Function Generator:

It generates different shape waveforms with adjustable frequency (From a few Hz to several 100 KHz) and amplitude. Usual outputs are Sine, Square, Triangular and Sawtooth waves, all of which can be simultaneously made available.

Square wave can be used to test the linearity of an amplifier, while the sawtooth can be used to connect to the horizontal deflection amplifier of CRO.

The function generator can be phase locked to an external source to its fundamental or harmonics. It can be phase locked to a frequency standard source, in which case the output of the Fn. Gen will have the same accuracy and stability of the standard source.

The block diagram of a function generator is as shown in the following figure.

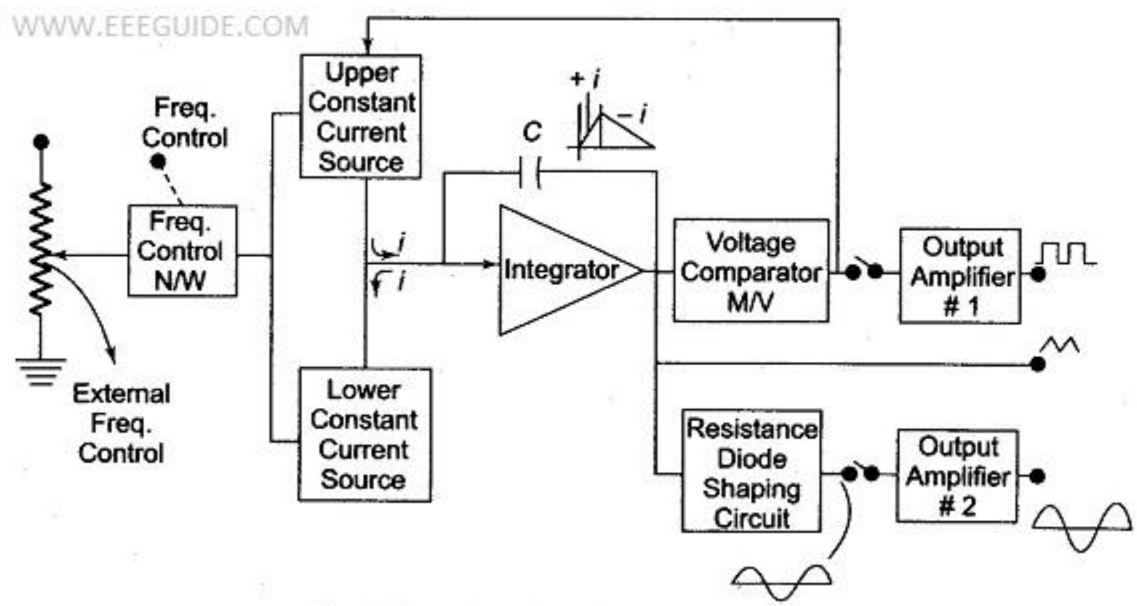

Fig. 8.5 Function Generator

Triangular wave is generated by an integrator. Two constant current sources are used for charging and discharging the capacitor of the integrator. It produces sine, square and triangular waves of frequency in the range of 0.01 Hz to 100 KHz.

The Upper constant current source supplies the charging current. Integrator capacitor charges by this current and its output increases linearly. When the output ramp level reaches a certain fixed level, the Voltage comparator M/V changes its output state and disables the upper source, which switches on the Lower constant current source. Now the capacitor starts discharging through the Lower current source path and the output of the integrator starts decreasing linearly. When the ramp level reaches a lower fixed limit, the Voltage comparator M/V comes back to its original state which switches on the Upper current source. This again starts charging the capacitor and cycle repeats there by producing a Triangular waveform.

The frequency of the triangular waveform can be controlled by charging and discharging currents magnitudes. When the two currents are same, the output of the Voltage comparator M/V is nothing but a Square Wave output of same frequency of triangular waveform.

The triangular voltage is converted to Sine wave of same frequency using a Resistance Diode shaping circuit. As the magnitude of the triangular wave changes, the resistive network changes the slope of the triangular wave to convert it to a sine wave shape.

BRIDGES

Bridges:

- to measure R, L and C values of components
- has four arms with a source of excitation and a current detector (galvanometer)
- one of the arm has the unknown component value

DC Bridges:

(1) **Wheatstone's bridge** – to measure Resistance
(2) **Kelvin's Bridge: -** to measure Resistance of low value

AC bridges:

(i) **Capacitance Comparison Bridge,**
(ii) **Inductance Comparison Bridge,**
(iii) **Maxwell's bridge:** to measure unknown inductance in terms of a known capacitor,
(iv) **Wein's bridge:** to measure frequency and Capacitance with high accuracy,
(v) **Wagner's earth connection:** to eliminate the effects of stray/coupling capacitances in the bridges.

Wheatstone's Bridge:

A Wheatstone bridge may be used to measure the dc resistance of various types of wires. For example, the resistance of motor windings, transformers, solenoids, and relay coils can be measured.

Wheatstone Bridge Circuit is also used extensively by telephone companies and others to locate cable faults. The fault may be two lines shorted together, or a single line shorted to ground.

A Wheatstone Bridge Circuit in its simplest form consists of a network of four resistance arms forming a closed circuit, with a dc source of current applied to two opposite junctions and a current detector connected to the other two junctions, as shown in Fig. 11.1.

The source of emf and switch is connected to points A and B, while a sensitive current indicating meter, the galvanometer, is connected to points C and D. The galvanometer is a sensitive micro ammeter, with a zero centre scale. When there is no current through the meter, the galvanometer pointer rests at 0, i.e. mid scale. Current in one direction causes the pointer to deflect on one side and current in the opposite direction to the other side.

When SW_1 is closed, current flows and divides into the two arms at point A, i.e. I_1 and I_2. The bridge is balanced when there is no current through the galvanometer, or when the potential difference at points C and D is equal, i.e. the potential across the galvanometer is zero.

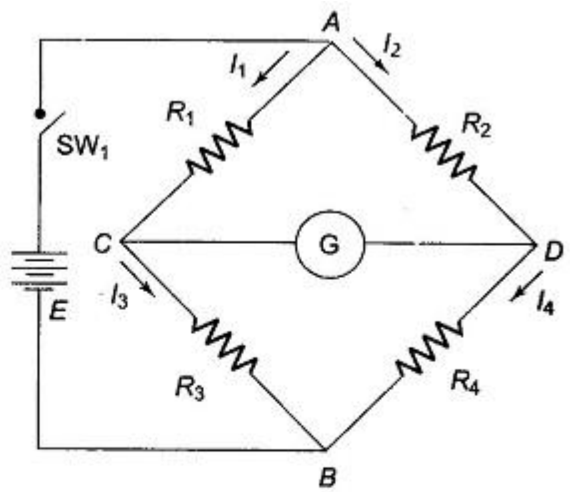

Fig. 11.1 Wheatstone's Bridge

At balance, the voltage between Galavanometer is same. That is, Vc and VD are same.

Hence, $I_1 = I_3$ and $I_2 = I_4$

To obtain the bridge balance equation, we have from the Fig. 11.1.

$$I_1 R_1 = I_2 R_2 \qquad (11.1)$$

For the galvanometer current to be zero, the following conditions should be satisfied.

$$\frac{E \times R_1}{R_1 + R_3} = \frac{E \times R_2}{R_2 + R_4}$$

$$R_1 \times (R_2 + R_4) = (R_1 + R_3) \times R_2$$

$$R_1 R_2 + R_1 R_4 = R_1 R_2 + R_3 R_2$$

$$R_4 = \frac{R_2 R_3}{R_1}$$

This is the equation for the bridge to be balanced.

In a practical Wheatstone Bridge Circuit, at least one of the resistance is made adjustable, to permit balancing. When the bridge is balanced, the unknown resistance (normally connected at R_4) may be determined from the setting of the adjustable resistor, which is called a standard resistor because it is a precision device having very small tolerance.

Hence,

$$R_x = \frac{R_2\ R_3}{R_1} \qquad (11.4)$$

The measurement accuracy is directly related to the accuracy of the bridge component and not to that of the null indicator used.

Sensitivity of a Wheatstone Bridge

When the bridge is in an unbalanced condition, current flows through the galvanometer, causing a deflection of its pointer. The amount of deflection is a function of the sensitivity of the galvanometer.

Sensitivity can be thought of as deflection per unit current. A more sensitive galvanometer deflects by a greater amount for the same current.

Deflection may be expressed in linear or angular units of measure, and sensitivity can be expressed in units of S = mm/µA or degree/µA or radians/µA.

Therefore it follows that the total deflection D is D = S x I, where S is defined above and I is the current in microamperes.

Unbalanced Wheatstone's Bridge

To determine the amount of deflection that would result for a particular degree of unbalance, general circuit analysis can be applied, but we shall use Thevenin's theorem.

Since we are interested in determining the current through the galvanometer, we wish to find the Thevenin's equivalent, as seen by the galvanometer.

Thevenin's equivalent voltage is found by disconnecting the galvanometer from the Wheatstone Bridge Circuit circuit, as shown in Fig. 11.2, and determining the open-circuit voltage between terminals a and b.

Applying the voltage divider equation, the voltage at point a can be determined as follows

$$E_a = \frac{E \times R_3}{R_1 + R_3} \quad \text{and at point } b, \quad E_b = \frac{E \times R_4}{R_2 + R_4}$$

Therefore, the voltage between a and b is the difference between E_a and E_b, which represents

$$E_{th} = E_{ab} = E_a - E_b = \frac{E \times R_3}{R_1 + R_3} - \frac{E \times R_4}{R_2 + R_4}$$

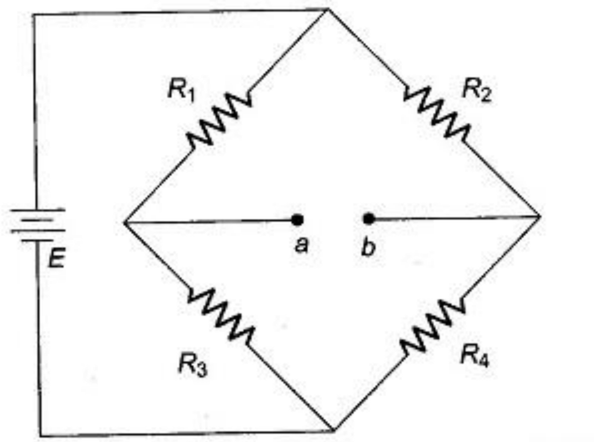

Fig. 11.2 Unbalanced Wheatstone's Bridge

Thevenin's equivalent voltage.

Therefore

$$E_{ab} = E\left(\frac{R_3}{R_1 + R_3} - \frac{R_4}{R_2 + R_4}\right)$$

Thevenin's equivalent resistance can be determined by replacing the voltage source E with its internal impedance or otherwise short-circuited and calculating the resistance looking into terminals a and b. Since the internal resistance is assumed to be very low, we treat it as 0 Ω. Thevenin's equivalent resistance circuit is shown in Fig. 11.3.

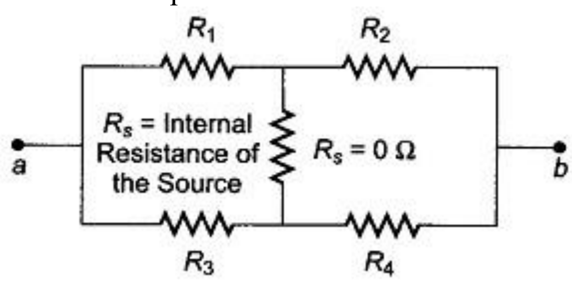

Fig. 11.3 Thévenin's Resistance

The equivalent resistance of the circuit is $R_1//R_3$ in series with $R_2//R_4$ i.e. $R_1//R_3 + R_2//R_4$.

$$R_{th} = \frac{R_1\,R_3}{R_1 + R_3} + \frac{R_2\,R_4}{R_2 + R_4}$$

Therefore, Thevenin's equivalent circuit is given in Fig. 11.4. Thevenin's equivalent circuit for the bridge, as seen looking back at terminals a and b in Fig. 11.2, is shown in Fig. 11.4.

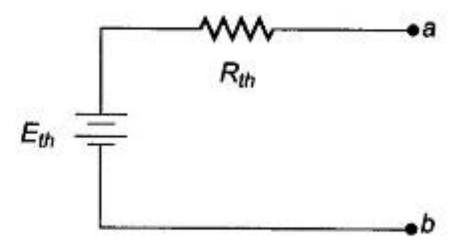

Fig. 11.4 Thévenin's Equivalent

If a galvanometer is connected across the terminals a and b of Fig.11.2, or its Thevenin equivalent Fig. 11.4 it will experience the same deflection at the output of the bridge. The magnitude of current is limited by both Thevenin's equivalent resistance and any resistance connected between a and b. The resistance between a and b consists only of the galvanometer resistance R_g. The deflection current in the galvanometer is therefore given by

$$I_g = \frac{E_{th}}{R_{th} + R_g} \qquad (11.5)$$

Slightly Unbalanced Wheatstone's Bridge

If three of the four resistor in a bridge are equal to R and the fourth differs by 5% or less, we can develop an approximate but accurate expression for Thevenin's equivalent voltage and resistance.

Consider the circuit in Fig. 11.7. The voltage at point a is

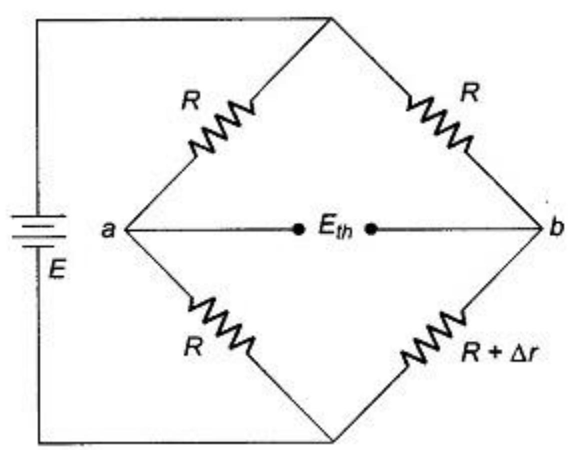

Fig. 11.7 Slightly Unbalanced Wheatstone's Bridge

The voltage at point b is

$$E_b = \frac{R + \Delta r \times E}{R + R + \Delta r} = \frac{E(R + \Delta r)}{2R + \Delta r}$$

Thevenin's equivalent voltage between a and b is the difference between these voltages.

Therefore, $E_{th} = E_b - E_a$

$$E_{th} = \quad = E\left(\frac{(R+\Delta r)}{2R+\Delta r} - \frac{1}{2}\right)$$

$$= E\left(\frac{2(R+\Delta r)-(2R+\Delta r)}{2(2R+\Delta r)}\right)$$

$$= E\left(\frac{2R+2\Delta r-2R-\Delta r}{4R+2\Delta r}\right)$$

$$= E\left(\frac{\Delta r}{4R+2\Delta r}\right)$$

If Δ r is 5% of R or less, Δ r in the denominator can be neglected without introducing appreciable error. Therefore, Thevenin's voltage is

$$E_{th} = \frac{E \times \Delta r}{4R} = E\left(\frac{\Delta r}{4R}\right)$$

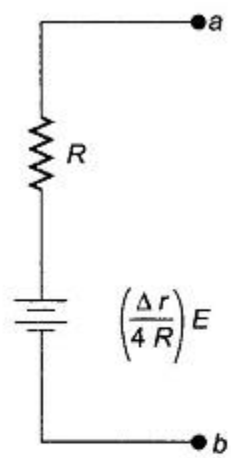

Fig. 11.8 Thévenin's Equivalent of a Slightly Unbalanced Wheatstone's Bridge

The equivalent resistance can be calculated by replacing the voltage source with its internal impedance (for all practical purpose short-circuit). The Thevenin's equivalent resistance is given by

$$R_{th} = \frac{R \times R}{R+R} + \frac{R(R+\Delta r)}{R+R+\Delta r}$$

$$= \frac{R}{2} + \frac{R(R+\Delta r)}{2R+\Delta r}$$

Again, if Δr is small compared to R, Δ r can be neglected. Therefore,

$$R_{th} = \frac{R}{2} + \frac{R}{2} = R$$

Using these approximations, the Thevenin's equivalent circuit is as shown in Fig. 11.8. These approximate equations are about 98% accurate if $\Delta r \leq 0.05$ R.

Problem:

Given a centre zero 200-0-200 µA movement having an internal resistance of 125 **Ω.** Calculate the current through the galvanometer by the approximation method, where the arms of the bridges are R=700 Ω and R4=735 Ω and applied voltage is 10V.

Soln:

Eth=E Δr / 4R =10 * 35 / 4*700 = 0.125V

Rth=R=700 Ω

Galvanometer current Ig= Eth/ (Rth+Rg) = 0.125 / (700+125) = 151.5 µA.

Application of Wheatstone's Bridge

A Wheatstone bridge may be used to measure the dc resistance of various types of wire, either for the purpose of quality control of the wire itself, or of some assembly in which it is used. For example, the resistance of motor windings, transformers, solenoids, and relay coils can be measured.

Wheatstone Bridge Circuit is also used extensively by telephone companies and others to locate cable faults. The fault may be two lines shorted together, or a single line shorted to ground.

Limitations of Wheatstone's Bridge

(i) For low resistance measurement, the resistance of the leads and contacts becomes significant and introduces an error. This can be eliminated by Kelvin's Double bridge.

(ii) For high resistance measurements in mega ohms, the resistance presented by the bridge becomes so large that the galvanometer is insensitive to imbalance and the Wheatstone's bridge cannot be used.

(iii) Another difficulty in Wheatstone Bridge Circuit is the change in resistance of the bridge arms due to the heating effect of current through the resistance. The rise in temperature causes a change in the value of the resistance.

AC Bridge:

Impedances at AF or RF are commonly determined by means of an ac Wheatstone bridge. The diagram of an ac bridge is given in Fig. 11.17. This bridge is similar to a dc bridge, except that the bridge arms are impedances. The bridge is excited by an ac source rather than dc and the galvanometer is replaced by a detector, such as a pair of headphones, for detecting ac. When the bridge is balanced,

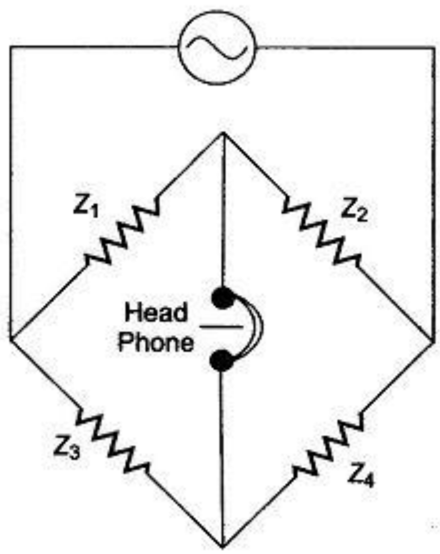

Fig. 11.17 ac Wheatstone's Bridge

$$\frac{Z_1}{Z_3} = \frac{Z_2}{Z_4}$$

where Z_1, Z_2, Z_3 and Z_4 are the impedances of the arms, and are vector complex quantities that possess phase angles. It is thus necessary to adjust both the magnitude and phase angles of the impedance arms to achieve balance, i.e. the bridge must be balanced for both the reactance and the resistive component.

Capacitance Comparison Bridge

Figure 11.18 shows the circuit of a capacitance comparison bridge. The ratio arms R_1, R_2 are resistive. The known standard capacitor C_3 is in series with R_3. R_3 may also include an added variable resistance needed to balance the bridge. C_x is the unknown capacitor and R_x is the small leakage resistance of the capacitor. In this case an unknown capacitor is compared with a standard capacitor and the value of the former, along with its leakage resistance is obtained.

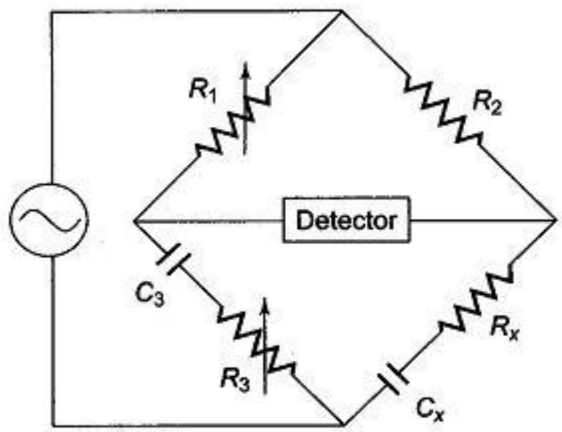

Fig. 11.18 Capacitance Comparison Bridge

$Z_1 = R_1$

$Z_2 = R_2$

$Z_3 = R_3$ in series with $C_3 = R_3 - j/\omega C_3$

$Z_x = R_x$ in series with $C_x = R_x - j/\omega C_x$

The condition for balance of the bridge is

$$Z_1 Z_x = Z_2 Z_3$$

i.e. $$R_1\left(R_x - \frac{j}{\omega C_x}\right) = R_2\left(R_3 - \frac{j}{\omega C_3}\right)$$

$\therefore$ $$R_1 R_x - \frac{jR_1}{\omega C_x} = R_2 R_3 - \frac{jR_2}{\omega C_3}$$

Two complex quantities are equal when both their real and their imaginary terms are equal. Therefore,

i.e. $$R_1 R_x = R_2 R_3 \qquad \therefore R_x = \frac{R_2 R_3}{R_1} \qquad [11.12(a)]$$

and $$\frac{R_1}{\omega C_x} = \frac{R_2}{\omega C_3} \qquad C_x = \frac{C_3 R_1}{R_2} \qquad [11.12(b)]$$

Since R_3 does not appear in the expression for C_x, as a variable element it is an obvious choice to eliminate any interaction between the two balance controls.

Inductance Comparison Bridge

Figure 11.20 gives a schematic diagram of an inductance comparison bridge. In this, values of the unknown inductance L_x and its internal resistance R_x are obtained by comparison with the standard inductor and resistance, i.e. L_3 and R_3.
The equation for balance condition is

$$Z_1 Z_x = Z_2 Z_3$$

The inductive balance equation yields

$$L_x = \frac{L_3 R_2}{R_1} \qquad [11.13(a)]$$

and resistive balance equations yields

$$R_x = \frac{R_2 R_3}{R_1} \qquad [(11.13(b)]$$

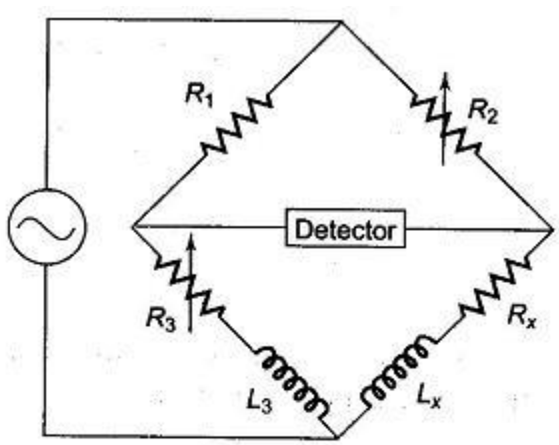

Fig. 11.20 Inductance Comparison Bridge

In this bridge R_2 is chosen as the inductive balance control and R_3 as the resistance balance control. (It is advisable to use a fixed resistance ratio and variable standards). Balance is obtained by alternately varying L_3 or R_3.

- If the Q of the unknown reactance is greater than the standard Q, it is necessary to place a variable resistance in series with the unknown reactance to obtain balance.
- If the unknown inductance has a high Q, it is permissible to vary the resistance ratio when a variable standard inductor is not available.

Wien Bridge :

The Wien Bridge Circuit Diagram shown in Fig. 11.27 has a series RC combination in one arm and a parallel combination in the adjoining arm. Wien's bridge in its basic form, is designed to measure frequency. It can also be used for the measurement of an unknown capacitor with great accuracy.

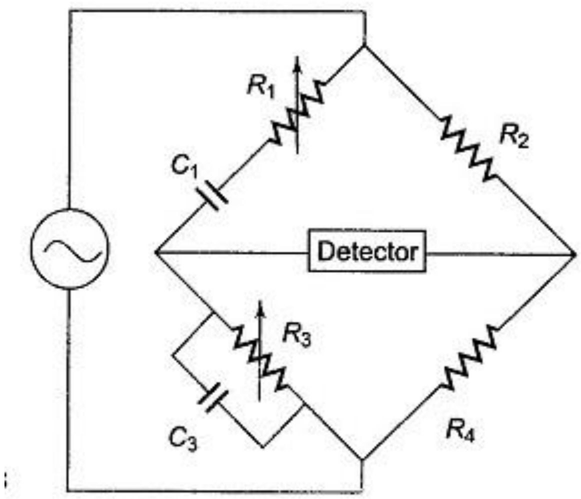

Fig. 11.27 Wien's Bridge

The impedance of arm 1 is

$$Z_1 = R_1 - j/\omega C_1$$

The admittance of the parallel arm is

$$Y_3 = 1/R_3 + j\,\omega\,C_3$$

Using the bridge balance equation,

we have

$$Z_1\,Z_4 = Z_2\,Z_3$$

Therefore,

$$Z_1\,Z_4 = Z_2/Y_3, \text{ i.e. } Z_2 = Z_1\,Z_4\,Y_3$$

$$R_2 = R_4\left(R_1 - \frac{j}{\omega C_1}\right)\left(\frac{1}{R_3} + j\omega C_3\right)$$

$$R_2 = \frac{R_1 R_4}{R_3} - \frac{j R_4}{\omega C_1 R_3} + j\,\omega\, C_3\, R_1\, R_4 + \frac{C_3 R_4}{C_1}$$

$$R_2 = \left(\frac{R_1 R_4}{R_3} + \frac{C_3 R_4}{C_1}\right) - j\left(\frac{R_4}{\omega C_1 R_3} - \omega C_3 R_1 R_4\right)$$

Equating the real and imaginary terms we have

$$R_2 = \frac{R_1 R_4}{R_3} + \frac{C_3 R_4}{C_1} \text{ and } \frac{R_4}{\omega C_1 R_3} - \omega\, C_3\, R_1\, R_4 = 0$$

Therefore $$\frac{R_2}{R_4} = \frac{R_1}{R_3} + \frac{C_3}{C_1} \qquad (11.21)$$

and $$\frac{1}{\omega C_1 R_3} = \omega\, C_3\, R_1 \qquad (11.22)$$

$\therefore$ $$\omega^2 = \frac{1}{C_1 R_1 R_3 C_3}$$

$$\omega = \frac{1}{\sqrt{C_1 R_1 C_3 R_3}}$$

as $$\omega = 2\,\pi f$$

$\therefore$ $$f = \frac{1}{2\pi\sqrt{C_1 R_1 C_3 R_3}} \qquad (11.23)$$

The two conditions for bridge balance, (11.21) and (11.23), result in an expression determining the required resistance ratio R_2/R_4 and another expression determining the frequency of the applied voltage. If we satisfy Eq. (11.21) and also excite the bridge with the frequency of Eq. (11.23), the bridge will be balanced.

In most Wien Bridge Circuit Diagram, the components are chosen such that $R_1 = R_3 = R$ and $C_1 = C_3 = C$. Equation (11.21) therefore reduces to $R_2/R_4 = 2$ and Eq. (11.23) to $f=1/2\pi RC$, which is the general equation for the frequency of the bridge circuit.

The bridge is used for measuring frequency in the audio range. Resistances R_1 and R_3 can be ganged together to have identical values. Capacitors C_1 and C_3 are normally of fixed values.

The audio range is normally divided into 20 — 200 — 2 k — 20 kHz ranges. In this case, the resistances can be used for range changing and capacitors C_1 and C3 for fine frequency control within the range.

The Wien Bridge can also be used for measuring capacitances (normally C3). In that case, the frequency of operation must be known.

The bridge is also used in a harmonic distortion analyzer, as a Notch filter, and in audio frequency and radio frequency oscillators as a frequency determining element.

An accuracy of 0.5% — 1% can be readily obtained using this bridge. Because it is frequency sensitive, it is difficult to balance unless the waveform of the applied voltage is purely sinusoidal.