

INSTRUCTION MANUAL
R-C-L COMPONENT TESTER

TYPE CPT 2

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DESCRIPTION

An RC oscillator providing frequencies of 100 Hz, 1 kHz, 10 kHz or 100 kHz supplies power to the bridge circuit via a transformer with closely coupled balanced output windings which provide accurately equal voltages to the unknown and the standard.

The measuring voltage is stabilized by an indirectly heated thermistor with the heater connected across the bridge terminals. In this way a very stable output is obtained which is practically independent of the load from varying impedances connected for measurement. Two sets of output terminals are provided, supplying test voltages of 0.3 volts and 3 volts respectively. The 0.3 volt output permits measurement on low impedances and large deviations, while the 3 volt output provides for measurement of high impedances and small deviations with a minimum of disturbance due to hum and noise.

The unbalance voltage from the junction between unknown and standard feeds into a specially designed input amplifier employing a field effect transistor at the input. The high input impedance thereby obtained ensures accurate measurement of high impedance values, and a guard output which follows the input closely allows the use of shielded leads and measuring circuits if required.

The output is fed through the range attenuators to two combined amplifier and phase detector circuits driving the impedance and phase angle meters. The meter outputs are available at a socket at the rear of the instrument for driving recorders, external meters, limit alarms, etc.

A switch shortcircuits the detector input for checking zero adjustment. Separate zero controls are provided for the two meters.

A calibrating voltage corresponding to 2% impedance difference is obtained from voltage dividers across the bridge voltage terminals. When the zero-set switch is closed the calibrating voltage may be fed directly to the detector input to enable setting the bridge voltage exactly. With the zero-set switch open the calibrating voltage is fed through the measuring impedances so that calibration may be checked at the actual existing impedance level, thus allowing accurate calibration at high impedance levels.

The instrument is fully transistorised, allowing a very compact design with small dimensions, low weight and low power consumption.

Zero and gain stability are of a very high order, and the calibration is easily checked and adjusted if necessary.

SPECIFICATIONS

Test Frequencies:	100 Hz, 1 kHz, 10 kHz, 100 kHz. Accuracy $\pm 2\%$.
Test Voltages:	0.3 volts and 3 volts across standard and unknown at balance. Stability $\pm 1\%$ for impedance above 3 Ω on 0.3 volt range, above 200 Ω on 3 volt range.
Impedance Deviation Ranges:	$\pm 2\%$, $\pm 6\%$, + 25 to - 20% f.s. on 0.3 volt range. $\pm 0.2\%$, $\pm 0.6\%$, $\pm 2\%$, $\pm 6\%$ f.s. on 3 volt range. Resolution 0.01%.
Phase Angle Deviation Ranges:	± 0.01 , ± 0.03 , ± 0.1 radian f.s. on 0.3 volt range. ± 0.001 , ± 0.003 , ± 0.01 radian f.s. on 3 volt range. Resolution 0.00005 radian.
Deviation Accuracy:	$\pm 3\%$ of f.s. (5% of f.s. at 100 kHz).
Impedance Range:	3 Ω to 5 M Ω at stated accuracy on 0.3 volt range. 100 Ω to 5 M Ω on 3 volt range.
Capacitance Range:	50 pF to 1.500 μ F at stated accuracy. Lower values down to 10 pF may be measured accurately by calibration adjustment.
Inductance Range:	10 μ H to 10.000 H.
High Impedance Range Extension:	By coupling the standard to the 0.3 volt output and the unknown to the 3 volt output the impedance and capacitance ranges may be extended to about 500 M Ω or about 2 pF. The impedances of the unknown and standard are in this case in the ratio 10 to 1 for balance.

Analog Output:	± 1 volt for f.s. Minimum load 1 k Ω .
Long Term Stability:	Zero stability: Better than 0.3% (3 mV) of f.s. for impedance meter. Better than 1% (10 mV) of f.s. for phase angle meter. Deflection stability: Better than 1% of deflection after 1 hour (both meters).
Measuring Time:	0.5 sec. for analog output and meters.
Ambient Temperature:	10 $^{\circ}$ to 40 $^{\circ}$ centigrade (50 $^{\circ}$ to 104 $^{\circ}$ F).
Power Supply:	100 to 130 volts or 200 to 260 volts, 50 to 60 Hz, 25 watts.
Dimensions:	340 wide x 240 high x 240 deep mm. (13 $\frac{1}{2}$ x9 $\frac{1}{2}$ x9 $\frac{1}{2}$ inch).
Weight:	8.5 kilos (18 $\frac{1}{2}$ lb.).
Accessories supplied:	3-core power cable, 12-pole output connector.

2. OPERATING INSTRUCTIONS

2.1. Installation

Set mains voltage selector switch to the required range (pull the switch knob, turn and push back). The 115 volt setting covers the range 100 to 130 volts and the 230 volt setting the range 200 to 260 volts. Check that the correct fuse is fitted, on 115 volts 0.5 A slow and on 230 volts 0.25 A slow.

2.2. Operation

2.2.1. Function of Panel Controls, Connectors and Meters

Mains Switch

Switched on in the down position.

Frequency Switch

Sets the measuring frequency. Note: All frequencies are adjusted to within 2% of the nominal values except 100 Hz which is about 10% high to avoid hum disturbance when operating on 50 Hz mains.

Adjust 2% Control

This control sets the oscillator amplitude and is used to adjust the bridge voltage to obtain correct calibration.

Generator Voltage Switch

Switches the reference inputs to either the 0.3 volt terminals or through voltage dividers to the 3 volt terminals. In the end positions of the switch (marked Check 2%) an unbalance of the bridge voltages is introduced corresponding to 2% impedance deviation, so that the calibration may be checked.

Note: The voltage values 0.3 and 3 volts indicate the approximate voltages across the standard or the unknown impedance.

Check-Measure Switch

In the Check position the detector input is disconnected from the detector terminal and connected to zero potential. In this position calibration may be checked by switching the Gen. Voltage Switch to one of the Check 2% positions. This applies the calibrating voltage directly to the detector input.

In the Measure position the detector input is connected to the detector terminal for the measurement. In this position the calibrating may also be checked with the Gen. Voltage Switch in one of the Check 2% positions.

This applies the calibrating voltage through the measuring impedances to the detector. Thus the calibration may be directly checked even for high impedance measurements, where the sensitivity is reduced due to the detector input impedance.

$\Delta Z\%$ and $\Delta\phi\%$ Switches

These set the impedance range and phase angle range respectively. The range markings correspond to full scale meter readings. The red markings are employed when using the 0.3 volt terminals, and the black markings for the 3 volt terminals.

Zero ΔZ and Zero $\Delta\phi$ Controls

Used to set the meters to zero in Check position of the Check-Measure switch.

ΔZ and $\Delta\phi$ Meters

Read the differences between impedances and phase angles of the unknown and the standard. The scales are used in conjunction with the corresponding range switch markings. The lower ΔZ scale (-20 to +25) is used only with the $\Delta Z\%$ range switch set at 20 (0.3 volt range).

Note: On the higher ΔZ ranges the use of linear scales introduces a small error. This error is minus half the actual deviation in percent and is thus only significant at above half scale deflection on the 6% range e.g. a deviation of +6% gives an error of -3% (a reading 3% low) and a deviation of -6% gives a reading 3% high.

Guard-Off Switch

Switches the guard circuit on in the Guard position. This reduces the detector input capacitance from 10 pF to about 4 pF and thus reduces errors at high impedance measurements. At the same time the guard voltage is connected to the Guard Terminal. The guard voltage follows the detector input voltage very closely (within about 1%) so that the effect of any external shielding may be reduced by connecting the shield to the guard terminal. This reduces the effective shield capacitance to about 1% of the value obtained with the shield grounded.

Note: When measuring inductive impedances of low values always switch the guard circuit off, otherwise in some cases instability may occur.

Adjust $\Delta\phi$ Pre-set Control

This control provides a small adjustment of the phase shift at 100 kHz. It may be used to compensate drift in the phase shift which may arise over long periods. The control may be adjusted by switching the $\Delta\phi$ range switch to 0.1% on the 3 volt range and switching the Gen. Voltage Switch to 2% (3 volt range) with the Check-Measure Switch on Check. Set the Adj. ϕ control so that the $\Delta\phi$ meter reads zero.

2.2.2. Setting-Up

Set the controls as follows:

Frequency Switch	- 1 kc.
Gen. Voltage Switch	- 0.3 volts
Check-Measure Switch	- Check
Guard Switch	- Off
$\Delta\phi$ Switch	- 10% (0.3 volt range)
ΔZ Switch	- 2% (0.3 volt range).

Switch on power and leave the instrument to stabilize for 2 minutes.

Adjust the meters to zero by the zero controls.

Switch Gen. Voltage Switch to Check 2% on 0.3 volt range.

Set Adj. 2% control for full scale reading on the ΔZ meter.

This concludes the setting-up procedure and no further adjustments are normally necessary except when measuring extreme impedance values, when operating for extended periods or if extreme accuracy is required (see notes on operation).

2.2.3. Measurement

Set Check-Measure Switch to Check.

Set frequency switch and Gen. Voltage Switch to the required settings.

Set the ΔZ and $\Delta\phi$ switches to the maximum range.

Connect the standard and the unknown impedance to the appropriate terminals (corresponding to the voltage setting on the Gen. Voltage Switch). The Det. terminal is common to both impedances.

Switch the Check-Measure Switch to Measure.

Set the ΔZ and $\Delta \phi$ switches to obtain the highest possible meter readings.

Read the meter scales corresponding to the switch settings. The polarity signs indicate the deviations of the unknown from the standard e.g. a positive reading on both meters indicates that the unknown has a higher impedance than the standard and that it has a phase angle positive compared to that of the standard.

Note: 1. The phase angle on the $\Delta \phi$ meter is given as a percentage of 1 radian.

Note: 2. When employing the 20% ΔZ range (0.3 volt) the lowest meter scale must be used (-20 to +25%).

2.2.4. Notes on Operation

Choice of Measuring Voltage

The 0.3 volt terminals are employed:

When measuring impedances below 100 Ω .

For impedance deviations above 6%.

For phase angle deviations above 1%.

For impedance measurements where voltage or dissipation must be limited.

The 3 volt terminals are employed:

When measuring high impedances.

For impedance deviations below 6%.

For phase angle deviations below 1%.

Note: The measuring voltages stated are the voltages across the standard or the unknown when equal.

Low Impedance Measurements

The limits for low impedance measurements are given by the available oscillator power and by stray impedances in the output transformer.

The minimum measuring impedances are: 3 volt range 100 Ohms. 0.3 volt range 1 Ohm.

At 100 kHz the minimum impedance values are somewhat higher due to stray inductance and losses in the transformer, especially on the 0.3 volt output. On the 3 volt output minimum impedance is about 200 Ohms and on the 0.3 volt output about 3 Ohms or, if the impedances are inductive about 10 μH . The bridge voltage is effectively stabilized at the 3 volt output so that loading by measuring impedances of 100 Ohms only reduces the voltage

by about 1%.

At the 0.3 volt output the measuring voltage varies more with the load, especially at 100 kc, where the maximum capacitive load may increase the output voltage by about 15% while an inductive load will reduce it correspondingly. However, this may be easily corrected for by calibrating with the measuring load connected up and readjusting the Adj. 2% control.

High Impedance Measurements

When measuring high impedance values errors may arise due to the detector impedance. The detector impedance in series with the two measuring impedances in parallel act as a voltage divider so that the detector input voltage will be reduced in value and also suffer a phase shift depending on the ratio between the measuring impedance and the detector input impedance.

The guard switch should always be on when measuring high impedance values. In this case the detector input Impedance is about 1.000 MΩ in parallel with 4 pF. This causes a reduction in the meter sensitivity of 5% for measuring resistors of 100 MΩ and 10% for 200 MΩ when using the lowest measuring frequency. If two approximately equal resistors are available this error may be corrected by calibrating in the Measure position of the Check-Measure Switch. The capacitive part of the input impedance will cause an erroneous reading on the $\Delta\phi$ meter with impedance deviations. This may be corrected by noting the change in reading of the $\Delta\phi$ meter when calibrating as described above and calculating the resulting $\Delta\phi$ deviation for the actual measured deviations. However, normally phase angle measurements are not very important for high impedance measurements.

When measuring low capacitance values a high measuring frequency is preferable e.g. 10 kHz or 100 kHz. In this case the detector input impedance is mainly capacitive, about 4 pF with guard on, which causes an error of 5% for 40 pF measuring capacitance and 10% for 20 pF. This may of course also be corrected for by calibration as mentioned previously.

When measuring high value impedances hum pick-up at the detector input may cause errors by overloading the phase detectors. This problem is usually not serious, as even on the lowest range about 100 mV hum input may be tolerated, and this is multiplied by the range factor on the higher ranges. When measuring high impedances with leads at a short distance from the front panel, it is normally sufficient to have a grounded shield below the measuring objects, or if low ground capacitance is essential the shield may be connected to guard. if a

long detector lead must be used, this should be a shielded low capacitance cable with the shield connected to guard. This reduces the effective shield capacitance to about 1% of its original value.

Long Term Drift

The only drift of importance occurring over long periods is a reduction of the generator voltage by about 10% due to heating of the regulating thermistor. This stabilizes completely after about 1 hour. Thus if longtime stability measurements are to be made, the instrument should be switched on for at least one hour before starting measurements. Minor zero drifts up to 2% may occur over long periods or for large temperature variations.

High Accuracy Measurements

When the highest accuracy is required zero and calibration must be checked at the actual measuring frequency used to eliminate small variations with frequency. At 100 kHz the zero setting should be checked at the actual ΔZ and $\Delta \phi$ ranges employed, as small variations may occur due to stray induced voltages.

2.2.5. 100 kHz Measurements

At 100 kHz, due to stray couplings and residual impedance, the accuracy is not as high as at the lower frequencies.

Errors in the instrument are compensated as far as possible, so that in most cases an accuracy of 5% full scale is obtained.

Additional errors may be caused by external lead impedance at low impedance values and by stray capacitance and detector loading at high impedance values, especially at small values of deviation.

If accurate measurements of small deviations are required, measurement by substitution is recommended. This eliminates most of the errors mentioned above.

2.2.6. Use of Output Socket

The output socket at the rear of the instrument provides the following facilities:

ΔZ Meter Output between pins 1 and 7.

$\Delta \phi$ Meter Output between pins 3 and 8.

Output voltages proportional to the meter readings are obtained at these outlets to drive external meters, recording devices, limit alarms, etc.

Pins 7 and 8 are connected to ground and pins 1 and 3 supply 1 volt $\pm 5\%$ for full scale meter reading. Output is limited to max. 2 volt. The output resistance is less than 10 Ohms, and at least 1 mA may be drawn from these outputs. If required, higher sensitivity than normal may be obtained by employing a sensitive meter, the stability of the instrument allowing at least a 3 times increase in sensitivity.

Check-Measure Connections (pins 5 & 9).

By connecting an external switch to these the input relay may be energized. The Check-Measure Switch should be set at Measure. Closure of the external switch now shorts the input corresponding to the check position of the Check-Measure Switch.

Stabilized Supply Voltages

are available at pin 10 (+24 volts) and pin 12 (-24 volts), both referred to ground (pins 1-3-11). 20 mA continuous may safely be drawn from these outputs with up to 50 mA for short periods.

3. PRINCIPLES OF OPERATION (refer functional diagram)

3.1. Oscillator and Bridge Circuit

An R-C oscillator followed by a power amplifier supply exactly equal voltages of opposite phase to the standard and unknown terminals via a toroid transformer. Two sets of windings and terminals provide measuring voltages of 0.3 volts and 3 volts respectively.

A 4-position switch changes capacitors in the "Wien bridge" oscillator circuit to obtain the 4 measuring frequencies. The oscillator amplitude is stabilized by negative feedback through an indirectly heated thermistor connected across the 3 volt terminals. Thus an effective stabilisation of the actual measuring voltage is obtained.

At the junction between the standard and unknown impedance a voltage is developed determined by the difference in impedance and phase of the two impedances. The component of this voltage in phase with the measuring voltage is proportional to the impedance difference, while the component 90 degrees out of phase is proportional to the phase angle difference.

3.2. Input Amplifier

The total signal voltage is applied to an input amplifier which functions as a high-low impedance converter with unity gain and in addition supplies a guard voltage which follows the input voltage closely.

The signal input amplifier must have a very high input impedance in order to enable measurement of high impedances with negligible error. This is achieved by using a field-effect transistor in a circuit with negative feedback.

The output signal from the amplifier is fed to two range attenuators and from these to two phase detector circuits, which resolve the input voltage into its two components and supply proportional d-c outputs to the meters.

3.3. Phase Detectors

The phase detector circuits function as follows:

Reference voltages of opposite phase are applied to two current amplifiers. The signal voltage is applied to a third current amplifier, which has its output connected to the commoned output emitters of the reference amplifiers. Thus the reference amplifiers function as a 'long-tailed pair'

with the signal amplifier as a high-impedance common emitter load. The signal amplifier output current is injected equally into the two reference amplifiers, and the resulting output currents from these are the vectorial sums of the signal and reference currents.

These two currents are very nearly equal to the sum and the difference of the reference current and the in-phase component of the signal current provided that the total signal current is small compared to the reference currents.

By applying these currents to a diode-ring circuit a rectified current is obtained with a mean value proportional to the difference between the two currents and, consequently, also proportional to the in-phase component of the signal current. This current is amplified in a d-c amplifier and drives a meter.

With zero signal input current, the two reference output currents will be very nearly equal due to the high common impedance constituted by the signal amplifier, and consequently the d-c output current will be very nearly zero.

As mentioned previously two phase detectors are employed. One obtains its reference voltages from the bridge voltages directly, so that it responds only to the component of the signal voltage in phase with the bridge voltage. Thus the meter will read only the impedance difference and may be calibrated in percentage impedance deviation.

The second phase detector circuit has applied reference voltages which are exactly in quadrature to the bridge voltages and will thus only respond to the signal component in quadrature to the bridge voltage. As noted above this component is proportional to the phase angle deviation, and the meter may be calibrated to read the phase angle directly.

In order to obtain reference voltages exactly in quadrature with the bridge voltages, an integrator type of phase shifter is employed, which theoretically gives exactly 90 degrees phase shift independent of frequency and component variation. In practice small corrections are necessary to obtain exact quadrature, but even so a very high phase stability is obtained.

It is important that the two reference output currents from the reference amplifiers are very nearly equal. This is because the reference currents must be large compared to the wanted signal current, and thus a small inequality would give an error current corresponding to a signal input, and this would show up on the meters as a zero shift.

The reason why the reference currents must be so large is that it may be required to measure a small signal current component with a large superposed quadrature component.

For example, if one wants to measure an impedance deviation of 6% concurrent with a phase angle deviation of 0.1%, the amplified input current will be composed of the wanted in-phase component and an unwanted quadrature component 60 times larger. In order to obtain good accuracy the reference current must be at least 3 times the total signal current and preferably even higher. Thus the reference should be some 200 times the input current corresponding to full scale meter reading, if a zero error of 2% full scale is accepted. This means that the reference currents must be equal within 1 part in 10.000.

The possibility of having a large quadrature component superposed on the wanted signal component is also the reason why the phase shift for the phase angle reference must be very accurate.

Using the above example again with an impedance deviation of 6% an error in phase shift of approx $1/20$ degree will cause an error reading on the phase angle meter of 0.005% or 5% of full scale on the 0.1% range. Thus the accuracy and stability of the phase shifter must be of the order of $1/20$ degree for the specified accuracy.

4. CIRCUIT DESCRIPTION

4.1. Physical Description

The instrument contains 7 printed circuit boards as listed below:

Board No.	89000	Phase Detector	Plug-in	Board	1
"	"	89001	"	"	2
"	"	89002	Oscillator & Phase Shifter	"	3
"	"	89003	Input Amplifier	Fixture	5
"	"	89004	Stabilizers	Plug-in	4
"	"	89005	Phase Shift Network	Fixture	7
"	"	89006	Frequency Network	"	6

Boards 1, 2, 3 & 4 are mounted from left to right as seen from the front. Board 5 is mounted beneath the chassis in a shield box. Boards 6 and 7 are mounted on the frequency switch.

4.2. Oscillator Circuit (refer circuit diagram 2)

The oscillator consists of the two cascaded transistors T28 - T27. Positive feedback from T27 collector is applied through the frequency-determining network (Board 6) to T28 base. At the 100 kc setting of Sw.4, the network impedance is reduced to about 40% of the value at lower frequencies by R153, R157 to reduce the influence of stray capacitance, and small adjustments of frequency and amplitude are provided by R154, C41. Negative feedback is applied from T27 collector through the indirectly heated thermistor TH to T28 emitter across R141. The heater winding of TH is supplied from the total 6 V bridge output through P 3. Thus a very effective stabilization of the bridge output voltage is obtained. R119 (Board 6) is adjusted on test, so that P3 provides an output adjustment from -20% to +25% of the nominal output. D-c stabilization of the oscillator is provided by R136 - R140.

The output amplifier consists of the drive transistor T 30 driving the complementary pair T 26 - T 29. T 30 is current-fed through R138, and negative feedback is obtained through R143 with R144 for fine adjustment. The d-c level is set by R143 - R142. The output is taken from point 1 (Board 3) to the bridge transformer primary.

4.3. Phase Shift Circuit (refer diagram 2).

This circuit supplies reference voltages to the $\Delta\phi$ phase detector. These voltages are shifted 90 degrees in phase relative to the bridge voltages. The circuit achieves this in the following way: T 31, T 32 (Board 3) function as a high-gain inverting amplifier. Capacitors C 50 to C 53 (Board 7) are switched from T 32 collector to T 31 base. A current in phase with the bridge voltage is injected through R158, R159 (Board 7) on to T 31 base. Due to the high gain of T 31, T 32, practically all this current will be routed through C 50 to C 53, so that at T 32 a voltage is developed which is very nearly 90 degrees out of phase with the input voltage from the bridge.

However, in order to limit the gain at low frequencies, a small amount of resistive feedback must be provided (R147, Board 3). To compensate the resulting phase shift error (about 3 degrees) and any errors arising in the rest of the circuits, correcting capacitors C 46 to C 49 (Board 7) are fitted shunting R 159.

Pre-set potentiometers R 160 to R 163 allow small phase shift adjustments in order to obtain exact compensation on all ranges. T 33 operates as a unity gain inverting amplifier so that the required balanced reference outputs may be obtained.

The d-c levels are fixed by R 147 - R 150 and R 148, R 149, R 153.

4.4. Bridge Circuit (refer diagram 1).

This comprises the bridge transformer Tr.2, voltage switch Sw.3 and bridge terminals.

The bridge transformer primary winding is made up of two windings wound in parallel and with the centre tap grounded. The oscillator feeds one winding. The free end of the other winding is not corrected, but this winding compensates stray capacitive coupling to the secondary thus obviating the necessity for any shielding. Two secondary windings are provided supplying 2 x 0.3 volt and 2 x 3 volt respectively. Each winding consists of 4 twisted wires. 2 and 2 are connected in parallel and series-connected with their junction employed as a centre tapping. In this way a high degree of symmetry and a very close coupling is ensured.

The voltage switch Sw.3 connects the reference outputs either directly to the 0.3 volt windings or through voltage divider networks R 2, R 6 and R9, R 11 to the 3 volt windings. In the end positions Sw.3 shifts the earth

connection from the winding centre taps to voltage dividers R 1, R 5 and R 4, R 7 to provide an unbalance corresponding to 2% impedance deviation.

Also, on the 0.3 volt range, Sw.3 connects resistor R 14 to reduce sensitivity on the 20% ΔZ range in order to obtain correct meter readings on this particular range.

The bridge supply terminals are connected directly to the transformer windings in order to obtain the lowest possible stray impedances.

The detector terminal is isolated from the front panel by a concentric shield in order to reduce the ground capacitance when necessary for high-impedance measurements. From the detector terminal a lead is taken to the input amplifier described in the following paragraph.

4.5. Input Amplifier (refer diagram 1).

The signal at the detector terminal feeds into a relay (Rel.) on the input amplifier board. This relay is energized from the negative 24 volt line in the 'CHECK' position of Sw.6. This disconnects the detector terminal from the amplifier input, which instead is switched to Sw.3. Switch Sw.3 in its intermediate positions connects the amplifier input to ground, so that the meters in these positions may be zeroed. In the end positions of Sw.3 the calibrating voltages developed across R 5 or R 7 are applied to the amplifier input for checking calibration.

With Sw.6 set to 'Measure' the relay is de-energized and the detector terminal is connected to the amplifier input for taking measurements. In this condition with the measuring impedances connected calibration may also be checked in the end positions of Sw.3. In this case the bridge supply voltages will be unbalanced by the voltage across R 5 or R 7, which exactly simulates an impedance unbalance, thus allowing accurate calibration for high impedance measurements where the input amplifier load reduces the sensitivity.

From the relay the input signal is routed via R 25 and C 5 to the gate of a field effect transistor T 3. An inverted signal from T 3 drain drives T 4 base, and once more an inverted signal is obtained at T 4 collector which drives emitter follower T 1. Thus at T 1 emitter a signal in phase with the input appears. This is fed to T 3 source and via C 4 to R 23 (T 3 gate resistor). Zener diodes D 1 and D 2 couple the signal on to drain resistor R 28 and T 4 emitter.

In this way the system functions as a 'boot-strap' amplifier with T 1 emitter following the input at T 3 gate very

closely. The voltage gain of the amplifier defined as the ratio between T 1 emitter a-c voltage and the input a-c voltage between T 3 gate and source is of the order of 200 times, so that T 1 emitter will follow the input at T 3 gate within about $\frac{1}{2}\%$. Thus the input resistance at T 3 gate will be effectively multiplied by 200 and the input capacitance divided by 200.

R 25 at the input is included to ensure stability for all values of input impedance, as without this resistor the input resistance would become negative at high frequencies. R 25 causes a small phase shift at the highest measuring frequency (100 kc). This is compensated in the circuitry of the following phase detectors. R 153, C 56 provide a step in the gain versus frequency characteristic to ensure stability at high frequencies.

From T 1 emitter circuit the signal is routed through the buffer emitter follower T 5 to the range attenuators. T 1 also drives buffer emitter follower T 2 which supplies the guard voltage. This is switched by Sw. 5 to a shield around the relay and to the detector terminal shield and also to a socket for connection to external shielding. In this way stray input capacitance to ground is effectively reduced, so that an input capacitance of the order of 4 pF is obtained.

Pre-set potentiometer R 16 adjusts the d-c operating level so that the voltage at output point 1 is zero. This prevents meter bounce when changing range.

4.6. Phase Adjustor and Attenuators (refer diagram 1).

The output signal from the input amplifier goes to the phase adjustor circuit. This provides an adjustable advance of phase at 100 kc by the preset potentiometer P 2 mounted on the front panel, so that any small variations due to changes in stray capacitance etc. may be compensated. From the phase adjustor the signal goes to two range attenuators Sw.1 and Sw.2. These are designed with constant input and output impedances at all settings.

4.7. Phase Detectors (refer diagram 1).

The two phase detectors (Boards 1 & 2) are practically identical, only due to the different sensitivity some of the components have different values.

The signal from the attenuator is applied to a three-stage amplifier T 18, T 17, T 19.

T 18 is an inverting amplifier driving the two cascaded emitter followers T 17, T 19.

Negative feedback is applied from T 19 emitter to T 18 base through R 88.

C 17, R 92 provide a small phase advance at 100 kc to compensate the phase shift developed in the input amplifier.

The standing current in T 19 is about 60 mA and is set by R 90 and R 88.

The amplifier functions as a current amplifier. The input impedance seen from the input amplifier is 1 k Ω , and the transfer conductance is $2.7 \times 10^3 / 1 \times 47$ app. 60 mA/V. The effective input voltage for full scale meter deflection on the $\Delta\phi$ meter is about 1.3 mV, resulting in an output current of about 78 μ A r.m.s. at T 19 collector. This current is fed into the commoned emitter resistors R 75 and R 76 of the two reference amplifiers and due to the circuit symmetry the current is divided equally between the two amplifiers.

The reference amplifiers are designed exactly like the signal amplifier, only with different values for the feedback resistors. The two reference amplifiers combined operate as a differential amplifier with very high common mode rejection due to the high common emitter impedance presented by the signal amplifier output. The residual shunt conductance caused by the feedback resistors R 71, R 72 is compensated by current feedback through R 80 to the signal amplifier input, so that a virtually infinite common emitter impedance is obtained, resulting in practically equal reference currents in the two amplifiers. Thus the requirements stated in the principles of operation are fulfilled.

The reference input voltages are about 300 mV each of opposite phase, and the resulting output currents at T 11 and T 12 collectors are 10 mA r.m.s. each.

The amplifiers obtain their supply current from the +24 volt line through T 6, T 7 operating as constant-current supplies so that the only effective shunt conductances are the base supply resistors R 58, R 59.

Emitter voltages of T 11, T 12 (8.8 volts) are set by R 74, R 71 and R 77, R 72.

T 8, T 9 collector voltages are set by R 58, R 61 and R 59, R 64.

In order to use as high a value as possible for R 58, R 59 transistors T 6, T 7 are selected for high current gain.

Thus practically the whole a-c current from T 8, T 9 collectors is routed through C 9, C 11 and C 55, C 10 to the diodes D 5, D 7 and D 4, D 6.

To obtain a small zero shift at the lowest measuring

frequency, C 55 - C 9 and C 10 - C 11 are selected in pairs within 5% mutually.

R 65 and R 66 are arranged to route the leakage currents in C 55, C 9 to ground, so that they are not passed on to the diode circuit.

At the junction between D 6, D 7 a rectified d-c current is obtained of a value one half the difference between the two mean output currents from T 8, T 9 collectors. This current is applied to a d-c amplifier.

To obtain low temperature drift the input stage consists of a differential pair T 14, T 15. The inverted output from T 14 collector drives output emitter follower T 16. Zener diode D 8 provides a suitable d-c working point for T 14 collector, and R 70 limits dissipation in T 16. The output is taken from the junction of R 79, R 83 through R 84 to the meter and also directly to the output socket.

Negative feedback is provided from the output through R 81 to T 14 base. Capacitive feedback through C 13 reduces signal frequency and hum output, and diodes D 9, D 10 biased by R 79, R 83 limit the output voltage to about twice the full scale voltage of 1 volt.

Zero adjustment is obtained by injecting a current through R 94 from P 1 (P 2) against an opposing current through R 67.

C 14 feeds hum and signal frequency voltages at T 14 base in opposite phase into the amplifier and thus reduces the gain at these frequencies, so that overload at the output is avoided.

As mentioned previously, the $\Delta\phi$ signal amplifier supplies about 78 μ A r.m.s. for full scale meter deflection.

This current also appears as the difference between the two currents feeding the diodes. The d-c output current is then $\frac{1}{2} \times 78 \mu\text{A} \times 0.9$ app. 35 μ A.

T 14 requires max. 1 μ A for full scale output, so that 34 μ A go through the feedback resistor. The full scale output voltage is 1 volt, so the resistor value becomes about 30 k Ω . The exact value is adjusted on test by shunt resistor R 82.

For the ΔZ board, the signal output current is twice the above value and the feed back resistor about 15 k Ω .

4.8. Power Supply (refer diagram 2).

The supply mains transformer has two windings, which are connected either in parallel or series by Sw.8.

Two separate 28 volt windings through bridge rectifier circuits supply approx. 35 volts d-c for the stabilizer supplies.

The stabilizers are normal series stabilizers with T 21, T 24 as series elements, T 20, T 23 as drivers and T 22, T 25 in the input states. Reference voltages are obtained from series connected zener diodes D 11, D 12 and D 13, D 14.

The output voltages are adjusted to 24 volts by shunt resistors R 101 and R 111. Compensation for mains voltage variation is provided by R 100, R 110. R 99, R 109 limit dissipation in T 21, T 24 at high mains voltages.

5. SERVICING INFORMATION

5.1. Dismantling and Reassembly Instructions

Before dismantling the instrument disconnect the mains supply.

Loosen the 4 screws holding the front panel. Turn instrument upside down, remove the 4 screws holding the bottom cover and remove this.

Remove the top cover by pulling the lower side panels outwards until the cover front-edge is clear of the front panel upper fixing screws. Then lift cover away. Fasten front panel screws lightly to ensure that the control knobs are free of the front panel.

The input amplifier is mounted beneath the chassis holding the printed circuit boards and becomes accessible by removing the shield cover. To gain access to the components, first disconnect the small plug on the lead from the detector terminal. This plug is pushed on to one of the wire terminals on the input relay mounted on the amplifier board. Then remove the three hexagonal studs holding the amplifier board. This may now be lifted out sufficiently to enable servicing, as all leads are connected to the front edge of the board.

To reassemble the instrument put on the top and bottom covers and fasten the bottom cover screws lightly. Then adjust the front panel frame so that it is flush with the top cover on all sides and tighten the top screws in the front panel.

With the instrument upside down, center the bottom cover and tighten the bottom front panel screws while pressing the front edge of the bottom cover down. Finally tighten the bottom cover screws.

5.2. Selected Components

Most of the components used are not critical in value. Resistors are carbon-film types with 5% accuracy, and capacitors are mostly normal types.

The components which must be selected are as follows:

All range attenuator resistors including input resistor R 89 on boards 1 and 2. Calibration divider resistors R 1, R 5, R 4 and R 7 on switch Sw. 3. Resistors R 75 and R 76 on boards 1 and 2.

All these resistors are either metal-film or carbon-film types selected within 1% mutually in each circuit group.

Capacitors C 7 - C 8, C 55 - C 9, C 10 - C 11 are selected within 5% for each pair.

Absolute values are not critical. (Large deviations between these capacitors will cause excessive zero shift at 100 Hz and for high mains hum input compared to the zero setting at higher frequencies).

If R 75 and R 76 above differ much in value, large quadrature signal voltages will also cause excessive zero shift at all frequencies.

5.3. Voltages and Currents

The following table states the normal operating voltages and currents. Most values of d-c voltage are normally accurate to $\pm 5\%$, when supply voltages are accurately adjusted to +24 volts and -24 volts.

The value are measured at 230 volts mains voltage, with check switch in the CHECK position and with the 'Adj. 2%' control set for full scale reading on the 2% range.

Measuring points:

From:	To:	Value:	Remarks:
In mains lead		125 mA a-c	moving-iron meter
C21 pos.	C21 neg.	37V/0.5V	d-c/a-c peak-to-peak
C22 pos.	C22 neg.	38V/0.8V	d-c/a-c peak-to-peak
Output 12	ground	-24V / $\pm 0.5V$ / <0.5mV	d-c/a-c peak-to-peak
Output 10	ground	+24V / $\pm 0.5V$ / <0.5mV	d-c/a-c peak-to-peak
T27 Coll.	ground	+11.5V/2.6V	d-c/a-c r.m.s.
T27 Em.	"	+6.5 V	d-c
R135-R137junc.	"	+11.5V/4.8V	d-c/a-c r.m.s.
T26 Em.	T27 Em.	+1 V	d-c
T32 Coll.	ground	+5.5V/290mV	d-c/a-c r.m.s.
T33 Coll.	"	+5.5V/270mV	d-c/a-c r.m.s.
3V Terminal	"	2.90 V r.m.s.	
T2 Em.	"	+13.5 V	d-c
T5 Em.	"	± 100 mV	d-c adj. on test
T19 Em.	"	+3V/4 mV	d-c/a-c r.m.s. f.s.
T11 Em.	"	+8.8V/1 V	d-c/a-c r.m.s.
T12 Em.	"	+8.8V/1 V	d-c/a-c r.m.s.
T8 Em.	"	+14.5V-16V/1V	d-c/a-c peak-to-peak (10 kHz)
Output 7	"	+2.5V/-1.8V	d-c max. on overload
Output 8	"	+2.5V/-1.8V	d-c max. on overload.

5.4. Setting-Up Information

The following information is an abstract of the factory test procedure and is provided to assist in servicing the instrument.

Normally, of course, it will not be necessary to go through the complete test procedure.

5.4.1. Test Equipment Required

- a) Universal d-c and a-c meter
- b) A-c voltmeter 50 Hz-100 kHz 2% accuracy.
- c) C-R oscilloscope 1 Hz-1 MHz, max. 1 mV/cm
- d) Vario-transformer 0-260 volt
- e) Decade resistor 0-1.000 Ω , 0.1 Ω resolution, $\frac{1}{2}$ % accuracy e.g. Danbridge Type DR4/A.
- f) Decade capacitor 50 μ F-1 μ F, $\frac{1}{2}$ % accuracy, e.g. Danbridge Type DK4SV.
- g) Pairs of standard resistors 2x1 Ω , 2x100 Ω , 2x1 k Ω equal mutually to 0.01% or preferably better, absolute accuracy 1%.
 Pairs of low-loss capacitors (polystyrene or similar) e.g. 2x5 nF and 2x50 nF, selected within 0.1% mutually. These capacitors must be small types, so that they may be suspended directly on their leads between the measuring terminals, as they are used for checking bridge symmetry and phase zero at 100 kHz.
 The above resistors and capacitors may be selected using the CPT 2. If no equal components are available, equality may be attained by shunting the high value resistors with small carbon resistors and shunting low value capacitors with small ceramic capacitors.
- h) CPT 2 output plug with connecting leads.

5.4.2. Power Supply

Check mains current at 230 volts with Check-Measure Switch at CHECK (relay operating), 80 to 90 mA measured on rectifier meter, 120 to 130 mA r.m.s.

Check positive and negative stabilized supply voltages at output plug, and adjust both to 24-24.5 volts by padding resistors R 111, R 101 on board 4.

Check hum and noise on scope, less than 500 μ V peak-to-peak. Vary input voltage from 190 to 260 volts and check that hum is within specifications. A hum minimum should be apparent at approx. 210 volts, indicating that compensation through R 100, R 110 works correctly.

5.4.3. Oscillator Circuit

Check frequencies against audio generator. 100 Hz nominal should be 110 Hz. If necessary adjust 100 kHz by padding capacitor C 41 or resistor R 154.

Check 3 volt output voltage and adjust R 119 for variation by P 3 ('Adj. 2%') from 2.4 V to at least 3.6 V undistorted output.

Connect 200 Ohms (decade resistor) across 3 V terminals and check that an undistorted output of minimum 3 V may be obtained.

If necessary adjust R 144 for symmetrical clipping.

With P 3 set at minimum output and open-circuit bridge terminals check that output stabilizes in a few seconds when switching from 1 kHz to 100 Hz. If instability appears increase R 138 to 5.1 k Ω and check again for distortion at max. output.

Check d-c voltage appr. 1 V between T 26 and T 29 emitters at minimum output.

Check phase-shifter outputs (10 and 11 on board 3) at all frequencies. These must be nearly equal and equal to the 0.3 volt bridge outputs except at 100 kc (about 10% low). Also check d-c voltages of 10 and 11 (5 to 6 volts).

5.4.4. Input Amplifier

Set Check-Measure Switch to CHECK and connect d-c voltmeter from signal output to ground, (signal output may easiest be obtained at ΔZ range switch input). Adjust pre-set potentiometer R 16 (Board 5) for zero output voltage (± 100 mV).

5.4.5. Phase Detectors and Calibration

Check d-c voltages at T 11 and T 12 collectors (14.5-16 V).

Check zero adjustment (P 1 and P 2) for symmetrical variation around meter zero (asymmetry less than 2/1).

With input switch at CHECK and both range switches at maximum deviation settings check zero shift for frequency changes and for variation of output voltage from minimum to maximum. Zero should not vary by more than 2% of full scale for any change.

Larger variations may be due to an abnormal conduction voltage of one of the diodes D 4 to D 7 or to large inequality of base voltages on T 14 - T 15.

At 100 Hz badly matched capacitor pairs, C 55 - C 9, C 10 - C 11, C 7 - C 8 may cause zero shift.

Connect the 2x1.000 Ohm resistor pair in series with 1.000 Ohm decade box across the 3 volt terminals with

decade box to unknown terminal and junction of 2x1.000 Ohms to detector terminal.

Switch to 1 kHz, ΔZ range 2%, voltage switch 3 V, input switch to check and decade box to zero.

Measure 3 V output and adjust to 2.90 volts.

Set input switch to measure and if necessary correct ΔZ meter zero. Set decade box to 20.2 Ohm and adjust R 82 (Board 1) to obtain full scale meter reading.

Set input switch to check and voltage switch to 2%. Check that full scale reading within $\pm 1\%$ is obtained.

Check full scale reading at all range switch settings (decade box settings: 0.2% 2.0 Ohm, 0.6% 6.0 Ohm, 6% 61.8 Ohm).

Interchange Boards 1 & 2. Set range switch to 2% and decade box to zero and set zero accurately in measure position. Set decade box to 10.0 Ohm and adjust R 82 (Board 2) for full scale reading. Replace Boards 1 and 2 in their correct positions.

Connect 2x1.000 Ohm and decade box to 0.3 volt terminals as above and repeat calibration check on 2% range (voltage switch to 2% on 0.3 volt range).

5.4.6. Bridge Circuit and Auxiliary Circuits

Connect 2x1.000 Ohm to 3 V terminals and detector terminal. Set frequency to 1 kc, voltage switch to 3 V and ΔZ range to 0.2%. Set zero in check position and then switch to measure position. Note reading.

Reverse the 2x1.000 Ohm resistor and measure again. Check that the two readings of opposite polarity are equal within 1% of full scale (this corresponds to an unbalance of 10^{-5}). Any unbalance is caused by unequal loading of the transformer windings and may be corrected by shunting one of the windings by a suitable value resistor. This may be done on the voltage switch by shunting across either R 1, R 5 or R 8, as the case may be.

Repeat the check using the 2x100 Ohm resistor. This test reveals any unbalance in the winding resistance. This is corrected by shortening one of the winding connections to the terminals.

Repeat check on the 0.3 V range using the 2x1 Ohm resistor.

Note: In this case the lead resistance and contact resistance to terminals may cause errors, unless care is taken to keep the lead lengths equal and contact resistance low for the checks.

5.4.7. Phase Shift Adjustment

Set Check-Measure Switch to CHECK, voltage switch to 3 V, frequency switch to 100 Hz, ΔZ range switch to 2% and $\Delta \phi$ range switch to 0.1%. Zero both meters and then change voltage switch to 2%. If phase shift is correct the $\Delta \phi$ meter should read zero. Any deviation may be corrected by adjusting the pre-set potentiometer R 160.

Repeat checks and adjustments at 1 kHz and 10 kHz, adjusting R 161 and 162 respectively.

Potentiometers R 160, R 161, R 162 and R 163 (for 100 kHz adjustment, as stated in the following paragraph) are located on the rear board of the frequency switch. They are arranged in order of increasing frequency, starting with R 160 at the centre of the top edge of the board, and with R 163 at the bottom of the right hand edge.

Note: When checking the phase shift, any external un-balanced load on the terminals may cause an error, so all external leads to the terminals should be disconnected.

5.4.8. 100 kHz Checks

At 100 kHz the various residual impedances and couplings increase the difficulties in obtaining perfect balance and phase accuracy at all impedance loads and range settings.

Errors are compensated as exactly as possible, so that normally reading errors of less than 5% of full scale are obtained. The main source of errors is the bridge transformer, and if replacement of this is necessary the instrument should be returned to the factory for readjustment. Small adjustments of balance are obtained by adjusting the positions of the leads from transformer to terminals, so displacement of these should be avoided.

Balance may be checked by connecting two equal impedances (e.g. on the 3 V range two selected 5 nF polystyrene capacitors) across the measuring terminals and comparing the meter readings before and after reversing the components.

For an error less than 5% of full scale, the difference between readings of opposite sign should be less than 10% of full scale.

Phase adjustment is best checked in the following way:

Connect two nearly equal polystyrene capacitors of 5 nF across the 3 V terminals and adjust meter zero with ΔZ range switch at 0.2% and $\Delta \phi$ switch at 1% in the

measuring position.

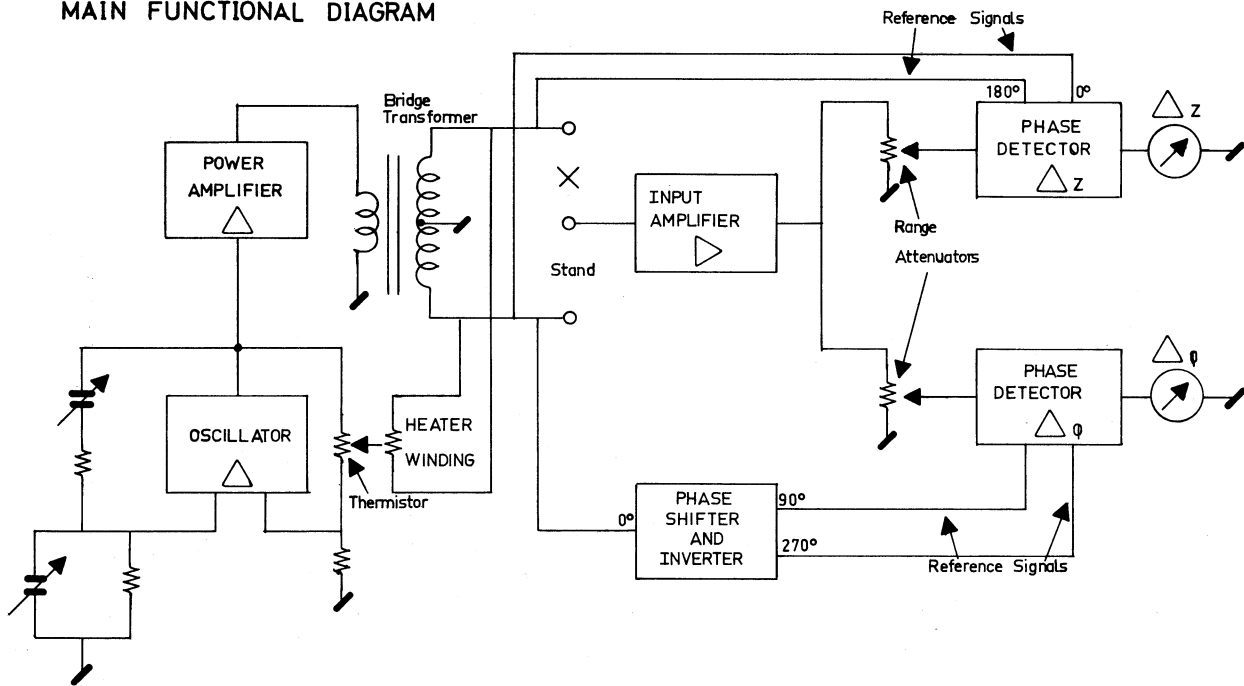
Connect a carbon-film resistor of value 33 kOhm across the unknown capacitor. This provides a phase angle of approx. 1%, which theoretically should cause a negative reading of impedance of 0.005%. If a small resistor of e.g. 1/4 watt is used the effective shunt capacitance is approx. 0.5 pF or 0.01%, so that a total negative reading of 0.015% results.

Thus by adjusting the $\Delta\phi$ pre-set control for a meter reading of minus 0.015% the ΔZ meter should read correctly for phase angle variations.

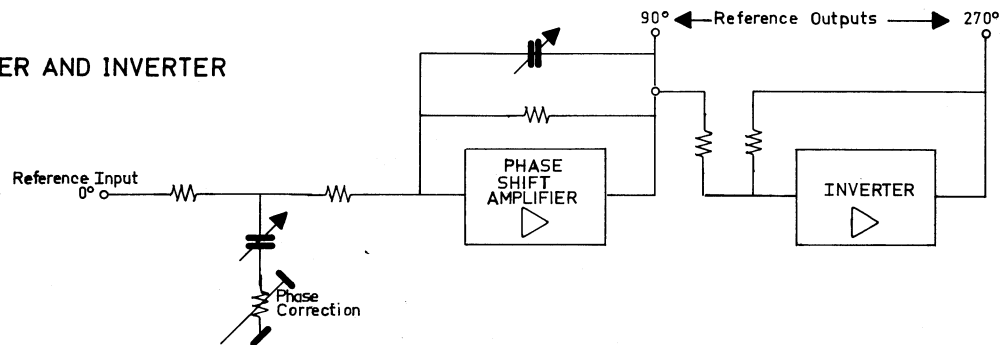
To set the phase angle of the $\Delta\phi$ phase detector set ΔZ range to 2% and $\Delta\phi$ range to 0.1%. Set zero on both meters in measure position with the two 5 nF capacitors connected, switch to CHECK and connect a 100 pF polystyrene capacitor across the 'standard' 5 nF. Switch to measure and adjust R 163 for zero on the $\Delta\phi$ meter.

Switch to CHECK and check that $\Delta\phi$ meter reading changes less than 5% of full scale when switching the voltage switch from '3 V' to CHECK 2%.

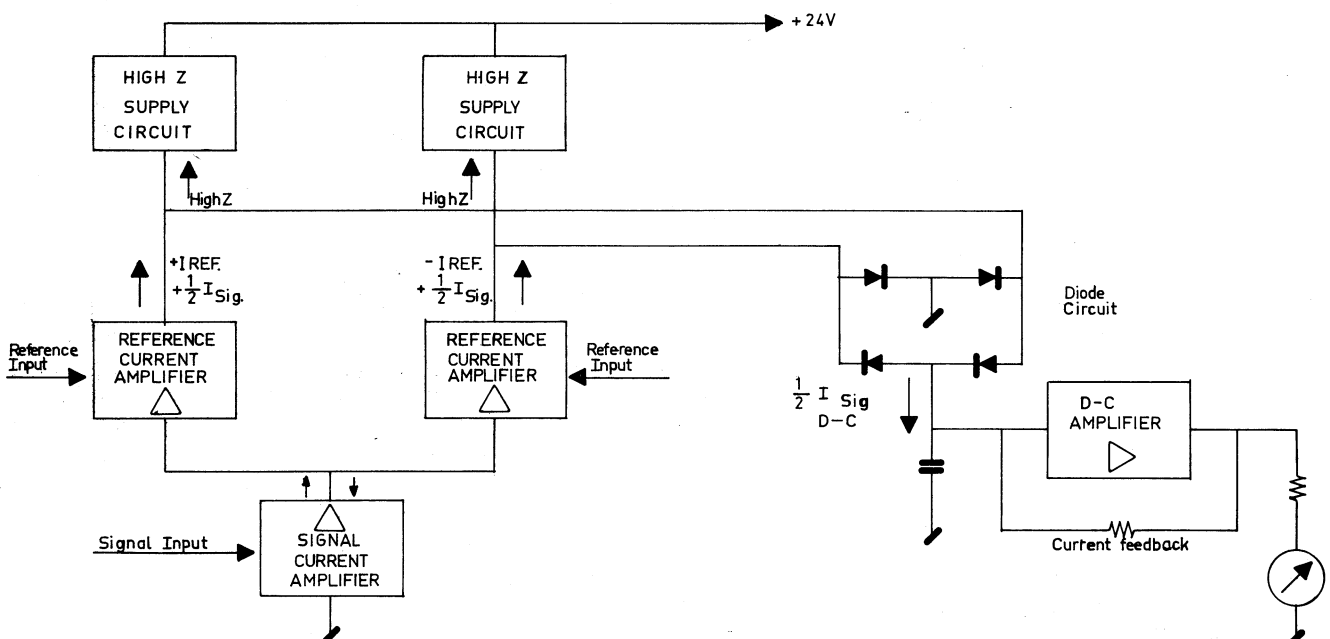
MAIN FUNCTIONAL DIAGRAM



PHASE SHIFTER AND INVERTER

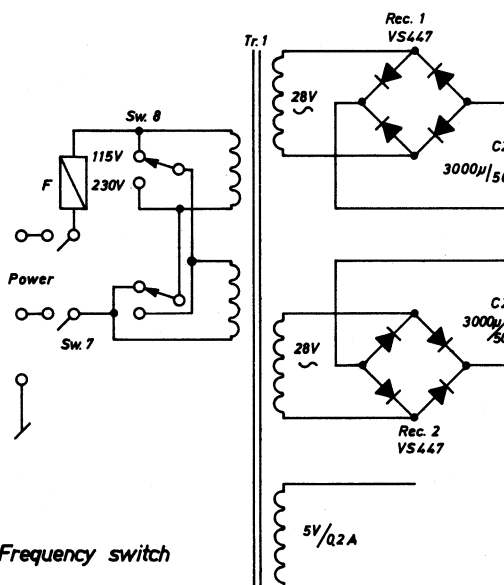


PHASE DETECTOR



CPT 2 FUNCTIONAL DIAGRAM 73600

Power supply



Frequency switch

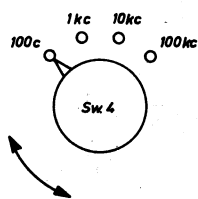


Diagram 1
Tr. 2
3V Terminals

P3
300
adj. 2%

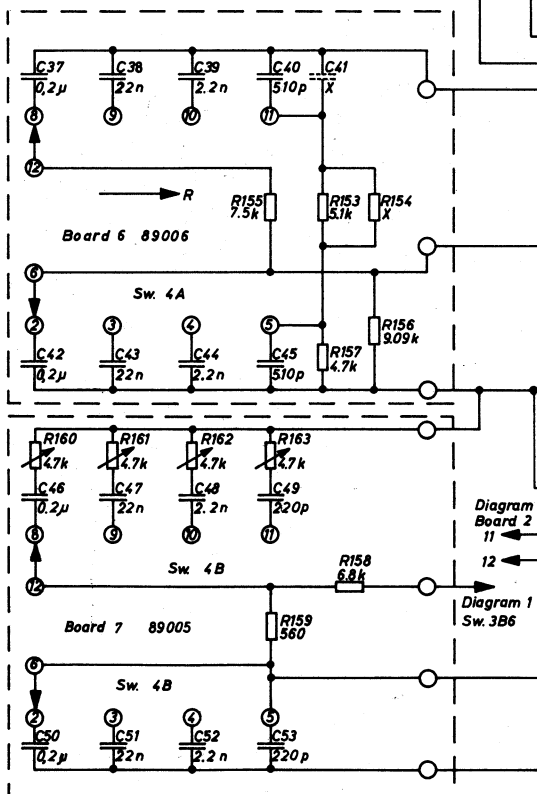
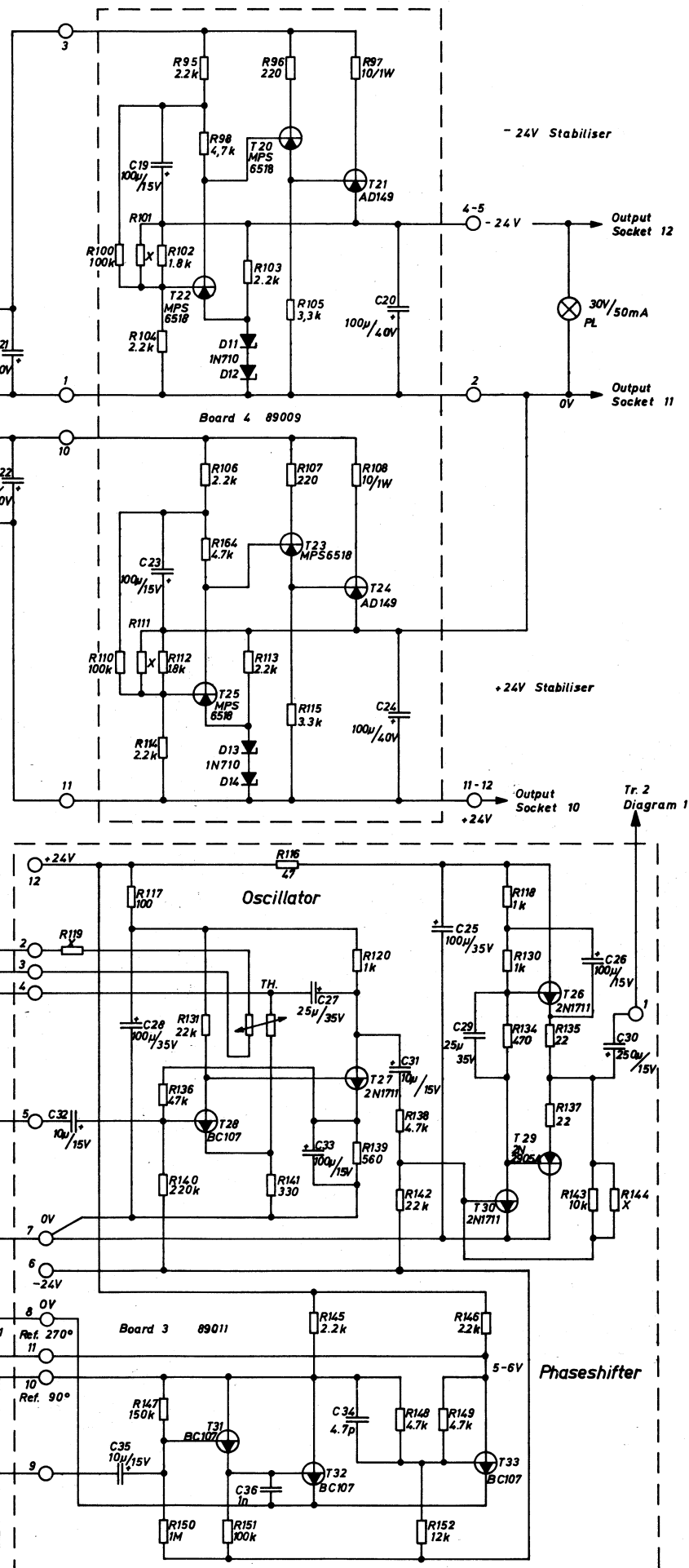


Diagram 1
Board 2
11

Diagram 1
Sw. 3B6



73600D

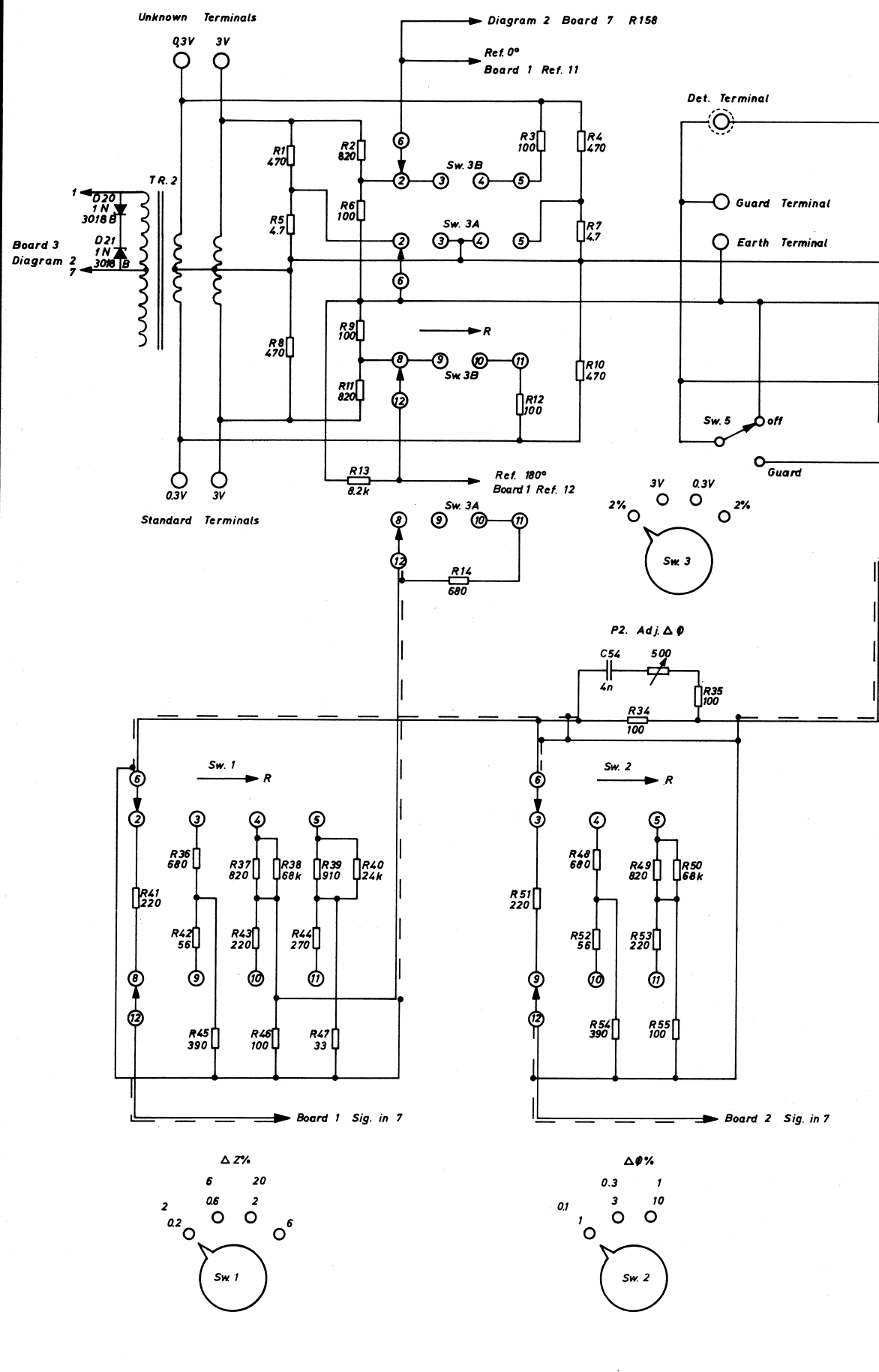
Circuit diagram

Component tester type CPT-2

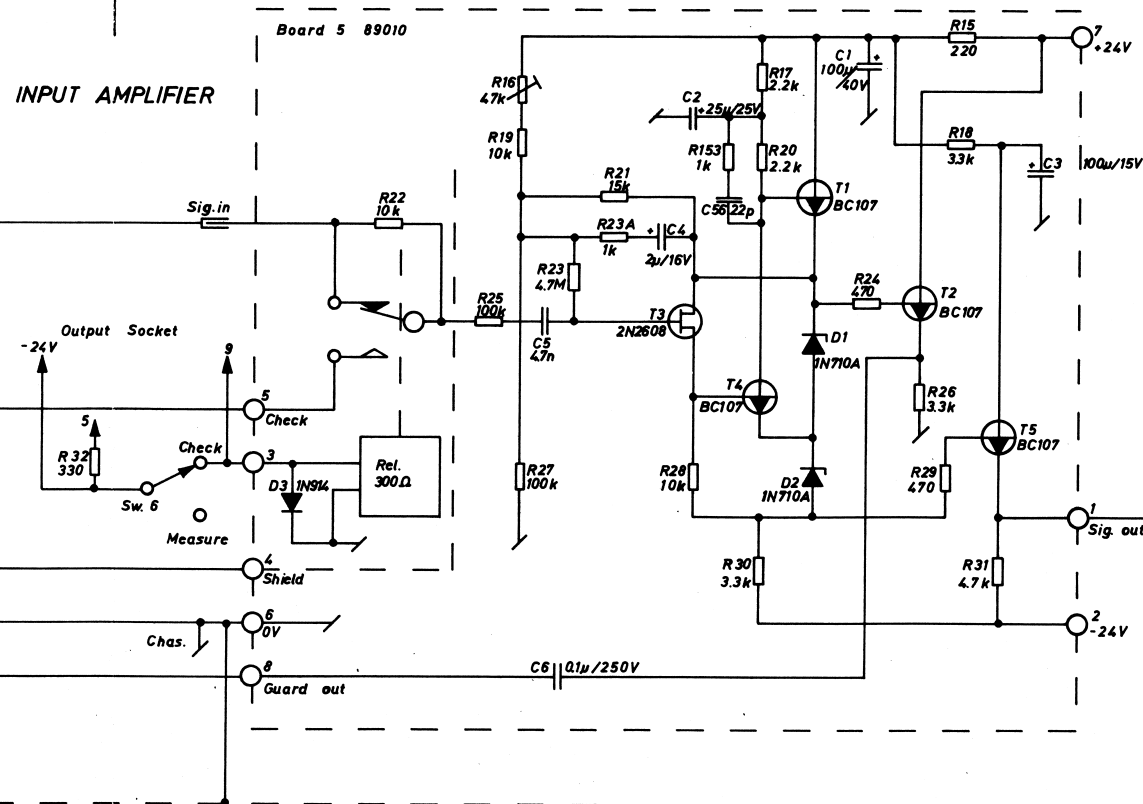
Konstrueret: V. Jensen		
Tegner: <i>H. Holm</i> BR.		
Dato: 9-12-88 180670 041170 111270		
Godkendt: <i>J</i> <i>J</i> <i>J</i> <i>J</i>		
041073	BR	<i>J</i>
RET TET	TEGN.	GODK.

A/S Danbridge

BRIDGE CIRCUIT



INPUT AMPLIFIER



NOTES TO CIRCUIT DIAGRAMS 1 & 2

Components marked X are adjusted on test.

Components marked □ have different values on boards 1 & 2.

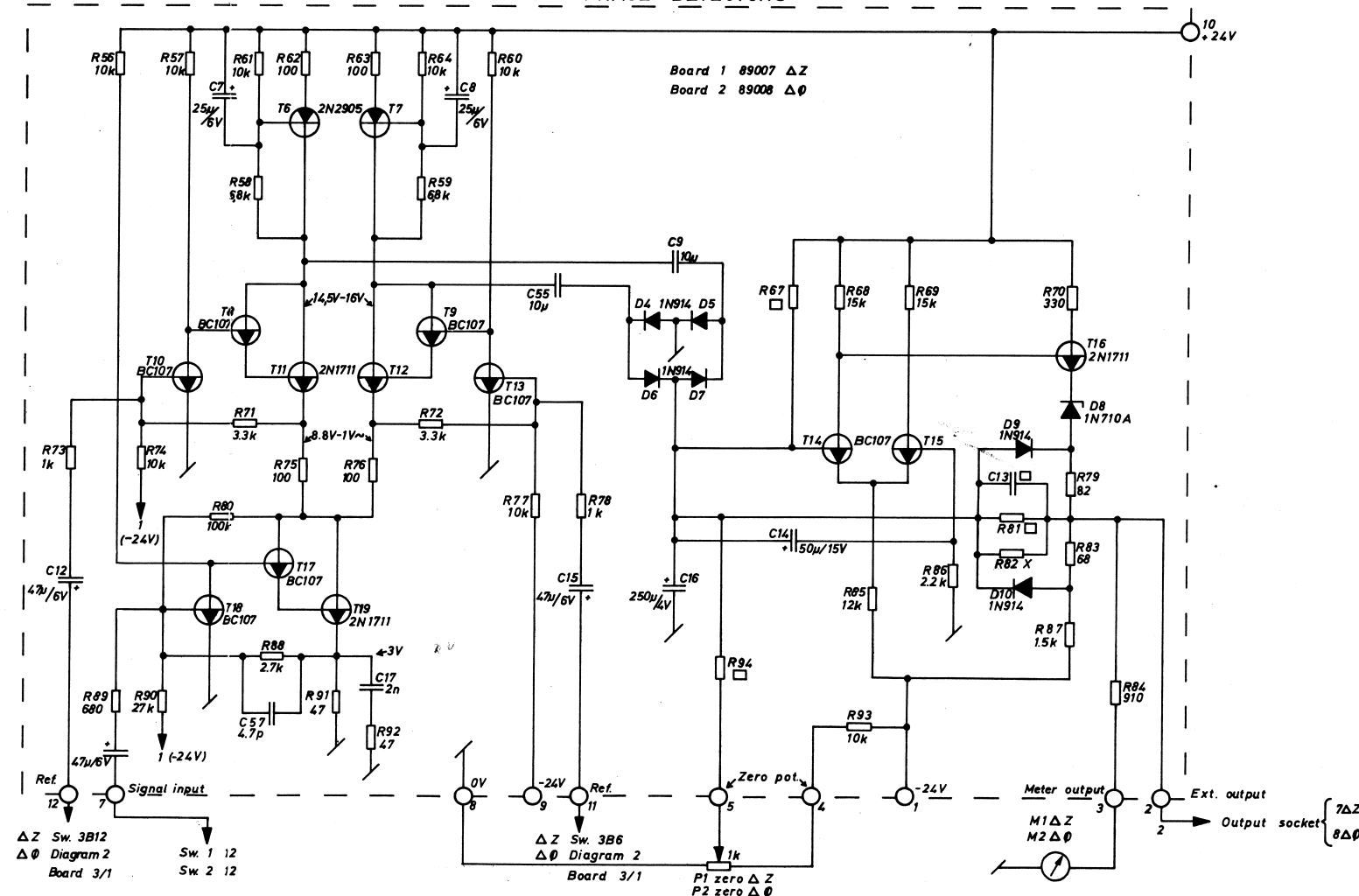
Board 1: R67A 820k, R81A 15k, R94A 47k, C13A 2.2μ

Board 2: R67B 1.5M, R81B 33k, R94B 100k, C13B 1μ

Switches are shown in anticlockwise position. Letter indications denote sections from front panel.

Voltages are measured at 2% full scale adjustment.

PHASE DETECTORS



73600C Circuit Diagram

Component Tester Type CPT 2

Konstrueret: V. Jensen

Tegner: *H. Holten* BR.

Dato: 13-11-69 180670 221271

Godkendt: *[Signature]*

A/S Danbridge