linger, Jastram and Daunt[6] in which an adjustable voltage is transformed by means of a vacuum tube into a proportional, adjustable current, which is used to drive a fixed mutual inductor. This arrangement avoids the need of a variable mutual inductor previously used for similar measurements.

An a-c 4-point-probe resistivity bridge devised by Logan,[7] shown in general form in Fig. 10, uses isolators and an inverter. This circuit makes possible measurements on a 4-terminal unknown without a preliminary balance, such as required by a Kelvin bridge. It can be easily shown that, if $Z_1 = Z_2$, then $Z_X = \alpha R Z_1/Z_3$. Note that all active devices used in this circuit have a common ground.

Integrators have been used in commercial transfer-ratio bridges to obtain the quadrature voltage reference required. Where complex transmission characteristics are measured by comparison with a simulated circuit, it is difficult to decide whether the device is a bridge or an analog computer. This latter field has a vast literature on the design and use of operational amplifiers.

A New Incremental Inductance Bridge • A simplified circuit diagram of a new incremental inductance bridge is shown in Fig. 11. It uses two isolators and a negative voltage-to-current converter. The null conditions can be easily obtained by setting $I_1 + I_2 + I_3 + I_4 = 0$. If we let R_B equal the total resistance to ground from point B, including R_f, then

$$\frac{I_1 + I_2 = I_3 + I_4}{E_{in}} = \frac{R'_B}{R'_B + R_x + j\omega L_x}\left(\frac{1}{R_f} + \alpha j\omega\, C_s + \alpha\beta G_s\right) - \frac{R_d}{R_e\,(R_c + R_d)} = 0 \quad (1)$$

or

$$\frac{1}{R_f} + \alpha\, j\omega C_s + \alpha\,\beta\, G_s = \frac{R'_B + R_x + j\omega L_x}{R'_B} \times \frac{R_d}{R_e\,(R_c + R_d)} \quad (2)$$

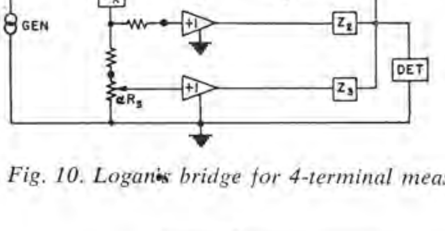

Fig. 10. Logan's bridge for 4-terminal measurements

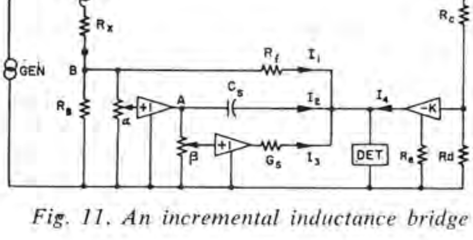

Fig. 11. An incremental inductance bridge

If

$$\frac{1}{R_f} = \frac{R_d}{R_e\,(R_c + R_d)}$$

then

$$L_x = \frac{\alpha\, C_s\, R'_B\, R_e\,(R_c + R_d)}{R_d} \quad (3)$$

$$R_x = \frac{\alpha\,\beta\, G_s\, R'_B\, R_e\,(R_c + R_d)}{R_d} \quad (4)$$

$$Q_x = \frac{\omega L_x}{R_x} = \frac{\omega C_s}{\beta\, G_s} \quad (5)$$

The potentiometer adjustment α can be calibrated to read L_X and β to read Q_X. If the second potentiometer is connected to point A instead of point B, it can be easily shown that β will be proportional to R_X instead of $1/Q_X$.

The advantages of this circuit are

1. It will read either Q_X or R_X. Use of the R_X connection when low-Q inductors are measured avoids the "sliding null" (slow balance convergence).
2. The bridge can easily be made to read Q directly at any number of frequencies if a switch is used to place the required value of G_S in the circuit.
3. The current through the unknown inductor is not affected by the balance adjustments. (A variable impedance in series with a nonlinear unknown can cause annoying difficulties.)
4. The resistor R_B may be of very low value since it is fixed and therefore the voltage applied to the unknown is very nearly equal to that applied to the bridge input terminals (a feature particularly important for measurements on nonlinear inductors).
5. Because R_B is small, a large direct current may be passed by the unknown without excessive power dissipation.
6. Because the alternating voltage across R_B is only a small fraction of the voltage across the unknown, a large voltage may be applied without overdriving the active devices.
7. The value of C_S may be changed at different frequencies to provide a reasonable inductance range at any frequency.
8. The oscillator and detector are both grounded and no output bridge transformer is used that would be subject to magnetic coupling to the unknown inductor or generator.
9. Both balance adjustments are continuously variable, making rapid adjustments possible.

This bridge has 1 per cent accuracy, limited mainly by the ability to read the dials. It is direct reading in Q at nine frequencies between 50 cps and 15.75 kc and has an over-all range from 0.1 μhenry to 1,000 henries.

PRACTICAL LIMITATIONS OF ACTIVE DEVICES

Unfortunately, the ideal active devices used in the preceding discussion are not available (and for that