage and the latter switched on, a sine voltage of about 22 should appear across



Kabelkopplingsschema för Servochassie.

Fig.11. Diagram of interconnecting cables.

the reference winding on the motor, shifted 90 degrees from the input square wave. Slight variations from these values can be compensated for by adjustment on P1 and P2. When the output stages have been installed in the antenna box, this can be checked by using one of the unused leads in the antenna cable as a lead for the scope. Care must be taken, however, to see that capacitance in the antenna cable does not give rise to a misleading indication and that the lead carrying the signal to the signal output stage does not pick up any of this voltage.

__Note.__ The sine wave at point 3 on the reference preamplifier will appear distorted if it is connected to the grid of the reference output stage and only L.T. is present on that tube.

Having taken care of the reference arm of the system we can now proceed to the signal side. Connect socket 1 on the preamplifier to socket 4 on the calibrator with the cable that would normally be used to connect it to the 10 ohm resistance in the crystal current ground lead. Turn calibrator control fully anticlockwise. Switch on HT to preamplifier. Check output at point 2 if a sufficiently sensitive scope is available. With the potentiometer turned fully clockwise, a square wave with sloping tops and about 6 millivolts p. to p. should be obtained. With the potentiometer turned fully anti-clockwise a slightly lower voltage will be obtained. About 3 millivolts should be available at point 3. If the calibrator control is now turned slowly clockwise the output voltage should diminish to zero and increase again to the former value but shifted 180 degrees in phase. Leave calibrator control in this maximum position. Switch on the signal amplifier and increase P1 until about 10 volts peak to peak are obtained at point 5. Adjust P3 for zero phase shift with respect to the square wave. It should be possible to increase P1 to obtain 60 volts peak to peak at point 5 without distortion. Reduce calibrator control to give about one microvolt. It should be possible to increase P2 to still obtain 20 volts peak to peak with this input. Move calibrator control slowly over the zero position. The sine wave should diminish and change phase on passage through zero.

Set P2 to give between 50 and 60 volts peak to peak for 10 microvolts from the calibrator. Connect point 6 to input of signal output stage and switch on H.T. to the latter. Adjust P2 to give 24 volts R.M.S. at the motor terminals. The motor should be going now at full speed. Turning the calibrator control ought to decrease the speed and increase it again but in the other direction. It should be possible, with a little practice, to set P2 so that full speed in each direction can be obtained for in- and out-of-phase voltages having any value between 0.5 microvolts and 10 microvolts. Check the voltage waveform at the signal winding on the motor with the oscilloscope. It should be in phase with the square wave. If it happens to be shifted slightly, adjust P3 on the signal amplifier to compensate.

Set calibrator at some voltage and move the oscilloscope cable to socket 2 on the signal amplifier which should have been free all this time. Note the voltage and move the oscilloscope to socket 3 on the suppressor. Connect 3 on suppressor to 2 on amplifier. With no pulses in to the suppressor the voltage should be somewhat less than measured at 2 on the signal amplifier. Connect the pulse generator to 1 on the suppressor unit and set the pulse width at between 40 and 60 microseconds. Switch off the H.T. to the preamplifier and adjust P1 and P2 on the suppressor unit to obtain as nearly a straight trace on the oscilloscope as possible. This can be done most conveniently by increasing the sensitivity of the oscilloscope progressively and adjusting P1 and P2 each time. If a sensitive d.c. oscilloscope is used, a small d.c. potential may be noticed but this is of no consequence. If the preamplifier is now switched on, practically the same voltage as at point 2 on the amplifier should be obtained for about 1200 microseconds of each half cycle. For the remaining 50 microseconds the signal should go down to zero. The pulse delay control on the pulse generator should be adjusted now to center the suppression periods about the points where the signal voltage changes sign. Adjust P2 and P[illegible] again to center the dead period along a vertical axis so that there is as much signal above as below. <u>Note</u>. for every change of pulse width, P2 and P1 must be readjusted for proper centering of the dead periods. Even with about 60 microseconds of suppression the sine wave at point 5 should have practically the same amplitude as with the suppressor-amplifier cable disconnected.

We can now go on to using the actual signal obtained from the crystal current. Connect socket 1 on the preamplifier to the 10 ohm resistor. Connect the oscilloscope to point 2 on the signal amplifier removing the cable from the suppressor unit for the purpose. Check the clipping action obtained by turning the potentiometer on the preamplifier. Maximum clipping should be obtained with the potentiometer turned fully anti-clockwise. <u>Note</u>. If the error signal is flattened out instead of the spikes being clipped, it means that the leads to the 10 ohm resistor must be interchanged. Connect the suppressor unit to the amplifier and check with the scope at point 2 on the suppressor unit to see if the suppression is satisfactory. Otherwise readjust pulse delay, pulse width and P1 and P2 on the suppressor unit. P1 on the amplifier should now be adjusted to give less than say 40 volts at point 5 on the amplifier for drifts occurring over a one minute period. I have chosen one minute as a safe suggestion but only actual trials with the new tripler in operation will show what the optimum position of P1 should be. The point to remember is that the gain must be low enough for a servo-uncorrected drift over a period of about 10 seconds not to overload the amplifier. If a sudden jump in the crystal current overloads the amplifier, the servo will lose control. Long period tests with the new tripler installed and in operation will show what inherent stability it has. If it is good, the servo system in its present form can be used to obtain regulation to better than a thousandth part of the crystal current. If the stability is poor, the servo sensitivity must be reduced in corresponding measure. It may happen that the general stability is good over long periods but that there is a tendency to make occasional big jumps ~~when~~ and the servo to lose~~s~~ control. If this turns out to be the case, and if it is established that overloading was the reason, the cure would be to introduce delayed A.G.C. in the signal amplifier. ~~As the signal levels in the early tubes are so low, it should suffice to apply A.G.C. to the grid of the last triode amplifier.~~

P2 should now be adjusted to obtain the required motor sensitivity. The amount of distortion free voltage available at point 5 is many times the voltage required at point 6 to drive the motor at full speed. It is therefore possible to choose any required sensitivity for motor operation.

5 With the servoscope it is possible to adjust the levels and phases of the voltages in the two arms of the system in a simple and easy manner. In addition, it provides a continuous check on the operation of the system.

The reticule on the face of the scope has two vertical and two horizontal lines. The horizontal distance between the two vertical lines is the X deflection obtain ed from a voltage at point 2 on the reference preamplifier which corresponds to the optimum voltage to the motor reference winding (22 volts). P1 should therefore be adjusted to give a trace extending to these vertical lines. The phase of the voltage can be checked by applying the 10 volt square wave to the Y plates by connecting the Y cable to point 4 on the calibrator. If any undesired phase shift has occurred in the passage of the waveform through the T-filter, two horizontal lines slightly overlapping each other in the vertical plane will be seen on the scope. P2 on the reference preamplifier should be adjusted to remove the overlap.

The Y cable can now be moved over to point 5 on the signal amplifier. The horizontal lines on the reticule correspond to a Y deflection of 60 volts which is the maximum allowable for distortion free amplification in the signal amplifier. The pattern obtained on the servoscope should never extend beyond the area included by the 4 lines. The phase of the signal voltage can now be seen from the pattern. For zero phase shift through the signal amplifier, a straight line pattern should be obtained. Whether the line is inclined to the left or to the right depends on the phase sense of the signal voltage. With all units connected and the servo in operation, the line should oscillate slowly about the horizontal position which latter corresponds to the absence of any error signal. The ends of the line should slide along the vertical marks on the reticule but should never quite reach the horizontal marks.