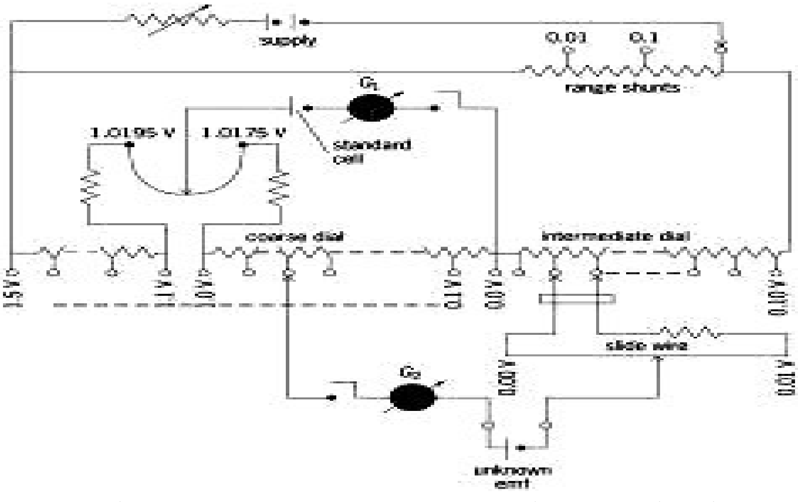
UNIT III COMPARISON METHODS OF MEASUREMENTS

D.C & A.C Potentiometers

An instrument that precisely measures an electromotive force (emf) or a voltage by opposing to it a known potential drop established by passing a definite current through a resistor of known characteristics. (A three-terminal resistive voltage divider is sometimes also called a potentiometer.) There are two ways of accomplishing this balance: (1) the current *I* may be held at a fixed value and the resistance *R* across which the *IR* drop is opposed to the unknown may be varied; (2) current may be varied across a fixed resistance to achieve the needed *IR* drop.

The essential features of a general-purpose constant-current instrument are shown in the illustration. The value of the current is first fixed to match an *IR* drop to the emf of a reference standard cell. With the standard-cell dial set to read the emf of the reference cell, and the galvanometer (balance detector) in position G_1, the resistance of the supply branch of the circuit is adjusted until the *IR* drop in 10 steps of the coarse dial plus the set portion of the standard-cell dial balances the known reference emf, indicated by a null reading of the galvanometer. This adjustment permits the potentiometer to be read directly in volts. Then, with the galvanometer in position G_2, the coarse, intermediate, and slide-wire dials are adjusted until the galvanometer again reads null. If the potentiometer current has not changed, the emf of the unknown can be read directly from the dial settings. There is usually a switching arrangement so that the galvanometer can be quickly shifted between positions 1 and 2 to check that the current has not drifted from its set value.



Circuit diagram of a general-purpose constant-current potentiometer, showing essential features

Potentiometer techniques may also be used for current measurement, the unknown current being sent through a known resistance and the *IR* drop opposed by balancing it at the voltage terminals of the potentiometer. Here, of course, internal heating and consequent resistance change of the current-carrying resistor (shunt) may be a critical factor in measurement accuracy; and the shunt design may require attention to dissipation of heat resulting from its I^2R power consumption.

Potentiometer techniques have been extended to alternating-voltage measurements, but generally at a reduced accuracy level (usually 0.1% or so). Current is set on an ammeter which must have the same response on ac as on dc, where it may be calibrated with a potentiometer and shunt combination. Balance in opposing an unknown voltage is achieved in one of two ways: (1) a slide-wire and phase-adjustable supply; (2) separate in-phase and quadrature adjustments on slide wires supplied from sources that have a 90° phase difference. Such potentiometers have limited use in magnetic testing.

An instrument that precisely measures an electromotive force (emf) or a voltage by opposing to it a known potential drop established by passing a definite current through a resistor of known characteristics. (A three-terminal resistive voltage divider is sometimes also called a potentiometer.) There are two ways of accomplishing this balance: (1) the current I may be held at a fixed value and the resistance R across which the IR drop is opposed to the unknown may be varied; (2) current may be varied across a fixed resistance to achieve the needed IR drop.

The essential features of a general-purpose constant-current instrument are shown in the illustration. The value of the current is first fixed to match an IR drop to the emf of a reference standard cell. With the standard-cell dial set to read the emf of the reference cell, and the galvanometer (balance detector) in position G_1, the resistance of the supply branch of the circuit is adjusted until the IR drop in 10 steps of the coarse dial plus the set portion of the standard-cell dial balances the known reference emf, indicated by a null reading of the galvanometer. This adjustment permits the potentiometer to be read directly in volts. Then, with the galvanometer in position G_2, the coarse, intermediate, and slide-wire dials are adjusted until the galvanometer again reads null. If the potentiometer current has not changed, the emf of the unknown can be read directly from the dial settings. There is usually a switching arrangement so that the galvanometer can be quickly shifted between positions 1 and 2 to check that the current has not drifted from its set value.

Potentiometer techniques may also be used for current measurement, the unknown current being sent through a known resistance and the IR drop opposed by balancing it at the voltage terminals of the potentiometer. Here, of course, internal heating and consequent resistance change of the current-carrying resistor (shunt) may be a critical factor in measurement accuracy

Potentiometer techniques have been extended to alternating-voltage measurements, but generally at a reduced accuracy level (usually 0.1% or so). Current is set on an ammeter which must have the same response on ac as on dc, where it may be calibrated with a potentiometer and shunt combination. Balance in opposing an unknown voltage is achieved in one of two ways: (1) a slide-wire and phase-adjustable supply; (2) separate in-phase and quadrature adjustments on slide wires supplied from sources that have a 90° phase difference. Such potentiometers have

limited use in magnetic testing

(1) An electrical measuring device used in determining the electromotive force (emf) or voltage by means of the compensation method. When used with calibrated standard resistors, a potentiometer can be employed to measure current, power, and other electrical quantites; when used with the appropriate measuring transducer, it can be used to gauge various non-electrical quantities, such as temperature, pressure, and the composition of gases.

distinction is made between DC and AC potentiometers. In DC potentiometers, the voltage being measured is compared to the emf of a standard cell. Since at the instant of compensation the current in the circuit of the voltage being measured equals zero, measurements can be made without reductions in this voltage. For this type of potentiometer, accuracy can exceed 0.01 percent. DC potentiometers are categorized as either high-resistance, with a slide-wire resistance ranging from The higher resistance class can measure up to 2 volts (V) and is used in testing highly accurate apparatus. The low-resistance class is used in measuring voltage up to 100 mV. To measure higher voltages, up to 600 V, and to test voltmeters, voltage dividers are connected to potentiometers. Here the voltage drop across one of the resistances of the voltage divider is compensated; this constitutes a known fraction of the total voltage being measured.

In AC potentiometers, the unknown voltage is compared with the voltage drop produced by a current of the same frequency across a known resistance. The voltage being measured is then adjusted both for amplitude and phase. The accuracy of AC potentiometers is of the order of 0.2 percent. In electronic automatic DC and AC potentiometers, the measurements of voltage are carried out automatically. In this case, the compensation of the unknown voltage is achieved with the aid of a servomechanism that moves the slide along the resistor, or rheostat. The servomechanism is actuated by the imbalance of the two voltages, that is, by the difference between the compensating voltage and the voltage that is being compensated. In electronic automatic potentiometers, the results of measurements are read on dial indicators, traced on recorder charts or received as numerical data. The last method makes it possible to input the data directly into a computer. In addition to measurement, electronic automatic potentiometers are also capable of regulating various parameters of industrial processes. In this case, the slide of the rheostat is set in a position that predetermines, for instance, the temperature of the object to be regulated. The voltage imbalance of the potentiometer drives the servomechanism, which then increases or decreases the electric heating or regulates the fuel supply.

A voltage divider with a uniform variation of resistance, a device that allows some fraction of a given voltage to be applied to an electric circuit. In the simplest case, the device consists of a conductor of high resistance equipped with a sliding contact. Such dividers are used in electrical engineering, radio engineering, and measurement technology. They can also be utilized in analog computers and in automation systems, where, for example, they function as sensors for linear or angular displacement

3.2 D.C & A.C Bridges

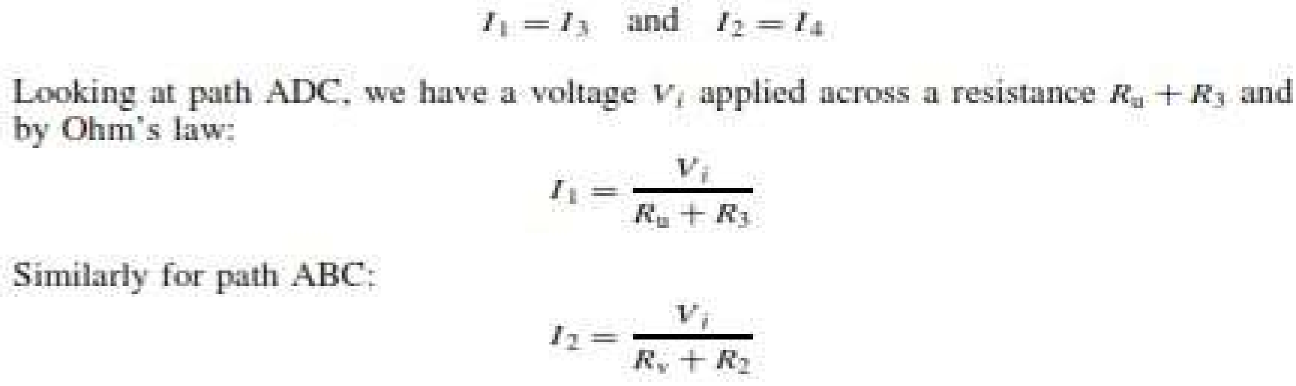
Bridge circuits are used very commonly as a variable conversion element in measurement systems and produce an output in the form of a voltage level that changes as the measured physical quantity changes. They provide an accurate method of measuring resistance, inductance and capacitance values, and enable the detection of very small changes in these quantities about a nominal value. They are of immense importance in measurement system technology because so many transducers measuring physical quantities have an output that is expressed as a change in resistance, inductance or capacitance. The displacement-measuring strain gauge, which has a varying resistance output, is but one example of this class of transducers. Normally, excitation of the bridge is by a d.c. voltage for resistance measurement and by an a.c. voltage for inductance or capacitance measurement. Both null and deflection types of bridge exist, and, in a like manner to instruments in general, null types are mainly employed for calibration purposes and deflection types are used within closed-loop automatic control schemes.

Null-type, d.c. bridge (Wheatstone bridge)

A null-type bridge with d.c. excitation, commonly known as a Wheatstone bridge, has the form shown in Figure 7.1. The four arms of the bridge consist of the unknown resistance R_u, two equal value resistors R_2 and R_3 and a variable resistor R_v (usually a decade resistance box). A d.c. voltage V_i is applied across the points AC and the resistance R_v is varied until the voltage measured across points BD is zero. This null point is usually measured with a high sensitivity galvanometer.

To analyses the Whetstone bridge, define the current flowing in each arm to be I_1 . . . I_4 as shown in Figure 7.1. Normally, if a high impedance voltage-measuring instrument is used, the current I_m drawn by the measuring instrument will be very small and can be approximated to zero. If this assumption is made, then, for I_m D 0:

$$I_1 = I_3 \text{ and } I_2 = I_4$$



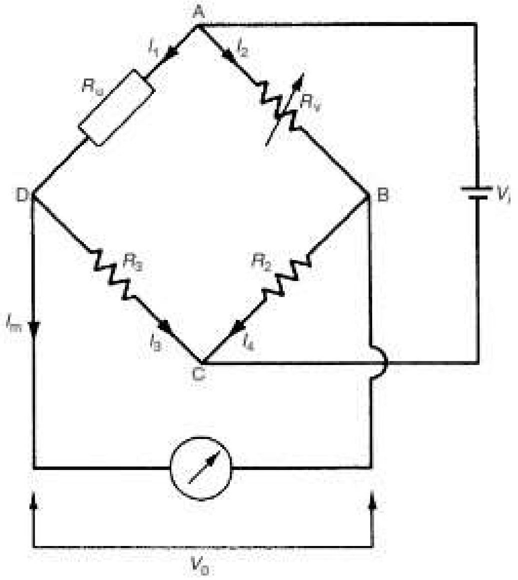
$$I_1 = I_3 \quad \text{and} \quad I_2 = I_4$$

Looking at path ADC, we have a voltage V_i applied across a resistance $R_u + R_3$ and by Ohm's law:

$$I_1 = \frac{V_i}{R_u + R_3}$$

Similarly for path ABC:

$$I_2 = \frac{V_i}{R_v + R_2}$$



Now we can calculate the voltage drop across AD and AB:

$$V_{\mathrm{AD}} = I_1 R_{\mathrm{v}} = \frac{V_i R_{\mathrm{u}}}{R_{\mathrm{u}} + R_3}; \quad V_{\mathrm{AB}} = I_2 R_{\mathrm{v}} = \frac{V_i R_{\mathrm{v}}}{R_{\mathrm{v}} + R_2}$$

By the principle of superposition,

$$V_0 = V_{\mathrm{BD}} = V_{\mathrm{BA}} + V_{\mathrm{AD}} = -V_{\mathrm{AB}} + V_{\mathrm{AD}}$$

Thus:

$$V_0 = -\frac{V_i R_{\mathrm{v}}}{R_{\mathrm{v}} + R_2} + \frac{V_i R_{\mathrm{u}}}{R_{\mathrm{u}} + R_3}$$

At the null point $V_0 = 0$, so:

$$\frac{R_{\mathrm{u}}}{R_{\mathrm{u}} + R_3} = \frac{R_{\mathrm{v}}}{R_{\mathrm{v}} + R_2}$$

Inverting both sides:

$$\frac{R_{\mathrm{u}} + R_3}{R_{\mathrm{u}}} = \frac{R_{\mathrm{v}} + R_2}{R_{\mathrm{v}}} \quad \text{i.e.} \quad \frac{R_3}{R_{\mathrm{u}}} = \frac{R_2}{R_{\mathrm{v}}} \quad \text{or } R_{\mathrm{u}} = \frac{R_3 R_{\mathrm{v}}}{R_2}$$

Thus, if $R_2 = R_3$, then $R_{\mathrm{u}} = R_{\mathrm{v}}$. As R_{v} is an accurately known value because it is derived from a variable decade resistance box, this means that R_{u} is also accurately known.

Deflection-type d.c. bridge

A deflection-type bridge with d.c. excitation is shown in Figure 7.2. This differs from the Wheatstone bridge mainly in that the variable resistance R_v is replaced by a fixed resistance R_1 of the same value as the nominal value of the unknown resistance R_u. As the resistance R_u changes, so the output voltage V_0 varies, and this relationship between V_0 and R_u must be calculated.

This relationship is simplified if we again assume that a high impedance voltage measuring instrument is used and the current drawn by it, I_m, can be approximated to zero. (The case when this assumption does not hold is covered later in this section.) The analysis is then exactly the same as for the preceding example of the Wheatstone bridge, except that R_v is replaced by R_1. Thus, from equation (7.1), we have:

$$V_0 = V_i * (R_u / R_u + R_3) - (R_1 / R_1 + R_2)$$

When R_u is at its nominal value, i.e. for R_u D R_1, it is clear that V_0 D 0 (since R_2 D R_3). For other values of R_u, V_0 has negative and positive values that vary in a non-linear way with R_u.

A.C bridges

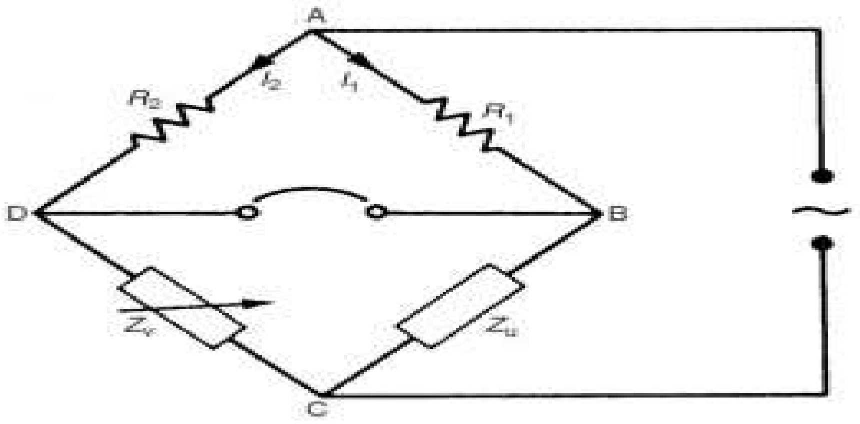
Bridges with a.c. excitation are used to measure unknown impedances. As for d.c. bridges, both null and deflection types exist, with null types being generally reserved for calibration duties.

Null-type impedance bridge

A typical null-type impedance bridge is shown in Figure 7.7. The null point can be conveniently detected by monitoring the output with a pair of headphones connected via an operational amplifier across the points BD. This is a much cheaper method of null detection than the application of an expensive galvanometer that is required for a d.c. Wheatstone bridge.

$$I_1R_1 = I_2R_2; \quad I_1Z_u = I_2Z_v$$

$$Z_u = \frac{Z_vR_1}{R_2}$$



If Z_u is capacitive, i.e. Z_u D $1/j\omega C_u$, then Z_v must consist of a variable capacitance box, which is readily available. If Z_u is inductive, then Z_u D R_u C $j\omega L_u$.

Notice that the expression for Z_u as an inductive impedance has a resistive term in it because it is impossible to realize a pure inductor. An inductor coil always has a resistive component, though this is made as small as possible by designing the coil to have a high Q factor (Q factor is the ratio inductance/resistance). Therefore, Z_v must consist of a variable-resistance box and a variable-inductance box. However, the latter are not readily available because it is difficult and hence expensive to manufacture a set of fixed value inductors to make up a variable-inductance box. For this reason, an alternative kind of null-type bridge circuit, known as the *Maxwell Bridge*, is commonly used to measure unknown inductances.

Maxwell bridge

Definition

A Maxwell bridge (in long form, a Maxwell-Wien bridge) is a type of Wheatstone bridge used to measure an unknown inductance (usually of low Q value) in terms of calibrated resistance and capacitance. It is a real product bridge.

The maxwell bridge is used to measure unknown inductance in terms of calibrated resistance and capacitance. Calibration-grade inductors are more difficult to manufacture than capacitors of similar precision, and so the use of a simple "symmetrical" inductance bridge is not always practical.

Circuit Diagram

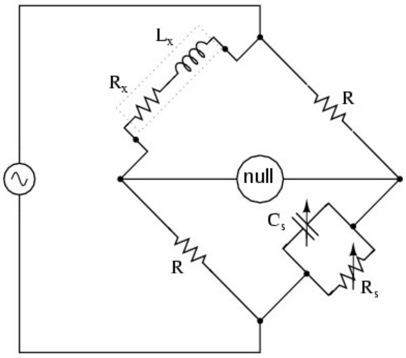


Figure 1.7.1. Maxwell Bridge

Explanation

With reference to the picture, in a typical application R1 and R4 are known fixed entities, and R2 and C2 are known variable entities.

R2 and C2 are adjusted until the bridge is balanced.R3 and L3 can then be calculated based on the values of the other components:

As shown in Figure, one arm of the Maxwell bridge consists of a capacitor in parallel with a resistor (C1 and R2) and another arm consists of an inductor L1 in series with a resistor (L1 and R4). The other two arms just consist of a resistor each (R1 and R3).

The values of R1 and R3 are known, and R2 and C1 are both adjustable. The unknown values are those of L1 and R4.

Like other bridge circuits, the measuring ability of a Maxwell Bridge depends on 'Balancing' the circuit.

Balancing the circuit in Figure 1 means adjusting C1 and R2 until the current through the bridge between points A and B becomes zero. This happens when the voltages at points A and B are equal.

Mathematically,

$Z1 = R2 + 1/\ (2\pi fC1)$; while $Z2 = R4 + 2\pi fL1$.

$(R2 + 1/\ (2\pi fC1))\ /\ R1 = R3\ /\ [R4 + 2\pi fL1]$;

or

$R1R3 = [R2 + 1/\ (2\pi fC1)]\ [R4 + 2\pi fL1]$

To avoid the difficulties associated with determining the precise value of a variable capacitance, sometimes a fixed-value capacitor will be installed and more than one resistor will be made variable.

The additional complexity of using a Maxwell bridge over simpler bridge types is warranted in circumstances where either the mutual inductance between the load and the known bridge entities, or stray electromagnetic interference, distorts the measurement results.

The capacitive reactance in the bridge will exactly oppose the inductive reactance of the load when the bridge is balanced, allowing the load's resistance and reactance to be reliably determined.

Advantages:

The frequency does not appear

Wide range of inductance

Disadvantages:

Limited measurement

It requires variable standard capacitor

SCHERING BRIDGE

Definition

A **Schering Bridge** is a bridge circuit used for measuring an unknown electrical capacitance and its dissipation factor. The dissipation factor of a capacitor is the the ratio of its resistance to its capacitive reactance. The Schering Bridge is basically a four-arm alternating-current (AC) bridge circuit whose measurement depends on balancing the loads on its arms. Figure 1 below shows a diagram of the Schering Bridge.

Diagram

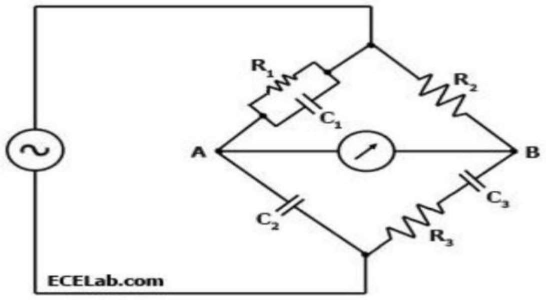


Figure 1.7.2. Schering Bridge

Explanation

In the Schering Bridge above, the resistance values of resistors R1 and R2 are known, while the resistance value of resistor R3 is unknown.

The capacitance values of C1 and C2 are also known, while the capacitance of C3 is the value being measured.

To measure R3 and C3, the values of C2 and R2 are fixed, while the values of R1 and C1 are adjusted until the current through the ammeter between points A and B becomes zero.

This happens when the voltages at points A and B are equal, in which case the bridge is said to be 'balanced'.

When the bridge is balanced, $Z1/C2 = R2/Z3$, where Z1 is the impedance of R1 in parallel with C1 and Z3 is the impedance of R3 in series with C3.

In an AC circuit that has a capacitor, the capacitor contributes a capacitive reactance to the impedance.

$$Z1 = R1/[2\pi fC1((1/2\pi fC1) + R1)] = R1/(1 + 2\pi fC1R1)$$

$$\text{while } Z3 = 1/2\pi fC3 + R3.\ 2\pi fC2R1/(1+2\pi fC1R1) = R2/(1/2\pi fC3 + R3);\ \text{or}$$

$$2\pi fC2\,(1/2\pi fC3 + R3) = (R2/R1)\,(1+2\pi fC1R1);\ \text{or}$$

$$C2/C3 + 2\pi fC2R3 = R2/R1 + 2\pi fC1R2\cdot$$

When the bridge is balanced, the negative and positive reactive components are equal and cancel out, so

$$2\pi fC2R3 = 2\pi fC1R2 \text{ or}$$

$$R3 = C1R2 / C2.$$

Similarly, when the bridge is balanced, the purely resistive components are equal,

so $C2/C3 = R2/R1$ or $C3 = R1C2 / R2$.

Note that the balancing of a Schering Bridge is independent of frequency.

Advantages:

Balance equation is independent of frequency

Used for measuring the insulating properties of electrical cables and equipment’s

HAY BRIDGE

Definition

A Hay Bridge is an AC bridge circuit used for measuring an unknown inductance by balancing the loads of its four arms, one of which contains the unknown inductance. One of the arms of a Hay Bridge has a capacitor of known characteristics, which is the principal component used for determining the unknown inductance value. Figure 1 below shows a diagram of the Hay Bridge.

Explanation

As shown in Figure 1, one arm of the Hay bridge consists of a capacitor in series with a resistor (C1 and R2) and another arm consists of an inductor L1 in series with a resistor (L1 and R4).

The other two arms simply contain a resistor each (R1 and R3). The values of R1and R3 are known, and R2 and C1 are both adjustable.

The unknown values are those of L1 and R4.

Like other bridge circuits, the measuring ability of a Hay Bridge depends on 'balancing' the circuit.

Balancing the circuit in Figure 1 means adjusting R2 and C1 until the current through the ammeter between points A and B becomes zero. This happens when the voltages at points A and B are equal.

Diagram

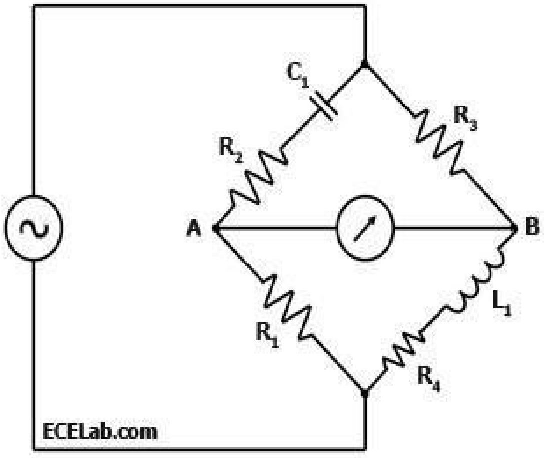


Figure 1.7.3. Hay Bridge

When the Hay Bridge is balanced, it follows that $Z1/R1 = R3/Z2$ wherein Z1 is the impedance of the arm containing C1 and R2 while Z2 is the impedance of the arm containing L1 and R4.

Thus, $Z1 = R2 + 1/(2\pi fC)$ while $Z2 = R4 + 2\pi fL1$.

$$[R2 + 1/(2\pi fC1)] \; / R1 = R3 / [R4 + 2\pi fL1]; \text{ or}$$

$$[R4 + 2\pi fL1] = R3R1 / [R2 + 1/(2\pi fC1)]; \text{ or } R3R1$$

$$= R2R4 + 2\pi fL1R2 + R4/2\pi fC1 + L1/C1.$$

When the bridge is balanced, the reactive components are equal, so

$2\pi fL1R2 = R4/2\pi fC1$, or $R4 = (2\pi f)\, 2L1R2C1$.

Substituting R4, one comes up with the following equation:

$$R3R1 = (R2+1/2\pi fC1)\,((2\pi f)\, 2L1R2C1) + 2\pi fL1R2 + L1/C1; \text{ or}$$

$$L1 = R3R1C1 / (2\pi f)\, 2R22C12 + 4\pi fC1R2 + 1);$$

$$L1 = R3R1C1 / [1 + (2\pi fR2C1)2]$$

After dropping the reactive components of the equation since the bridge is

Thus, the equations for L1 and R4 for the Hay Bridge in Figure 1 when it is balanced are:

$L1 = R3R1C1 / [1 + (2\pi fR2C1)2]$; and

$R4 = (2\pi fC1)2R2R3R1 / [1 + (2\pi fR2C1)2]$

Advantages:

Simple expression

Disadvantages:

It is not suited for measurement of coil

WIEN BRIDGE:

Definition

A Wien bridge oscillator is a type of electronic oscillator that generates sine waves. It can generate a large range of frequencies. The circuit is based on an electrical network originally developed by Max Wien in 1891. Wien did not have a means of developing electronic gain so a workable oscillator could not be realized. The modern circuit is derived from William Hewlett's 1939 Stanford University master's degree thesis. Hewlett, along with David Packard co-founded Hewlett-Packard. Their first product was the HP 200A, a precision sine wave oscillator based on the Wien bridge. The 200A was one of the first instruments to produce such low distortion.

Diagram

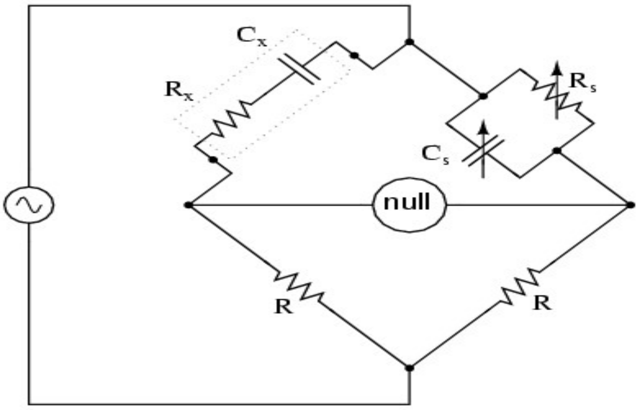


Figure 1.7.4 Wein bridge

Amplitude stabilization:

The key to Hewlett's low distortion oscillator is effective amplitude stabilization.

The amplitude of electronic oscillators tends to increase until clipping or other gain limitation is reached. This leads to high harmonic distortion, which is often undesirable.

Hewlett used an incandescent bulb as a positive temperature coefficient (PTC) thermistor in the oscillator feedback path to limit the gain.

The resistance of light bulbs and similar heating elements increases as their temperature increases

If the oscillation frequency is significantly higher than the thermal time constant of the heating element, the radiated power is proportional to the oscillator power.

Since heating elements are close to black body radiators, they follow the Stefan-Boltzmann law.

The radiated power is proportional to T4, so resistance increases at a greater rate than amplitude.

If the gain is inversely proportional to the oscillation amplitude, the oscillator gain stage reaches a steady state and operates as a near ideal class A amplifier, achieving very low distortion at the frequency of interest.

At lower frequencies the time period of the oscillator approaches the thermal time constant of the thermistor element and the output distortion starts to rise significantly.

Light bulbs have their disadvantages when used as gain control elements in Wien bridge oscillators, most notably a very high sensitivity to vibration due to the bulb's micro phonic nature amplitude modulating the oscillator output, and a limitation in high frequency response due to the inductive nature of the coiled filament.

Modern Distortion as low as 0.0008% (-100 dB) can be achieved with only modest improvements to Hewlett's original circuit.

Wien bridge oscillators that use thermistors also exhibit "amplitude bounce" when the oscillator frequency is changed. This is due to the low damping factor and long time constant of the crude control loop, and disturbances cause the output amplitude to exhibit a decaying sinusoidal response.

This can be used as a rough figure of merit, as the greater the amplitude bounce after a disturbance, the lower the output distortion under steady state conditions.

Analysis:

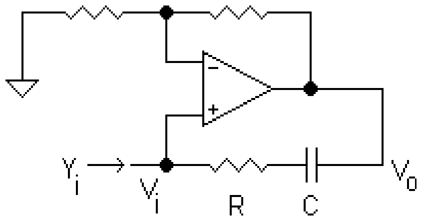


Figure 1.7.4 Input analysis

Input admittance analysis

If a voltage source is applied directly to the input of an ideal amplifier with feedback, the input current will be:

Where vin is the input voltage, vout is the output voltage, and Zf is the feedback impedance. If the voltage gain of the amplifier is defined as:

—

And the input admittance is defined as:

—

Input admittance can be rewritten as:

—

If Av is greater than 1, the input admittance is a negative resistance in parallel with an inductance.

If a resistor is placed in parallel with the amplifier input, it will cancel some of the negative resistance. If the net resistance is negative, amplitude will grow until clipping occurs.

If a resistance is added in parallel with exactly the value of R, the net resistance will be infinite and the circuit can sustain stable oscillation at any amplitude allowed by the amplifier.

Advantages:

Frequency sensitive

Supply voltage is purely sinusoidal

3.3 Transformer Ratio Bridges & Self-Balancing Bridges

TRNSFORMER RATIO BRIDGES

INTRODUCTION

The product to which this manual refers should be installed, commissioned, operated and maintained under the supervision of a competent ***Electrical Engineer*** in accordance with relevant statutory requirements and good engineering practice, including Codes of Practice where applicable, and properly used within the terms of the specification.

The instructions in this manual should familiarize qualified personal with the proper procedures to keep all new unit(s) in proper operating condition. These instructions for installation, operation and maintenance of Package Compact Substation should be read carefully and used as a guide during installation and initial operation.

These instructions do not propose to cover all details or variations in equipment, nor to provide for every contingency to be met in connection with installation, operation, or maintenance. Should further information be desired, or particular problems arise which are not covered, please contact the nearest ABB office.

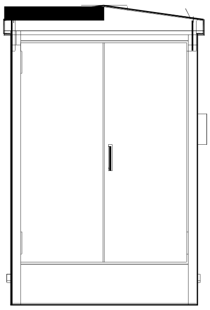
We would in particular stress the importance of care in:

- Site selection and design, embodying features that provide adequate ventilation, protection and security and which have taken account of appropriate fire, moisture and explosion hazards.
- Jointing.
- Earthing.
- Selection and setting of electrical protection in primary and secondary, against overload, overvoltage and short-circuit.
- Carrying out regular inspection and electrical and mechanical maintenance.

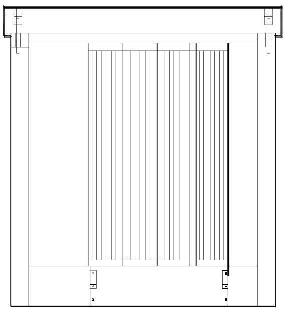
The Package Compact Substation(s) covered by these instructions have been repeatedly inspected and tested to meet all applicable standards of IEC, to ensure you of a first-rate quality product, which should give many years of satisfactory performance.
The specific ratings of each Package Compact Substation are shown on the drawings.

File these instructions in a readily accessible place together with drawings and descriptive data of the Package Compact Substation. These instructions will be a guide to proper maintenance of the equipment and prolong its life and usefulness

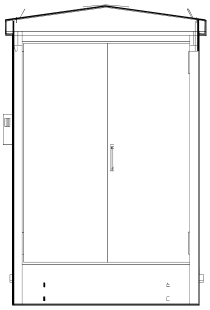
GENERAL



LV FRONT



SUBSTATION S



HV FRONT

The Package Compact Substations are completely self-contained, mounted on an integral base, factory assembled in a totally enclosed, aesthetically and acceptable cladding, vandal-proof, vermin-proof and weather-proof housing ready for installation into position on a concrete base pad or pier. The base frame is of welded structural steel and been hot-dipped galvanized after fabrication to assure affective corrosion resistance in service. Housing of the Package Compact Substation is made of special material called ALUZINK, a sheet steel with a metallic alloy coating. The alloy consists of 55% aluminum and 43.4% zinc. This provides optimum corrosion protection. The housing has three compartments, separated with ALUZINK sheet. The transformer compartment is completely separated from the medium voltage and low voltage compartments.

RECEIVING / INSPECTION / STORAGE

The Package Compact Substation is shipped from the factory ready for installation on site. It has been submitted to all normal routine tests before being shipped, and it is not required to do any voltage testing before putting it into service, provided the substation has not sustained any damage during transportation.

Immediately upon receipt of the Package Compact Substation, examine them to determine if any damage or loss was sustained during transit. If abuse or rough handling is evident, file a damage claim with carrier and promptly notify the nearest ABB office. ABB ELECTRICAL INDUSTRIES CO. LTD. is not responsible for damage of goods after delivery to the carrier; however, we will lend assistance if notified of claims.

PERSONNEL SAFETY

The first and most important requirements are the protection against contact with live parts during normal service as well as maintenance or modifications.

This is the reason why all live parts have been metal enclosed, so that when the parts are live and the Package Compact Substation doors are open, no one can be able to touch them.

Also, it is safe in case any short-circuiting or sparking occurs at the busbars.

VENTILATION

Transformer compartment has been provided with sand trap louvers, to prevent ingress of sand and that proper air circulation should take place.

EARTHING

Proper earthing busbar has been provided.

HANDLING

Lifting lugs has been provided on top of four corners of the housing for lifting the DPS by crane and chains as a single unit, otherwise this can be done by a forklift of sufficient capacity, but the lifting fork must be positioned under the transformer portion.

INSTALLATIONS

A clean, flat surface capable of supporting the Package Compact Substation unit weight is the only requirement for a foundation. It is, however, important that adequate accessibility, ventilation and ease of inspection of the unit must be provided.

In all installation work, the safety regulations for electrical installations have to be observed.

Each Package Compact Substation must be permanently grounded or earthed by connecting an affective recognised ground or earth as prescribed by the latest applicable edition of IEC or ANSI requirements.The Package Compact Substation is designed to operate with a solidly grounded neutral system. The neutral connection should be solidly and permanently grounded.

Tap connections

All units have taps located in the High Voltage winding. The tap arrangement is shown on the nameplate of the transformer. These taps are provided to furnish rated output voltage when the input voltage differs from the rated voltage.
To change tap connections, do the following steps:

1. De-energized the unit, short-circuit both the high and low voltage connections and ground both sides.
2. Unlock the tap changer handle, and then move the taps changer handle to the desired tap, then locked the tap changer handle.
3. Remove safety shorts and ground connections from the high voltage and low voltage buses.

After ensuring that no tools or hardware was left in the enclosure, and the enclosures are closed properly, you may then re-energize the Package Compact Substation. Make sure that the tap connections are proper for the required voltage as listed on the nameplate. The transformer is normally shipped with the tap changer for the rated voltage.

Cable connections

When making outside cable connections, conductors suitable for at least 85°C should be used. All connections should be made without placing undue stress on the terminals. Conductors should be securely fastened in place and adequately supported with allowances for expansion and contraction.

FINAL INSPECTION PRIOR TO ENERGIZATION

After the Package Compact Substation has been found to be in good condition and the protective equipment is operational, the substation may be connected to the network. However, it is recommended that the transformer to be left to settle for 1 or 2 days after installation so those air bubbles in the oil have time to dissolve before connecting the voltage.
Before energizing the unit, a complete electrical inspection should be made. The following checklist should be used as a minimum requirement.

Electrical Inspection

All external connections have been made properly (phasing of connections to terminals, etc.).

All connections are tight and secure.

All accessory circuits are operational. Check the transformer protective equipment and test

the function of their electrical circuits:
Thermometers (alarms, tripping)

Pressure relay (tripping)
Oil level indicator

Ensure that all fuses are inserted and in the correct position

All tap connections are properly positioned.

The neutral and ground connections have been properly made.

Mechanical Inspection

All shipping members have been removed.

There is no obstructions in or near the openings for ventilation.
No tools or other articles are left inside the enclosures.
All protective covers are in place or closed and bolted tight.

MAINTENANCE AND PERIODIC INSPECTION

In order to assure a long lifetime and correct and reliable operation of equipment delivered for this facility it is of utmost importance to perform maintenance regularly.
Following general rules should always be considered before starting maintenance activity.

1. Authority from responsible engineer shall always be obtained before starting any maintenance.
2. Follow safety procedure established in carrying out the work.

Realize that no set of safety *or maintenance instructions* will ever be written that can adequately cover all accident possibilities.
Therefore **"SAFETY"** as dictated by actual current conditions, always takes precedence over any previously prepared safety or maintenance instructions. Assume nothing. Take the precautions that you personally deem necessary in addition to those included in standard practice.

- Be familiar with the drawings and previous test records before starting activity.
- Scrutinize maintenance instructions given for the equipment to be maintained.

Maintenance information is given in the Operation and Maintenance Manual for each type of equipment.
The main dangers of such process are:

- Inaccessible lubrication points (greased for life) cannot be lubricated and may seize up.
- Areas not lubricated may be subject to corrosion.
- The high-pressure spray may damage equipment.
- Especially protective coatings may be removed.

Bolt Tightness

All connections should be tight and secure. Bolts and nuts on busbar and terminal lugs should be torqued and marked properly.

Inspection and Testing

The need for preventive maintenance will vary on operating conditions. Where heavy dust conditions exist, an accumulation of dust on the equipment may effect the operation of unit substation and its protective apparatus.

When normal maintenance inspection and cleaning of bus connections, relays, lug connections, and other part of the distribution system is being made, it is advisable to operate and check circuit breakeror switch-disconnector operation.

Routine Field Testing

Routine field testing of the electrical equipment is intended to enable maintenance personal to determine, without laboratory conditions or complicated equipment, that a particular electrical equipment is able to perform its basic circuit functions.

The following constitutes a guide to tests that might be performed during routine maintenance.

1. **Insulation Resistance Test**

   Extreme atmospheres and conditions may reduce the dielectric withstand ability of any insulating material. An instrument commonly known as "megger" is used to perform this test.

   The voltage recommended for this test should be at least 50 percent greater than the circuit rating; however, a minimum of 500 volts is permissible. Tests should be made between phases of opposite polarity as well as from current carrying parts of the circuit protective device to ground. Also, a test should be made between the line-and-load terminals with the circuit protective device in the "OFF" position.

   Resistance values below one mega ohm are considered unsafe and should be investigated for possible contamination on the surfaces.

   NOTE: For individual circuit protective device's resistance readings, load and line conductors should be disconnected. If not disconnected, the test measurements will also include the characteristics of the attached circuits.

   A temperature and humidity reading are recommended and recorded during the testing period.

   Insulation resistivity is markedly effected by temperature and humidity conditions. Based condition of one (1) mega ohm per kV assumes a 20°C wet bulb reading. The following table shall be used to adjust readings to the 20°C constant.

2. **Connection Test**

   Connections to the circuit protective device should be inspected to determine that a proper electrical joint is present. If overheating in these connections is evident by discoloration or signs of arcing, the connections should be removed and the connecting surfaces clean before re-connections. It is essential that electrical connections be made properly to prevent and reduce overheating.

3. **Mechanical Operation**

During routine tests, mechanical operation of the circuit protective devices or disconnects should be checked by turning it "ON" and "OFF" at least three times.

3.5 INTERFERENCE AND SCREENING

Interference is one of the most serious as well as most common problems in audio electronics. We encounter interference when it produces effects like noise, hiss, hum or cross-talk. If a radio engineer faces such problems, good theoretical knowledge as well as experience is required to overcome them.

However, it should be considered, that interference is always present. All technical remedies only aim at reducing the effect of interference to such a degree, that it is neither audible nor disturbing. This is mainly achieved by different ways of screening. This paper will explain the technical background of interference and provides some common rules and hints which may help you to reduce the problems.

TYPES OF INTERFERENCE.

Theoretically, the effects and mechanism of a single interference can well be calculated. But in practice, the complex coupling systems between pieces of equipment prevent precise prediction of interference. The following picture shows the different types of interference coupling. The different types of interference between the components of an electric system. If we consider all possible coupling paths in the diagram above we will find 10 different paths. This means a variety of 1024 different combinations. It should be noted, that not only the number of paths, but also their intensity is important.

SYMMETRICAL AND ASYMMETRICAL INTERFERENCE.

Having a closer look at the interference of cable, we find that hf-interference currents cause measurable levels on signal (audio) lines and on supply lines. A ground-free interference source would produce signals on a cable which spread along the line. These voltages and currents can be called symmetrical interference. In practice this rarely occurs.

Through interference, asymmetrical signals are produced in respect to the ground. The asymmetrical interference current flows along the two wires of the symmetrical line to the sink and via the ground back to the source. These interference signals are cancelled at the symmetrical input.

GALVANIC COUPLING OF INTERFERENCE.

Galvanic coupling of interference occurs if the source and the sink of interference are coupled by a conductive path. As can be seen from the equivalent circuit diagram, the source impedance of the interference consists of the resistance RC and the inductance LC of the conductor, which are common to the two parts of the circuit. From these elements the interference source voltage can be calculated.

CAPACITIVE COUPLING OF INTERFERENCE.

The capacitive coupling of interference occurs due to any capacitance between the source and sink of interference.

Principle of capacitive coupling of interference.

The current in the interference sink can be calculated as
The interference voltage in the sink is proportional to its impedance. Systems of high impedance are therefore more sensitive to interference than those of low impedance. The coupled interference current depends on the rate of change of the interference and on the coupling capacitance CC.

INDUCTIVE COUPLING OF INTERFERENCE.

Inductive coupling of interference occurs if the interference sink is in the magnetic field of the interference source (e.g. coils, cables, etc.)
Principle of the inductive coupling of interference.

The interference voltage induced by inductive coupling is

- **increasing the distance between conductors**
- **mounting conductors close to conductive surfaces**
- **using short conductors**
- **avoiding parallel conductors**
- **screening**
- **using twisted cable**

Note that by the same means the capacitive as well as the inductive coupling of interference will be reduced.

3.5 Electrostatic And Electromagnetic Interference

INTERFERENCE BY RADIATION.

Interference by electromagnetic radiation becomes important at cable lengths greater than 1/7 of the wavelength of the signals. At frequencies beyond 30Mhz, most of the interference occurs by e.m. radiation

Principle of the coupling by e.m. Interference.

INTERFERENCE BY ELECTROSTATIC CHARGE.

Charged persons and objects can store electrical charges of up to several micro- Coulombs, which means voltages of some 10kV in respect to ground. Dry air, artificial fabrics and friction favour these conditions. When touching grounded equipment, an instantaneous discharge produces arcing with short, high current pulses and associated strong changes of the e.m. field.

REDUCTION OF INTERFERENCE

There are a number of methods to prevent interference. But all of them only **reduce** the interference and never fully prevent it. This means there will never be a system which is 100% safe from interference. Because the efforts and the cost will rise with the degree of reduction of interference, a compromise has to be found between the effort and the result.
The requirement for the reduction of interference will depend on:

- The strength of the interference source
- The sensitivity of the interference sink
- The problems caused by interference

- The costs of the equipment

We will discuss ways of preventing interference, their effect, and the main aspects for the optimum efficiency of each method.

3.6 GROUNDING (OR EARTHING).

This is one of the simplest but most efficient methods to reduce interference. Grounding can be used for three different purposes:

1. Protection Ground

Provides protection for the operators from dangerous voltages. Widely used on mains-operated equipment.

2. Function Ground

The ground is used as a conductive path for signals.

Example: in asymmetrical cables screen, which is one conductor for the signal, is connected to the ground.

3. Screening Ground

Used to provide a neutral electrical path for the interference, to prevent that the interfering voltages or currents from entering the circuit. In this chapter we will only consider the third aspect. Grounding of equipment is often required for the cases 1 or 2 anyhow, so that the screening ground is available "free of charge". Sometimes the grounding potential, provided by the mains connection, is very "polluted". This means that the ground potential itself already carries an interfering signal. This is especially likely if there are big power consumers in the neighbourhood or even in the same building. Using such a ground might do more harm than good.

The quality of the ground line can be tested by measuring it with a storage scope against some other ground connection, e.g. a metal water pipe or some metal parts of the construction.

Never use the Neutral (N) of the mains as ground.

It might contain strong interference, Because it carries the load current of all electrical consumers. The grounding can be done by single-point grounding or by multi-point grounding. Each method has advantages which depend on the frequency range of the signal frequencies. All parts to be grounded are connected to one central point. This results in no "ground loops" being produced. This means the grounding conductors do not form any closed conductive path in which magnetic interference could induce currents. Furthermore, conductive lines between the equipment are avoided, which could produce galvanic coupling of interference. Central grounding requires consistent arrangement of the grounding circuit and requires insulation of the individual parts of the circuit. This is sometimes very difficult to achieve.*A* system using the single-point grounding.

MULTI-POINT GROUNDING:

In multi-point grounding all parts are connected to ground at as many points as possible. This requires that the ground potential itself is as widely spread as possible. In practice, all conductive parts of the chassis, the cases, the shielding, the room and the installation are included in the network.

SCREENING.

When considering the effect of electrical and magnetic fields, we have to distinguish between low and high frequencies. At high frequencies the skin effect plays an important roll for the screening. The penetration describes the depth from the surface of the conductor, where the current density has decayed to 37% compared to the surface of the conductor.

SCREENING OF CABLES.

When signal lines run close to interference sources or when the signal circuit is very sensitive to interference, screening of signal lines will give an improvement. There are different ways of connecting the cable screen:

Three different ways of connecting the cable screen .Cable screen not connected. This screen will not prevent any interference, because the charge on the screen, produced by interference, will remain and will effect the central signal line. Also, the current induced by interference in the line will flow through the sink, effecting the signal. Cable screen grounded on one side only. This screen will only prevent interference at low frequency signals. For electromagnetic interference, where the wavelength is short compared to the length of the cable, the screening efficiency is poor. Cable screen grounded on either side is effective for all kinds of interference. Any current induced in the screen by magnetic interference will flow to ground. The inner of the cable is not affected. Only the voltage drop on the screen will affect the signal in the screen. type of grounding is
- Ensure proper and careful connection of the screens.
- Use suitable plugs in connection with the cable screen.

3.7 MULTIPLE EARTH AND EARTH LOOPS

SIMPLE TWO SYNODIC PERIOD CYCLER (CASE 1)

The simple two Earth-Mars synodic period cycler. In the circular coplanar model it has a period P=l.348 years, a radius of aphelion R~ =1 .15 A U and the V, at Earth is 5.6 *M s* . For the "Up" transfer, the Earth-Mars transfer is Type I or I1 and the Mars-Earth leg is Type VI. The trajectory departs the Earth with the V, inward of the Earth's velocity vector taking it through a perihelion of about 0.93 AU, crossing the Earth's orbit ahead of the Earth and outward to Mars' orbit. As seen from Figure 1 the transfer to Mars is about 225 degrees and takes a little over nine months. The trajectory continues onward making three complete orbits about the Sun without coming near either the Earth or Mars again until passing through its original starting point on the Earth's orbit for the third time, somewhat behind the Earth and finally encountering the Earth 2/7 of a revolution about the Sun (102.9 deg.) from the starting point. The cycler has made 3 2/7 complete orbits about the Sun while Earth has made 4 2/7. The Earth flyby must now rotate the incoming V, vector, which is outward, to the symmetrically inward orientation to begin the next cycle. Unfortunately, the rotation angle required is approximately 135 degrees and with a V, of 5.65 km/s the Earth can only rotate the V, vector about 82 degrees. Now in the actual Solar System, the orbit of Mars is elliptical with a semi-major axis of 1.524 AU, a perihelion of 1.381 AU and **an** aphelion of 1.666 AU. Thus the simple Case 1 cycler does not quite reach Mars' average distance from the Sun. It is thus clear that a real world version of the Case 1 cycler would require **AV** to make up for the inability of the Earth to rotate the V, vector, as well as for the fact that over the course of seven cycles, of two synodic periods each, the Case 1 cycler will not make it to Mars' orbit more than one half of the time. The real value of Case 1 is as a basis for variations that can address these deficiencies.

TWO SYNODIC PERIOD CYCLER WITH "BACKFLIP" (CASE 2)

Modifylng Case 1 by introducing another Earth flyby, approximately six months and 180 degrees after the first, changes the situation somewhat. This six month, 180 degree transfer, or "backflip" trajectory, was first introduced for lunar trajectories by U p h ~ f f . ~ The "Up" trajectory for this version leaves the Earth with a Type I or I1 short transfer to Mars and a Type V transfer back to Earth. This transfer to the first Earth encounter makes 2 11/14 revolutions about the Sun in 3 11/14 years. The Earth flyby then puts the vehicle onto a heliocentric orbit with a period of one year which re-encounters the Earth approximately six months and 180 degrees later, completing the **3** 217 revolutions in 4 2/7 years. This second Earth flyby then sends the vehicle on to the next Mars encounter, continuing the cycle. Figure 2 shows this cycler trajectory. Note that the first Earth encounter is in the lower portion of the plot. The backflip trajectory is not shown since its difference from the Earth's orbit is primarily in the z-direction. The second Earth flyby and departure point for the second cycle is indicated slightly left of straight up on the Earth's orbit. In the circular co-planar model the Earth-Mars-Earth trajectory has a period P=l.325 years, a radius of aphelion R~ z l . 4A5 U and the V, at Earth is 4.15 ***MS***F**.**or Case 2, the transfer does not reach Mars' orbit in the circular co-planar model, but in the real world does reach Mars when Mars is near its perihelion.

The lower V, for Case 2 enables the Earth to rotate the V, vector as much as about 102 degrees, thus easily enabling the first Earth flyby to rotate the incoming V, to the required near polar orientation required for the backflip trajectory outgoing V, as well as the second earth flyby to rotate the near polar incoming V, to the outgoing V, required

for the transfer to the next Mars, Thus, although Case 2 has many desirable characteristics, it cannot be used for an entire seven cycles. If fact it will reach Mars for at most two of the seven cycles without propulsive AV to augment the gravity assists.

TWO SYNODIC PERIOD CYCLER WITH "BACKFLIP" PLUS 1-YEAR LOOP (CASE 3)

Modifying Case 2 to introduce a third Earth flyby in addition to the "backflip" adds additional flexibility. This is accomplished by adding a one year Earth-Earth loop either before or after the backflip. The order of the one year loop and the "backflip" can be chosen to best advantage in the real world. The **TJp"** trajectory for this version leaves the Earth with a Type I short transfer to Mars and a Type I11 or IV transfer back to Earth. This transfer to the first Earth encounter makes 1 11/14 revolutions about the Sun in 2 11/14 years. The Earth flyby the puts the vehicle onto a heliocentric orbit with a period of one year which re-encounters the Earth approximately six months and 180 degrees later and then re-encounters the Earth one year later, or vice versa. The final Earth flyby then sends the vehicle on to the next Mars encounter. Figure 3 shows this cycler trajectory. Again as in Case 2, the backflip trajectory is not seen. The one year Earth-Earth loop is also not shown. In the circular co-planar model the Earth-Mars-Earth trajectory has a period **P=l.484** years, a radius of aphelion R~=l .65A U and the V, at Earth is **5.4** km/s.

In this case the transfer reaches an aphelion approximately equal to Mars' aphelion and will thus always cross Mars orbit in the real world. Analysis of Case 3 with the actual ephemerides of Earth and Mars is considered in more detail below.

1-YEAR LOOP (CASE 3)

TWO SYNODIC PERIOD CYCLER WITH ONE OR TWO 1-YEAR LOOPS

Modifying Case 1 to introduce one or two one year Earth-Earth loops or even a two year Earth-Earth loop without a backflip is also possible, it leads however, to much higher V,'s less desirable characteristics that any of Cases 1,2 or 3, or the Aldrin Cycler for that matter.

DETAILED ANALYSIS OF CASE 3

A detailed analysis of Case 3 was performed using the actual ephemerides of the Earth and Mars. The trajectories were modeled as Sun-centered point-to-point conics connecting the Earth and Mars flybys. The flybys were modeled as instantaneous V m rotations. This – V m -matching‖ model gives excellent insight into both the heliocentric and planetocentric trajectories and sufficient accuracy for developing long term trajectory scenarios that can be closely reproduced with fully numerically integrated trajectory models. The Table shows data for a full cycle of seven two-synodic period cyclers (30 years). This should approximately repeat since the Earth and Mars are very nearly at the same inertial positions every 15 years.The choice of one year loop or backflip and whether the backflip is –north‖ or –south‖ needs to be made in each case to make best use of the arrival and departure V,‘s to minimize the required bending by the Earth and potential required **AV.** The Mars flybys (given to the nearest 1000 km) are all at reasonably high altitudes. Whereas in the circular co-planar analysis the Mars flybys are arbitrarily high, in the real world the Mars gravity assist must control the inclination of the heliocentric orbit as well as adjust the energy slightly to properly phase for the next encounter. The Mars V,‘s vary between about 3 km/s and **8** km/s which compares to the value of 5.3 km/s in the circular coplanar case. The Earth V,‘s vary between about **4** km/s and 7.5 km/s which compares to 5.4 km/s.