# V H F ADMITTANCE BRIDGE

## B801B

## INSTRUCTION MANUAL

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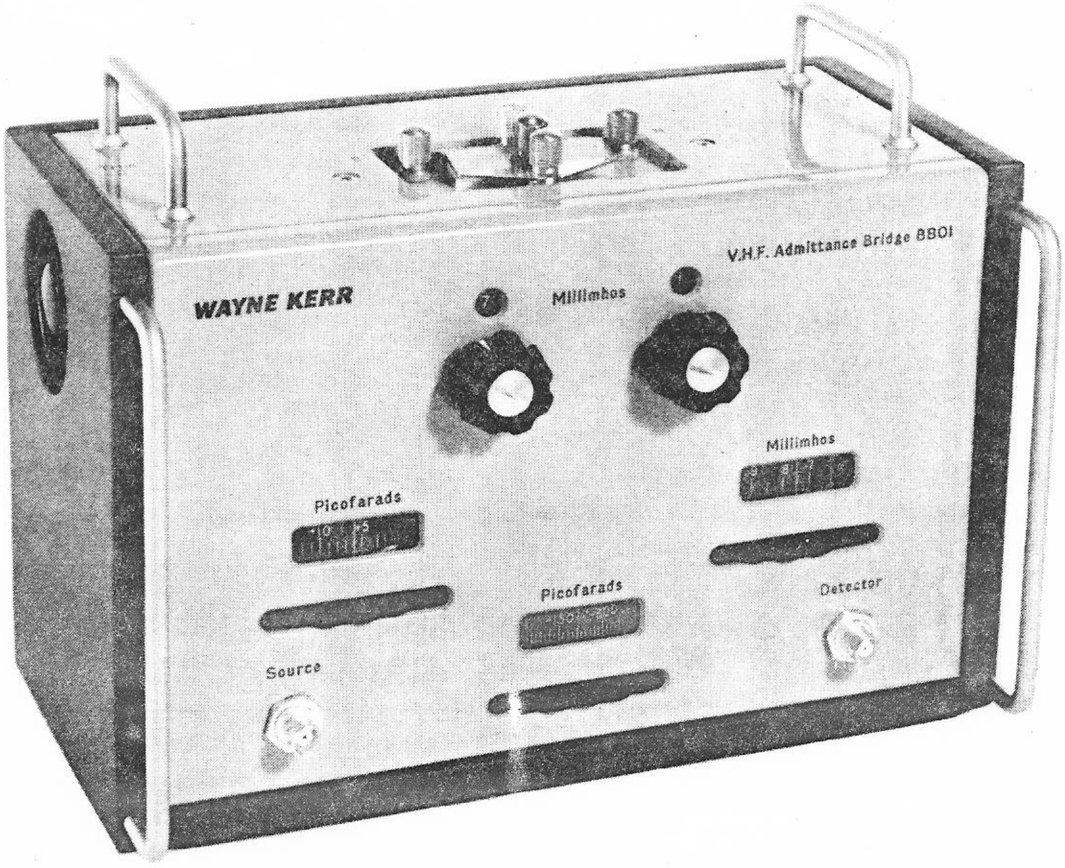
CONTENTS


V.H.F. Admittance Bridge B801
WAYNE KERR
Millimhos
Millimhos
Picofarads
Picofarads
Detector
Source

# INTRODUCTION

VHF Admittance Bridge B801B can be operated at any frequency between 1 Mc/s and 100 Mc/s for the simultaneous measurement of the capacitance and conductance of aerials, feeders, lines and components, whether balanced or unbalanced.

A wide measurement range is available from only a few Standards whose effective values are extended by the use of ratio transformers. This technique permits the values of the Standards to be selected for maximum stability and minimum phase-angle.

A number of ancillary equipments, described in separate publications, are available for use with the B801B. They include:

| | |
|---|---|
| S161B | Bridge Source, covering 5-100 Mc/s in 3 bands. The output is amplitude-modulated at 1000 c/s and an output level control is provided. Operation is from a. c. supplies of 110 or 230 volts. |
| R161 | Bridge Detector, tunable from 5 to 100 Mc/s in 3 bands. Designed for operating headphones. A Sensitivity control is fitted. 110/230 V a. c. |
| Q761 | External standards for checking the performance of the Bridge against frequency. |
| Q801 | Adaptor and D. C. Control Unit enabling the B801B to be used for measuring all admittance parameters of PNP and NPN transistors. Also checks diodes. |

# SPECIFICATION

| | |
|---|---|
| Frequency Range | 1 to 100 Mc/s |
| Conductance Range | 0 to 100 millimhos |
| Conductance Accuracy | ± 2 per cent ± 0·1 millimho |
| Conductance Discrimination | 0·02 millimho up to 50 Mc/s<br>0·1 millimho at 100 Mc/s |
| Capacitance Range | 0 to ± 230 pF |
| Capacitance Accuracy | ± 2 per cent ± 1·5 pF |
| Capacitance Discrimination | 0·2 pF |
| Dimensions | Width: 11 in. (28 cm)<br>Height: 9 in. (23 cm)<br>Depth: 7 1/2 in. (19 cm) |
| Weight | Approx. 9 lb. (4·1 kg) |

## PRINCIPLE OF OPERATION

A simplified diagram of the bridge circuit is shown in Fig. 1A and the corresponding terminal connections in Fig. 1B.

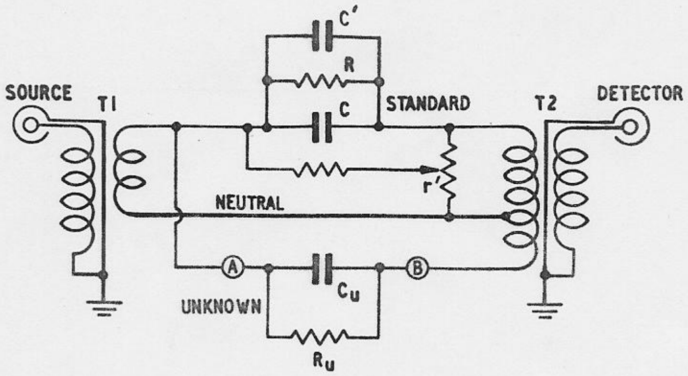



FIG. 1A

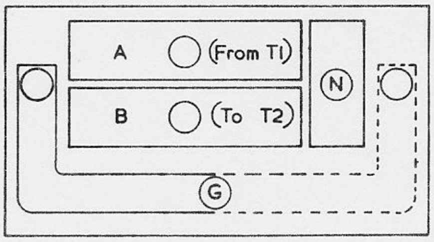



FIG. 1B

The source voltage is applied to the bridge through transformer T1, the secondary winding of which drives a current through the standards (C, R) and part of the primary winding of T2, the current transformer, which is connected to the detector. The same voltage drives a current through the unknown capacitance and resistance ($C_uR_u$) and the other part of the primary winding of T2.

The two parts of the primary winding of T2 are in opposition, so that if the ampere-turns in each part are equal there will be no flux linked with the secondary winding and the output to the detector will be zero. The detector will thus indicate balance under this condition.

If the turns on the primary winding of T2 are tapped at a known fixed ratio, the standard and the unknown impedances must have the same ratio if the currents through them are to produce equal and opposite ampere-turns at balance.

This ratio is 9:1, obtained by tapping both the voltage and current transformers.

The resistive component of the unknown impedance is balanced by means of decade resistors (R in Fig. 1A). The two subsidiary balance controls (C' and r') are used to balance the bridge at any frequency with the main dials (C and R) set to zero.

## INTERNAL STANDARDS

The standard of capacitance is a 60 pF variable capacitor shunted by a 4 pF vernier capacitor, both designed to have minimum series inductance.

The fixed capacitance between the two 'Unknown' terminal mounting strips is so adjusted that, with the terminals free, the bridge is balanced with the standard capacitors half engaged. This gives a range of positive and negative capacitance values about the balance point.

The susceptance (B) can be derived from the expression:

$$B = 2\pi fC$$

The standard of conductance consists of miniature high-stability resistors of special design made up into two decade drums, providing tens and units. A potentiometer provides continuous fine coverage for a range of at least 0 to 1 millimho.

## THREE-TERMINAL MEASUREMENTS

In many situations, three-terminal measurements can be made to the same high accuracy as two-terminal measurements, even at the upper freq-uencies, without the need for applying any special corrections. An Appendix describes procedures for minimising any errors arising when the total loading on the bridge (Unknown plus associated shunt admittances) cannot be ignored.

# SETTING UP THE BRIDGE

## SOURCE AND DETECTOR

A suitable source is an oscillator or signal generator capable of providing approximately 1 V r. m. s. into a load of 50-100 ohms.

A standard Communications Receiver is suitable for a detector, provided that its sensitivity does not fall below 5 microvolts at 100 Mc/s. It is important that no direct coupling takes place between the source and the detector (see SCREENING below).

Suitable sources and detectors can be supplied by Wayne Kerr Laboratories. Source S161B covers the range 5 to 100 Mc/s in three bands:

5-13 Mc/s, 13-37 Mc/s and 37-100 Mc/s.

The output is amplitude-modulated at a nominal frequency of 1000 c/s. An output level control is fitted. Detector R161 has the same coverage and incorporates a sensitivity control. It is intended for use with headphones. Both instruments include power packs for operation from a. c. supplies.

## SCREENING

Unless the screening of the source and detector is extremely good, errors in measurement will be caused by direct radiation, particularly between the unknown and the input to the receiver.

Any signal so radiated will be picked up by the receiver and, unless cancelled by an equal anti-phase signal from the bridge, the latter will be off balance at the true null point.

As it is difficult to screen the unknown adequately, particular care should be taken with the input to the detector.

The amount of radiation can be checked when the bridge is connected to the source and detector by withdrawing the detector plug from the bridge and turning it so that the inner conductor is screened while the outer shell of the plug is touching the outer rim of the socket. This breaks the receiver circuit but leaves the screening of the cables intact. Under these conditions the signal picked up should be negligible when the receiver sensitivity is at maximum.

## CONNECTION TO TERMINALS

For measuring components and balanced admittances, the 'Unknown' is connected across the block terminals A and B with the Ground terminal and Neutral block left free.

For measuring unbalanced admittances, the Ground terminal and the block terminal nearest the front panel are connected together by means of the plate provided. Errors in measurement may occur if other means of grounding are adopted.

The Ground connection can be extended to either end of the measurement blocks by means of the L-shaped strap provided.

Fig. 2 shows the internal connection of the neutral terminal of the B801B Bridge. 'A' 'B' and 'N' are the normal block terminals.

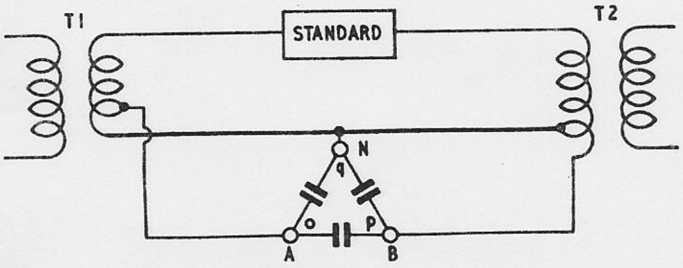



FIG. 2

If a three-terminal capacitance is connected as shown in the figure, the capacitances o-q and p-q are effectively in shunt across the transformer windings and do not affect the Bridge at balance.

When a component is connected to the Bridge with screened leads of appreciable length, the screens can be connected together and to the neutral block. If the series impedance of the leads can be neglected, the only effective impedance is that of the unknown.

The effective series inductance to the block terminals is in the order of 1 mμH for the A block and 0·5 mμH for the B block and for the neutral block.

Direct currents of up to 250 mA can be passed into the bridge, through the block terminals, without damage. This current should not be passed for more than 30 minutes on any one occasion.

The standard Terminal Block Adaptor supplied with the Bridge is type TBA1. This has the upper faces of the A and B blocks inclined at an angle to one another. This Adaptor is detachable and a flat-topped block assembly (TBA2) can be substituted. The flat construction is more convenient for certain types of measurement. Neither type should be fitted when Transistor Adaptor Q801A is to be used.

## MEASUREMENT PROCEDURE

### INITIAL TRIMMING

1 Connect Source and Detector and tune both to the desired measurement frequency.

2 Remove any components connected to the measurement terminals and set all G and C dials at zero.

3 If the Unknown is unbalanced, connect the front block terminal to ground, using the plate provided.

4 Increase source output level, and detector sensitivity, slowly from zero until a moderately loud tone is obtained on the headphones (or mid-scale

deflection if a meter indicator is used).

5 Adjust the two TRIM controls for minimum detector output. As the final null point is approached, the source output level and detector sensitivity should be increased.

6 In some circumstances there may be a tendency for the Bridge to 'pull' the tuning of the source off frequency. The correct tuning is obtained by re-adjusting the source frequency for maximum output from the detector.

7 Whenever the measurement frequency is changed, the Bridge must be re-trimmed.

## MEASUREMENT OF R AND C

Connect the component to be measured between the A and B block terminals and adjust the main G and C dials for minimum detector output. As with the Initial Trimming, it is good practise to slowly increase the source output level and detector sensitivity, from minimum, as balance is approached. If this procedure is not adopted overloading may occur, producing false null positions. Once the bridge is balanced, the dials give a direct reading of the unknown in terms of the equivalent parallel components of conductance and capacitance. The conductance dials are direct-reading and independent of frequency, and the parallel resistance value is given by $1/G$ where G is the bridge reading.

The susceptance value can be derived from the capacitance reading on the main dial at the frequency of measurement ($B = 2\pi fC$).

Expressions for converting the parallel components into the equivalent series circuit are shown in a later section.

The vernier capacity control is provided to permit interpolation between the calibrated points on the main capacity dial. For maximum accuracy, use of the vernier control should be restricted to this function.

## MEASUREMENT OF R AND L

The bridge measures values of R and L as a parallel combination of G and negative C, i. e. the value of negative capacitance which has the same reactance as the unknown inductance at the frequency of measurement.

In order to derive the value of inductance, the source frequency must be known. The accuracy of inductance measurements is dependent on the accuracy of measurement of the source frequency.

The measurement procedure is the same as that for the measurement of R and C. The G scale is independent of frequency, and the value of L is calculated as follows from the expression $L = 1/(\omega^2 C)$.

## EQUIVALENT SERIES CIRCUIT

If the constants of the unknown are required in terms of equivalent series components, they can be calculated from the relationships:

$$R_s = 1/[G(1 + Q^2)] \qquad [Q = 2\pi f C/G]$$

$$C_s = C[1 + (1/Q^2)]$$

$$L_s = -1/[\omega^2 C(1 + 1/Q^2)]$$

$$X_s = X/[1 + (1/Q^2)]$$

where G and C are the values of the parallel components obtained from the bridge main dials.

If $Q >> 1$:

$$R_s \simeq 1/Q^2 G \qquad C_s \simeq C \qquad L_s \simeq 1/(\omega^2 C) \qquad X_s \simeq X$$

If $Q << 1$:

$$R_s \simeq 1/G \qquad C_s \simeq C/Q^2 \qquad L_s \simeq Q^2/(\omega^2 C) \qquad X_s \simeq Q^2 X$$

## MEASUREMENT OF DIELECTRIC LOSS

Losses can be measured with the aid of an external air-dielectric capacitor by the substitution method and, by making use of the neutral terminal in conjunction with a three-terminal capacitor, a virtually lossless capacitor can be obtained on the bridge.

When measuring a capacitor with a very low dielectric loss, the bridge may not balance at the high frequency extreme owing to the loss on the standard side exceeding that on the 'Unknown' side. If an exact balance is required for comparison purposes, it is permissible to obtain it by means of the 'Trim G' control, which increases the loss on the Unknown side without affecting the capacitance.

## MEASUREMENT OF TRANSMISSION LINES AND AERIALS

The bridge will measure accurately the admittance of all transmission lines and aerials, whether unbalanced or balanced. The procedure is the same as that described earlier but particular care must be taken to ensure that the detector is thoroughly screened from the aerial or cable under test.

# MEASUREMENT TECHNIQUE

## PULLING OF SOURCE

The frequency of the oscillator source should be adjusted to suit the frequency to which the receiver is tuned. As the balance point is approached, there is a tendency for the bridge to 'pull' the frequency of the oscillator off tune, and this pulling may be sufficient to give a false indication of balance due to loss of signal.

It is essential to retune the source when approaching balance whenever a measurement is made.

## GROUNDING

The source, detector and bridge should be well connected to a common ground point, and if unreliable results are suspected the ground connection should first be examined.

The units should be mounted in such a way that they are not subject to any movement during the measurement, and should preferably be in the same plane. If this is not practicable, the Unknown should be connected as rigidly as possible to the terminals of the bridge and its position should not be allowed to vary during the test.

## CALIBRATION

The bridges are carefully adjusted laboratory instruments and are not proof against rough handling or hard mechanical shock. If the calibration is suspected after mishandling it can be checked by measuring a known standard.

# APPENDIX

## ANALYSIS OF PERFORMANCE FOR 3-TERMINAL MEASUREMENTS

The basic operation of the Bridge is illustrated in fig. 3.

$Y_s$ = Calibrated Standard Admittance

$Y_u$ = Unknown Admittance to be measured

$I_s$ = Current in the Standard Arm - $EY_s$

$I_u$ = Current in the Unknown Arm - $EY_u$

$N_s$ $N_u$ = Turns on Current Transformer

The senses of the Standard and Unknown windings in the Current Transformer are arranged in opposition.

When $I_s N_s = I_u N_u$ then the net flux $\phi = 0$

and $E Y_s N_s = E Y_u N_u$

$$Y_s N_s = Y_u N_u$$

$$Y_u = \frac{Y_s N_s}{N_u} = Y_s \text{ if } N_s = N_u$$

This is called the 'balance' or 'null' condition. In practise both the Current and Voltage Transformers are tapped to suit the Bridge design and admittance range to be covered.

In fig. 4 the transformers are considered 'ideal' and $Z_{ES}$, $Z_{EU}$, $Z_{IS}$, $Z_{IU}$, represent the effective series impedances of the transformer windings and the Bridge layout.

Admittances $Y_{FS}$ and $Y_{FU}$ represent the permanent admittances in the Bridge network.

1 Two-Terminal Conditions

Balance equation becomes:

$$\frac{E \times 3}{Z_{ES} + Z_{IS} + (Y_{FS} + Y_S)^{-1}} = \frac{E \times {}^1/_3}{Z_{EU} + Z_{IU} + (Y_{FU} + Y_U)^{-1}}$$

whence $Y_U = 9[(Z_{ES} + Z_{IS}) - 9(Z_{EU} + Z_{IU}) + (Y_{FS} + Y_S)^{-1}]^{-1} - Y_{FU}$

N. B. The Bridge indication at balance $Y_M = 9Y_S$

Therefore for no error $Y_U = Y_M = 9Y_S$

By design $(Z_{ES} + Z_{IS}) = 9(Z_{EU} + Z_{IU})$

$\therefore \; Y_U = 9Y_S + 9Y_{FS} - Y_{FU}$

Also the term $(9Y_{FS} - Y_{FU})$ is made equal to zero by zero trimming the Bridge before connecting $Y_U$.

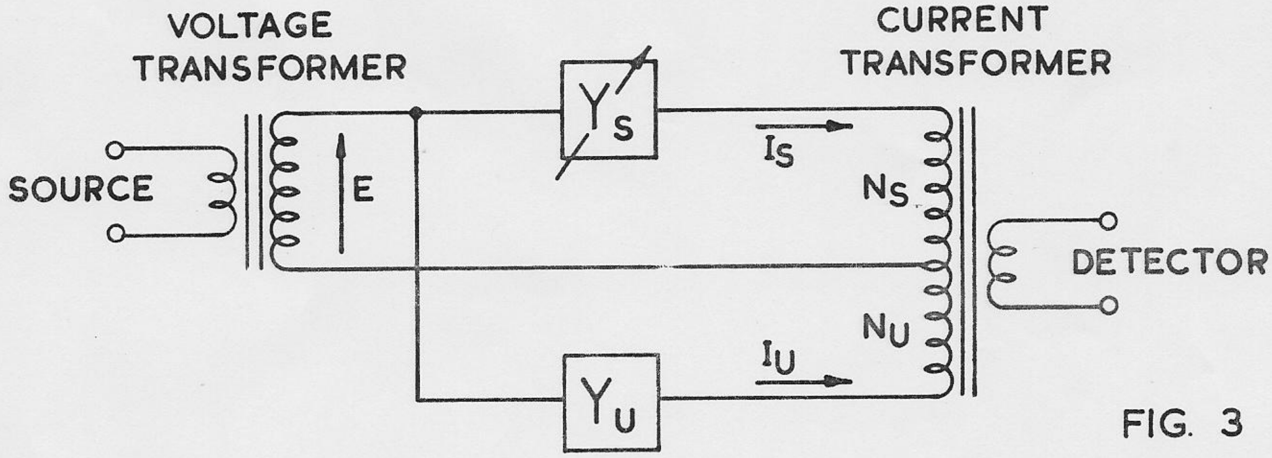



FIG. 3

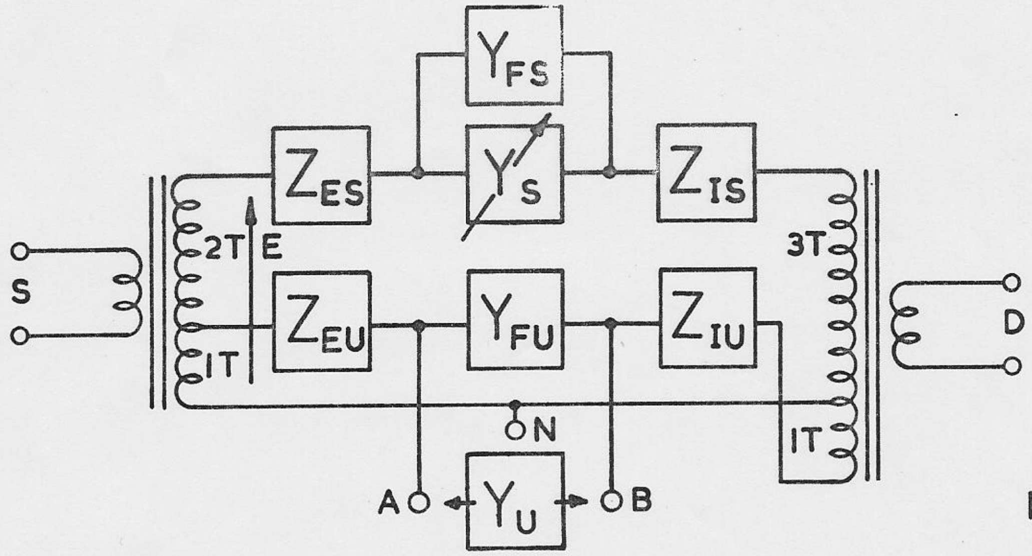



FIG. 4

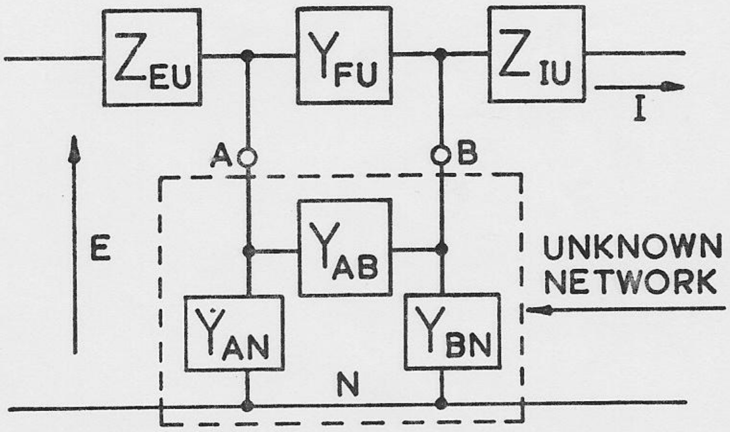



FIG. 5

Therefore $Y_U = 9Y_S = Y_M$

## 2 Three-Terminal Conditions

When measuring a transfer admittance the reasoning in 1 above still applies but in addition errors arise due to the loading to neutral presented by the unknown network. For convenience in analysis consider the unknown network as a 'π' equivalent (see fig. 5).

The transfer admittance required is $Y_{AB}$

Providing $Z_{EU} << 1/Y_{AN}$, and $Z_{IU} << 1/Y_{BN}$

$$\frac{I}{E} = Y_M = (Y_{AB} + Y_{FU})[1-(Z_{EU}\,Y_{AN} + Z_{IU}\,Y_{BN})]$$

$$\therefore\ Y_M = Y_{AB} + Y_{FU} - Y_{AB}(Z_{EU}\,Y_{AN} + Z_{IU}\,Y_{BN}) - Y_{FU}(Z_{EU}\,Y_{AN} + Z_{IU}\,Y_{BN})$$

The admittance $Y_{FU}$ is eliminated from the balance equation by trimming the Bridge for zero with the unknown network not in circuit.

Hence $Y_{AB} = Y_M + \underbrace{Y_{AB}(Z_{EU}\,Y_{AN} + Z_{IU}\,Y_{BN})}_{\text{REGULATION ERROR}} + \underbrace{Y_{FU}(Z_{EU}\,Y_{AN} + Z_{IU}\,Y_{BN})}_{\text{DISTURBANCE ERROR}}$

% Regulation Error $= (Z_{EU}\,Y_{AN} + Z_{IU}\,Y_{BN}).\,100.$

% Disturbance Error $= (Z_{EU}\,Y_{AN} + Z_{IU}\,Y_{BN}).\,\dfrac{Y_{FU}}{Y_{AB}}\,.\,100$

A typical Bridge has:-

$Z_{EU}$ = inductive reactance due to 1·2mμH = j 0·75Ω at 100 Mc/s

$Z_{IU}$ = " " " " 0·5 " = j 0·31Ω at 100 Mc/s

$Y_{FU}$ = capacitive susceptance due to 600pF = j 0·265 at 100 Mc/s

∴ % Regulation Error per m. mho loading AN $= \dfrac{0{\cdot}75}{1000} \times 100 = {\cdot}075\%$

" " " " " BN $= \dfrac{0{\cdot}31}{1000} \times 100 = {\cdot}031\%$

Hence, <u>for 20 mmho loading at 100 Mc/s errors <2%</u>

Disturbance error per m. mho loading AN $= \frac{0{\cdot}75}{1000} \times {\cdot}265 \times 10^3$ m. mho

$= \underline{0{\cdot}2 \text{ m. mho}}$

Disturbance error per m. mho loading BN $= \frac{0{\cdot}31}{1000} \times {\cdot}265 \times 10^3$ m. mho

$= \underline{0{\cdot}082 \text{ m. mho}}$

N. B. Magnitude only has been considered. The quadrant of the error vector will depend on the nature of the loading.

Conclusions

Although not designed primarily for 3-terminal measurements, the B801B can be used in this manner for many applications. For example, the Transistor Adaptor Q801A permits accurate values to be obtained with common emitter and common base configurations and in the presence of d. c. supply components.

For most measurements the regulation error may be ignored since loading to neutral in excess of 20 m. mho is unusual at 100 Mc/s.

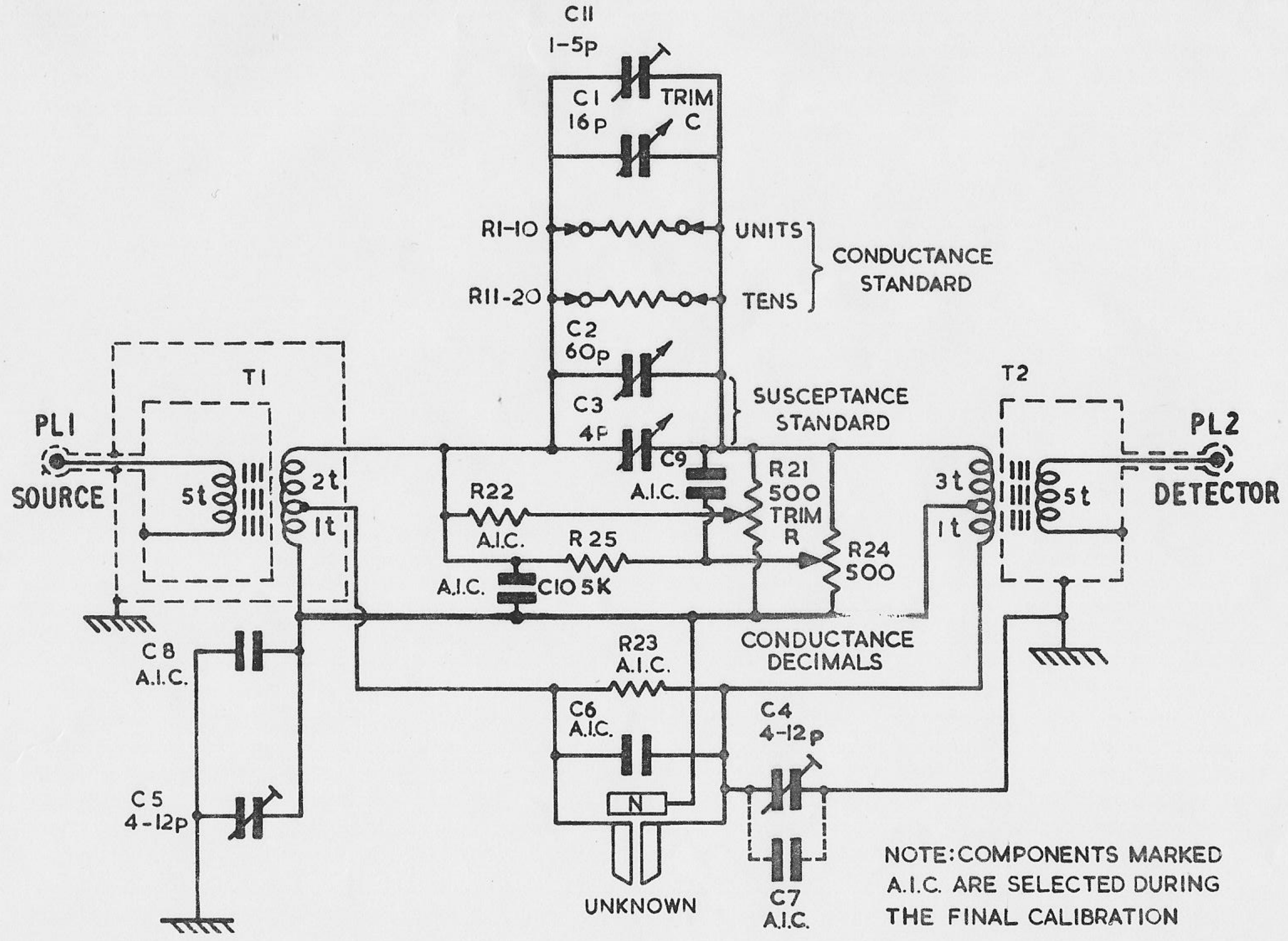
The Disturbance Error is the more important limitation particularly when the ratio $\frac{Y_{FU}}{Y_{AB}}$ is large and in the presence of a high loading admittance. However, Disturbance Errors can often by eliminated by balancing the Bridge for initial trim with the loading $Y_{AN}$ and $Y_{BN}$ present but $Y_{AB}$ removed.

## COMPONENTS LIST

| | | |
|---|---|---|
| C 1 | 16 pF | Air Dielectric Trimmer |
| C 2 | 60 pF | Internal Standard WKL Dwg. CWP. 3110 |
| C 3 | 4 pF | Air Dielectric Trimmer |
| C 4 | 12 pF | " " " |
| C 5 | 12 pF | " " " |
| C 6 | 5-50pF | Adjusted in Test |
| C 7 | 5-20pF | " " |
| C 8 | 5-20pF | " " |
| C 9 | A I C | |
| C10 | A I C | |
| C11 | 1-5 pF | |

| | Ohms | |
|---|---|---|
| R 1 | | Dummy Resistor |
| R 2 | 9000 | |
| R 3 | 4500 | |
| R 4 | 3000 | |
| R 5 | 2250 | |
| R 6 | 1800 | + 0 - 1 per cent 1/8 W. H. S. Carbon |
| R 7 | 1500 | |
| R 8 | 1286 | |
| R 9 | 1125 | |
| R10 | 1000 | |
| R11 | | Dummy Resistor |
| R12 | 900 | |
| R13 | 450 | |
| R14 | 300 | |
| R15 | 225 | |
| R16 | 180 | + 0 - 1 per cent 1/8 W. H. S. Carbon |
| R17 | 150 | |
| R18 | 129 | |
| R19 | 112·5 | |
| R20 | 100 | |
| R21 | 500 | ± 20 per cent 1/4 W. Carbon Linear |
| R22 | | ± 20 per cent 1/4 W. Carbon Adjusted in Test |
| R23 | | ± 20 per cent 1/4 W. Carbon Adjusted in Test |
| R24 | 500 | ± 20 per cent 1/4 W. Carbon Linear |
| R25 | 5000 | ± 5 per cent 1/8 W. H. S. Carbon |

| | |
|---|---|
| T 1 | Input Transformer to WKL. Dwg. CWP. 1187 |
| T 2 | Output " to WKL. Dwg. CWP. 1188 |




NOTE: COMPONENTS MARKED A.I.C. ARE SELECTED DURING THE FINAL CALIBRATION

**V.H.F. ADMITTANCE BRIDGE B801 B**
(DRG. D11076/B)

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1·0 | 1·00000 | 99010 | 98039 | 97087 | 96154 | 95238 | 94340 | 93458 | 92593 | 91743 |
| 1·1 | 90909 | 90090 | 89286 | 88496 | 87719 | 86957 | 86207 | 85470 | 84746 | 84034 |
| 1·2 | 83333 | 82645 | 81967 | 81301 | 80645 | 80000 | 79365 | 78740 | 78125 | 77519 |
| 1·3 | 76923 | 76336 | 75758 | 75188 | 74627 | 74074 | 73529 | 72993 | 72464 | 71942 |
| 1·4 | 71429 | 70922 | 70423 | 69930 | 69444 | 68966 | 68493 | 68027 | 67568 | 67114 |
| 1·5 | 66667 | 66225 | 65789 | 65359 | 64935 | 64516 | 64103 | 63694 | 63291 | 62893 |
| 1·6 | 62500 | 62112 | 61728 | 61350 | 60976 | 60606 | 60241 | 59880 | 59524 | 59172 |
| 1·7 | 58824 | 58480 | 58140 | 57803 | 57471 | 57143 | 56818 | 56497 | 56180 | 55866 |
| 1·8 | 55556 | 55249 | 54945 | 54645 | 54348 | 54054 | 53763 | 53476 | 53191 | 52910 |
| 1·9 | 52632 | 52356 | 52083 | 51813 | 51546 | 51282 | 51020 | 50761 | 50505 | 50251 |
| 2·0 | 50000 | 49751 | 49505 | 49261 | 49020 | 48780 | 48544 | 48309 | 48077 | 47847 |
| 2·1 | 47619 | 47393 | 47170 | 46948 | 46729 | 46512 | 46296 | 46083 | 45872 | 45662 |
| 2·2 | 45455 | 45249 | 45045 | 44843 | 44643 | 44444 | 44248 | 44053 | 43860 | 43668 |
| 2·3 | 43478 | 43290 | 43103 | 42918 | 42735 | 42553 | 42373 | 42194 | 42017 | 41841 |
| 2·4 | 41667 | 41494 | 41322 | 41152 | 40984 | 40816 | 40650 | 40486 | 40323 | 40161 |
| 2·5 | 40000 | 39841 | 39683 | 39526 | 39370 | 39216 | 39063 | 38911 | 38760 | 38610 |
| 2·6 | 38462 | 38314 | 38168 | 38023 | 37879 | 37736 | 37594 | 37453 | 37313 | 37175 |
| 2·7 | 37037 | 36900 | 36765 | 36630 | 36496 | 36364 | 36232 | 36101 | 35971 | 35842 |
| 2·8 | 35714 | 35587 | 35461 | 35336 | 35211 | 35088 | 34965 | 34843 | 34722 | 34602 |
| 2·9 | 34483 | 34364 | 34247 | 34130 | 34014 | 33898 | 33784 | 33670 | 33557 | 33445 |
| 3·0 | 33333 | 33223 | 33113 | 33003 | 32895 | 32787 | 32680 | 32573 | 32468 | 32362 |
| 3·1 | 32258 | 32154 | 32051 | 31949 | 31847 | 31746 | 31646 | 31546 | 31447 | 31348 |
| 3·2 | 31250 | 31153 | 31056 | 30960 | 30864 | 30769 | 30675 | 30581 | 30488 | 30395 |
| 3·3 | 30303 | 30211 | 30120 | 30030 | 29940 | 29851 | 29762 | 29674 | 29586 | 29499 |
| 3·4 | 29412 | 29326 | 29240 | 29155 | 29070 | 28986 | 28902 | 28818 | 28736 | 28653 |
| 3·5 | 28571 | 28490 | 28409 | 28329 | 28249 | 28169 | 28090 | 28011 | 27933 | 27855 |
| 3·6 | 27778 | 27701 | 27624 | 27548 | 27473 | 27397 | 27322 | 27248 | 27174 | 27100 |
| 3·7 | 27027 | 26954 | 26882 | 26810 | 26738 | 26667 | 26596 | 26525 | 26455 | 26385 |
| 3·8 | 26316 | 26247 | 26178 | 26110 | 26042 | 25974 | 25907 | 25840 | 25773 | 25707 |
| 3·9 | 25641 | 25575 | 25510 | 25445 | 25381 | 25316 | 25253 | 25189 | 25126 | 25063 |
| 4·0 | 25000 | 24938 | 24876 | 24814 | 24752 | 24691 | 24631 | 24570 | 24510 | 24450 |
| 4·1 | 24390 | 24331 | 24272 | 24213 | 24155 | 24096 | 24038 | 23981 | 23923 | 23866 |
| 4·2 | 23810 | 23753 | 23697 | 23641 | 23585 | 23529 | 23474 | 23419 | 23364 | 23310 |
| 4·3 | 23256 | 23202 | 23148 | 23095 | 23041 | 22989 | 22936 | 22883 | 22831 | 22779 |
| 4·4 | 22727 | 22676 | 22624 | 22573 | 22523 | 22472 | 22422 | 22371 | 22321 | 22272 |
| 4·5 | 22222 | 22173 | 22124 | 22075 | 22026 | 21978 | 21930 | 21882 | 21834 | 21786 |
| 4·6 | 21739 | 21692 | 21645 | 21598 | 21552 | 21505 | 21459 | 21413 | 21368 | 21322 |
| 4·7 | 21277 | 21231 | 21186 | 21142 | 21097 | 21053 | 21008 | 20964 | 20921 | 20877 |
| 4·8 | 20833 | 20790 | 20747 | 20704 | 20661 | 20619 | 20576 | 20534 | 20492 | 20450 |
| 4·9 | 20408 | 20367 | 20325 | 20284 | 20243 | 20202 | 20161 | 20121 | 20080 | 20040 |
| 5·0 | 20000 | 19960 | 19920 | 19881 | 19841 | 19802 | 19763 | 19724 | 19685 | 19646 |
| 5·1 | 19608 | 19569 | 19531 | 19493 | 19455 | 19417 | 19380 | 19342 | 19305 | 19268 |
| 5·2 | 19231 | 19194 | 19157 | 19120 | 19084 | 19048 | 19011 | 18975 | 18939 | 18904 |
| 5·3 | 18868 | 18832 | 18797 | 18762 | 18727 | 18692 | 18657 | 18622 | 18587 | 18553 |
| 5·4 | 18519 | 18484 | 18450 | 18416 | 18382 | 18349 | 18315 | 18282 | 18248 | 18215 |
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

PROPORTIONAL PARTS OF MEAN DIFFERENCES

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1·0 | | | | | | | | | |
| 1·1 | | | | | | | | | |
| 1·2 | | | | | | | | | |
| 1·3 | | | | | | | | | |
| 1·4 | | | | | | | | | |
| 1·5 | 42 | 83 | 125 | 167 | 209 | 250 | 292 | 334 | 375 |
| 1·6 | 37 | 74 | 110 | 147 | 184 | 221 | 258 | 294 | 331 |
| 1·7 | 33 | 65 | 98 | 131 | 164 | 196 | 229 | 262 | 294 |
| 1·8 | 29 | 58 | 88 | 117 | 146 | 175 | 204 | 234 | 263 |
| 1·9 | 26 | 53 | 79 | 105 | 132 | 158 | 184 | 210 | 237 |
| 2·0 | 24 | 48 | 71 | 95 | 119 | 143 | 167 | 190 | 214 |
| 2·1 | 22 | 43 | 65 | 86 | 108 | 130 | 151 | 173 | 194 |
| 2·2 | 20 | 40 | 59 | 79 | 99 | 119 | 139 | 158 | 178 |
| 2·3 | 18 | 36 | 54 | 72 | 91 | 109 | 127 | 145 | 163 |
| 2·4 | 17 | 33 | 50 | 67 | 84 | 100 | 117 | 134 | 150 |
| 2·5 | 15 | 31 | 46 | 62 | 77 | 92 | 108 | 123 | 139 |
| 2·6 | 14 | 29 | 43 | 57 | 72 | 86 | 100 | 114 | 129 |
| 2·7 | 13 | 26 | 40 | 53 | 66 | 79 | 92 | 106 | 119 |
| 2·8 | 12 | 25 | 37 | 49 | 62 | 74 | 86 | 98 | 111 |
| 2·9 | 12 | 23 | 35 | 46 | 58 | 69 | 81 | 92 | 104 |
| 3·0 | 11 | 22 | 32 | 43 | 54 | 65 | 76 | 86 | 97 |
| 3·1 | 10 | 20 | 30 | 40 | 51 | 61 | 71 | 81 | 91 |
| 3·2 | 10 | 19 | 29 | 38 | 48 | 57 | 67 | 76 | 86 |
| 3·3 | 9 | 18 | 27 | 36 | 45 | 53 | 62 | 71 | 80 |
| 3·4 | 8 | 17 | 25 | 34 | 42 | 50 | 59 | 67 | 76 |
| 3·5 | 8 | 16 | 24 | 32 | 40 | 47 | 55 | 63 | 71 |
| 3·6 | 8 | 15 | 23 | 30 | 38 | 45 | 53 | 60 | 68 |
| 3·7 | 7 | 14 | 21 | 28 | 36 | 43 | 50 | 57 | 64 |
| 3·8 | 7 | 14 | 20 | 27 | 34 | 41 | 48 | 54 | 61 |
| 3·9 | 6 | 13 | 19 | 26 | 32 | 38 | 45 | 51 | 58 |
| 4·0 | 6 | 12 | 18 | 24 | 31 | 37 | 43 | 49 | 55 |
| 4·1 | 6 | 12 | 17 | 23 | 29 | 35 | 41 | 46 | 52 |
| 4·2 | 6 | 11 | 17 | 22 | 28 | 33 | 39 | 44 | 50 |
| 4·3 | 5 | 11 | 16 | 21 | 27 | 32 | 37 | 42 | 48 |
| 4·4 | 5 | 10 | 15 | 20 | 26 | 31 | 36 | 41 | 46 |
| 4·5 | 5 | 10 | 14 | 19 | 24 | 29 | 34 | 38 | 43 |
| 4·6 | 5 | 9 | 14 | 18 | 23 | 28 | 32 | 37 | 41 |
| 4·7 | 4 | 9 | 13 | 18 | 22 | 26 | 31 | 35 | 40 |
| 4·8 | 4 | 9 | 13 | 17 | 22 | 26 | 30 | 34 | 39 |
| 4·9 | 4 | 8 | 12 | 16 | 20 | 25 | 29 | 33 | 37 |
| 5·0 | 4 | 8 | 12 | 16 | 20 | 24 | 27 | 31 | 35 |
| 5·1 | 4 | 8 | 11 | 15 | 19 | 23 | 26 | 30 | 34 |
| 5·2 | 4 | 7 | 11 | 15 | 18 | 22 | 25 | 29 | 33 |
| 5·3 | 3 | 7 | 10 | 14 | 18 | 21 | 24 | 28 | 31 |
| 5·4 | 3 | 7 | 10 | 14 | 17 | 20 | 24 | 27 | 30 |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 5·5 | 18182 | 18149 | 18116 | 18083 | 18051 | 18018 | 17986 | 17953 | 17921 | 17889 |
| 5·6 | 17857 | 17825 | 17794 | 17762 | 17731 | 17699 | 17668 | 17637 | 17606 | 17575 |
| 5·7 | 17544 | 17513 | 17483 | 17452 | 17422 | 17391 | 17361 | 17331 | 17301 | 17271 |
| 5·8 | 17241 | 17212 | 17182 | 17153 | 17123 | 17094 | 17065 | 17036 | 17007 | 16978 |
| 5·9 | 16949 | 16920 | 16892 | 16863 | 16835 | 16807 | 16779 | 16750 | 16722 | 16694 |
| 6·0 | 16667 | 16639 | 16611 | 16584 | 16556 | 16529 | 16502 | 16474 | 16447 | 16420 |
| 6·1 | 16393 | 16367 | 16340 | 16313 | 16287 | 16260 | 16234 | 16207 | 16181 | 16155 |
| 6·2 | 16129 | 16103 | 16077 | 16051 | 16026 | 16000 | 15974 | 15949 | 15924 | 15898 |
| 6·3 | 15873 | 15848 | 15823 | 15798 | 15773 | 15748 | 15723 | 15699 | 15674 | 15649 |
| 6·4 | 15625 | 15601 | 15576 | 15552 | 15528 | 15504 | 15480 | 15456 | 15432 | 15408 |
| 6·5 | 15385 | 15361 | 15337 | 15314 | 15291 | 15267 | 15244 | 15221 | 15198 | 15175 |
| 6·6 | 15152 | 15129 | 15106 | 15083 | 15060 | 15038 | 15015 | 14993 | 14970 | 14948 |
| 6·7 | 14925 | 14903 | 14881 | 14859 | 14837 | 14815 | 14793 | 14771 | 14749 | 14728 |
| 6·8 | 14706 | 14684 | 14663 | 14641 | 14620 | 14599 | 14577 | 14556 | 14535 | 14514 |
| 6·9 | 14493 | 14472 | 14451 | 14430 | 14409 | 14388 | 14368 | 14347 | 14327 | 14306 |
| 7·0 | 14286 | 14265 | 14245 | 14225 | 14205 | 14184 | 14164 | 14144 | 14124 | 14104 |
| 7·1 | 14085 | 14065 | 14045 | 14025 | 14006 | 13986 | 13966 | 13947 | 13928 | 13908 |
| 7·2 | 13889 | 13870 | 13850 | 13831 | 13812 | 13793 | 13774 | 13755 | 13736 | 13717 |
| 7·3 | 13699 | 13680 | 13661 | 13643 | 13624 | 13605 | 13587 | 13569 | 13550 | 13532 |
| 7·4 | 13514 | 13495 | 13477 | 13459 | 13441 | 13423 | 13405 | 13387 | 13369 | 13351 |
| 7·5 | 13333 | 13316 | 13298 | 13280 | 13263 | 13245 | 13228 | 13210 | 13193 | 13175 |
| 7·6 | 13158 | 13141 | 13123 | 13106 | 13089 | 13072 | 13055 | 13038 | 13021 | 13004 |
| 7·7 | 12987 | 12970 | 12953 | 12937 | 12920 | 12903 | 12887 | 12870 | 12853 | 12837 |
| 7·8 | 12821 | 12804 | 12788 | 12771 | 12755 | 12739 | 12723 | 12706 | 12690 | 12674 |
| 7·9 | 12658 | 12642 | 12626 | 12610 | 12594 | 12579 | 12563 | 12547 | 12531 | 12516 |
| 8·0 | 12500 | 12484 | 12469 | 12453 | 12438 | 12422 | 12407 | 12392 | 12376 | 12361 |
| 8·1 | 12346 | 12330 | 12315 | 12300 | 12285 | 12270 | 12255 | 12240 | 12225 | 12210 |
| 8·2 | 12195 | 12180 | 12165 | 12151 | 12136 | 12121 | 12107 | 12092 | 12077 | 12063 |
| 8·3 | 12048 | 12034 | 12019 | 12005 | 11990 | 11976 | 11962 | 11947 | 11933 | 11919 |
| 8·4 | 11905 | 11891 | 11876 | 11862 | 11848 | 11834 | 11820 | 11806 | 11792 | 11779 |
| 8·5 | 11765 | 11751 | 11737 | 11723 | 11710 | 11696 | 11682 | 11669 | 11655 | 11641 |
| 8·6 | 11628 | 11614 | 11601 | 11587 | 11574 | 11561 | 11547 | 11534 | 11521 | 11507 |
| 8·7 | 11494 | 11481 | 11468 | 11455 | 11442 | 11429 | 11416 | 11403 | 11390 | 11377 |
| 8·8 | 11364 | 11351 | 11338 | 11325 | 11312 | 11299 | 11287 | 11274 | 11261 | 11249 |
| 8·9 | 11236 | 11223 | 11211 | 11198 | 11186 | 11173 | 11161 | 11148 | 11136 | 11123 |
| 9·0 | 11111 | 11099 | 11086 | 11074 | 11062 | 11050 | 11038 | 11025 | 11013 | 11001 |
| 9·1 | 10989 | 10977 | 10965 | 10953 | 10941 | 10929 | 10917 | 10905 | 10893 | 10881 |
| 9·2 | 10870 | 10858 | 10846 | 10834 | 10823 | 10811 | 10799 | 10787 | 10776 | 10764 |
| 9·3 | 10753 | 10741 | 10730 | 10718 | 10707 | 10695 | 10684 | 10672 | 10661 | 10650 |
| 9·4 | 10638 | 10627 | 10616 | 10604 | 10593 | 10582 | 10571 | 10560 | 10549 | 10537 |
| 9·5 | 10526 | 10515 | 10504 | 10493 | 10482 | 10471 | 10460 | 10449 | 10438 | 10428 |
| 9·6 | 10417 | 10406 | 10395 | 10384 | 10373 | 10363 | 10352 | 10341 | 10331 | 10320 |
| 9·7 | 10309 | 10299 | 10288 | 10277 | 10267 | 10256 | 10246 | 10235 | 10225 | 10215 |
| 9·8 | 10204 | 10194 | 10183 | 10173 | 10163 | 10152 | 10142 | 10132 | 10121 | 10111 |
| 9·9 | 10101 | 10091 | 10081 | 10070 | 10060 | 10050 | 10040 | 10030 | 10020 | 10010 |
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 5·5 | 3 | 7 | 10 | 13 | 16 | 20 | 23 | 26 | 29 |
| 5·6 | 3 | 6 | 9 | 13 | 16 | 19 | 22 | 25 | 28 |
| 5·7 | 3 | 6 | 9 | 12 | 15 | 18 | 21 | 24 | 27 |
| 5·8 | 3 | 6 | 9 | 12 | 15 | 18 | 20 | 23 | 26 |
| 5·9 | 3 | 6 | 9 | 11 | 14 | 17 | 20 | 23 | 25 |
| 6·0 | 3 | 6 | 8 | 11 | 14 | 16 | 19 | 22 | 25 |
| 6·1 | 3 | 5 | 8 | 11 | 13 | 16 | 19 | 21 | 24 |
| 6·2 | 3 | 5 | 8 | 10 | 13 | 15 | 18 | 21 | 23 |
| 6·3 | 2 | 5 | 7 | 10 | 12 | 15 | 17 | 20 | 22 |
| 6·4 | 2 | 5 | 7 | 10 | 12 | 14 | 17 | 19 | 22 |
| 6·5 | 2 | 5 | 7 | 9 | 12 | 14 | 16 | 19 | 21 |
| 6·6 | 2 | 5 | 7 | 9 | 11 | 14 | 16 | 18 | 20 |
| 6·7 | 2 | 4 | 7 | 9 | 11 | 13 | 15 | 18 | 20 |
| 6·8 | 2 | 4 | 6 | 9 | 11 | 13 | 15 | 17 | 19 |
| 6·9 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 17 | 19 |
| 7·0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 |
| 7·1 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 |
| 7·2 | 2 | 4 | 6 | 8 | 10 | 11 | 13 | 15 | 17 |
| 7·3 | 2 | 4 | 6 | 7 | 9 | 11 | 13 | 15 | 17 |
| 7·4 | 2 | 4 | 5 | 7 | 9 | 11 | 13 | 15 | 16 |
| 7·5 | 2 | 4 | 5 | 7 | 9 | 11 | 12 | 14 | 16 |
| 7·6 | 2 | 3 | 5 | 7 | 9 | 10 | 12 | 14 | 15 |
| 7·7 | 2 | 3 | 5 | 7 | 8 | 10 | 12 | 13 | 15 |
| 7·8 | 2 | 3 | 5 | 7 | 8 | 10 | 11 | 13 | 15 |
| 7·9 | 2 | 3 | 5 | 6 | 8 | 9 | 11 | 13 | 14 |
| 8·0 | 2 | 3 | 5 | 6 | 8 | 9 | 11 | 12 | 14 |
| 8·1 | 2 | 3 | 5 | 6 | 8 | 9 | 11 | 12 | 14 |
| 8·2 | 1 | 3 | 4 | 6 | 7 | 9 | 10 | 12 | 13 |
| 8·3 | 1 | 3 | 4 | 6 | 7 | 9 | 10 | 11 | 13 |
| 8·4 | 1 | 3 | 4 | 6 | 7 | 8 | 10 | 11 | 13 |
| 8·5 | 1 | 3 | 4 | 5 | 7 | 8 | 10 | 11 | 12 |
| 8·6 | 1 | 3 | 4 | 5 | 7 | 8 | 9 | 11 | 12 |
| 8·7 | 1 | 3 | 4 | 5 | 7 | 8 | 9 | 10 | 12 |
| 8·8 | 1 | 3 | 4 | 5 | 6 | 8 | 9 | 10 | 12 |
| 8·9 | 1 | 3 | 4 | 5 | 6 | 8 | 9 | 10 | 11 |
| 9·0 | 1 | 2 | 4 | 5 | 6 | 7 | 9 | 10 | 11 |
| 9·1 | 1 | 2 | 4 | 5 | 6 | 7 | 8 | 10 | 11 |
| 9·2 | 1 | 2 | 4 | 5 | 6 | 7 | 8 | 9 | 11 |
| 9·3 | 1 | 2 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 9·4 | 1 | 2 | 3 | 4 | 6 | 7 | 8 | 9 | 10 |
| 9·5 | 1 | 2 | 3 | 4 | 5 | 7 | 8 | 9 | 10 |
| 9·6 | 1 | 2 | 3 | 4 | 5 | 6 | 8 | 9 | 10 |
| 9·7 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 10 |
| 9·8 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 9·9 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |