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PART I

THE USE OF A MAGNETIC PICKUP AS AN ALIGNMENT INDICATOR WITH A STRETCHED-WIRE TECHNIQUE

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PROPOSED SYSTEMS AND CIRCUITS FOR MAGNETIC ALIGNMENT PICKUPS

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PART I

THE USE OF A MAGNETIC PICKUP AS AN ALIGNMENT INDICATOR WITH A STRETCHED-WIRE TECHNIQUE

The 8 BeV and 20 BeV spectrometers require continuous alignment information as the angles of the instruments are changed. A stretched wire reference is practical for the distance involved; we, therefore, need a non-intercepting, remote reading, location device. The problem is similar to that of the beam points or indicators on the accelerator.

Let us consider a wire passing through a small "door frame" magnet, wound either with a pair of "elephant ear" windings or two identical windings around the legs (Fig. 1). Let the proportions be as shown and let the number of turns be n. Let a current i at a frequency $\omega/2\pi$ be passed through the wire and let us observe the current I induced in the magnet winding. Let us apply the flux reciprocity theorem

$$\sum_{i=1}^{n} \Phi_i \; I_i' = \sum_{i=1}^{n} \Phi_i' \; I_i \qquad (1)$$

where Φ_i is the flux linking the i^{th} circuit carrying a current I_i and Φ_i' and I_i' similar quantities under different excitation. This theorem can easily be derived from the symmetry under interchange of i and j of the coefficient of mutual inductance

$$M_{ij} = \frac{\mu_o}{4\pi} \int \int \frac{d\vec{\ell}_i \cdot d\vec{\ell}_j}{r_{ij}} = \frac{\Phi_i}{I_j} = \frac{\Phi_j}{I_i} \qquad (2)$$

between the i^{th} and j^{th} circuit, where $d\vec{\ell}_i$ and $d\vec{\ell}_j$ are elementary lengths of conductors separated by a distance r_{ij}. Consider first the case where $i = 0$ in circuit B and where I has a given value.

The magnetic field in the gap is uniform and is given by $B = n \mu_o I/g$. The flux linking coil B is then

$$\Phi = \frac{x \ell n \mu_o I}{g} \tag{3}$$

since at $x = 0$ the flux through the opening and through the return yoke would exactly cancel. The mutual inductance between circuits A and B is thus

$$M = \mu_o x \ell n/g \tag{4}$$

and thus the voltage induced in A if B is excited by a current i, becomes, ignoring a phase factor:

$$V = \frac{\omega \mu_o x \ell n i}{g} \tag{5}$$

The self inductance of circuit A is

$$L = \frac{n^2 \mu_o w \ell}{g} \tag{6}$$

and this is maximum power transferred to an external circuit is

$$P = V^2/2\omega L = \frac{i^2}{2} \left\{ \frac{\mu_o x^2 \ell}{g w} \omega \right\} \tag{7}$$

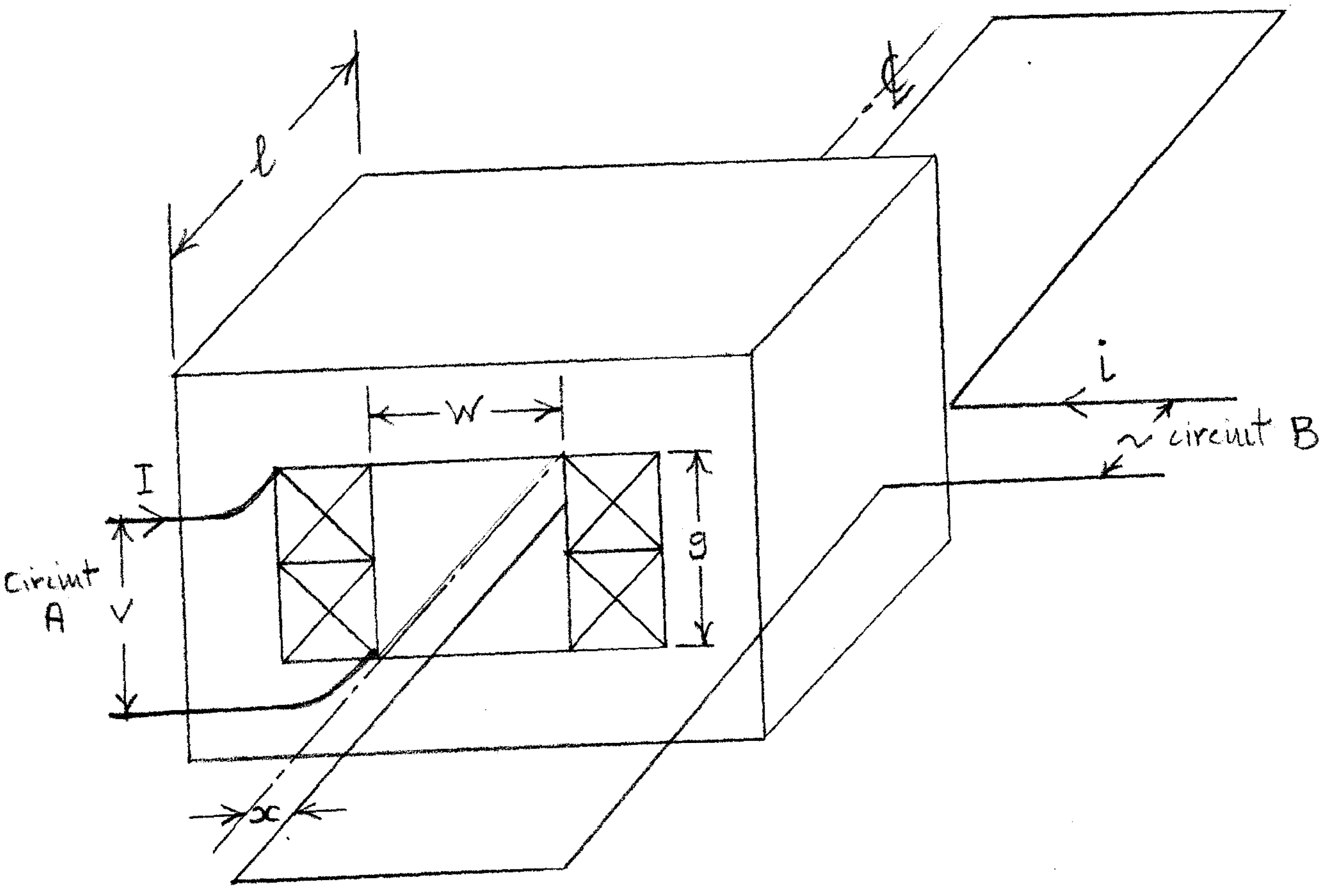
For an effective noise temperature T_n the noise power is

$$P_n = (2/\pi) k T_n \Delta \omega \tag{8}$$

at a bandwidth $\Delta\omega$, and thus the signal/noise ratio is

$$P/P_n = \frac{i^2}{k\,T_n}\left(\frac{\pi\,\mu_0}{4}\right)\frac{x^2\,\ell}{g\,w}\left(\frac{\omega}{\Delta\omega}\right) \tag{9}$$

Numerical examples show that P/P_n is very large for most practical cases.



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PART II

PROPOSED SYSTEMS AND CIRCUITS FOR MAGNETIC ALIGNMENT PICKUPS

It is required to provide an input to the computer from the magnetic pickup described by W. Panofsky.

Three of the magnetic pickups will be mounted on both ends of each magnet of the 8 and 20 BeV spectrometers and will sense the positions of the magnets, using two alignment wires as a reference. The computer will read the outputs from the pickups and determine whether the magnets are correctly positioned within their tolerances. In the event of their being malpositioned, the computer will provide the information necessary to place them back in alignment.

The magnetic pickups are similar to a scaled down bending magnet with a laminated door frame magnetic circuit (see Figure 1a). They are mounted on the spectrometer magnets so that the alignment wire passes through the window in each pickup.

A 10 kc/s current on the alignment wire induces an emf in the coil of the pickups that relates their position to that of the wire. The electrical circuit of the pickup may consist of one elephant ear winding similar to the coil on a bending magnet, or two coils, one on each limb of the door frame magnetic circuit (Figure 1b). The main factor affecting the linearity of a pickup is the flatness and parallelism of the pole faces. However, if a small (0.007 inch) slit is cut in the y axis to divide the magnetic circuit in the center of the poles, the sensitivity of the pickup increases considerably and the effect on the linearity is negligible. The presence of a slit facilitates the removal or replacement of a pickup without disturbing the rest of the system since the alignment wire is fine enough to be passed through the slit. In addition, a broken alignment wire may be replaced by lowering the new span of wire through the slits in the pickups rather than by slotting the wire through each window, a process that requires considerable skill in order to avoid kinking or damaging the fine wire.

Figure 1b shows a magnetic pickup that is similar in mode of operation to the pickup in Figure 1a. This pattern of pickup is suggested because it is more economical to produce in quantity, and uses standard transformer coil forms.

In the experimental model of this pickup, the magnetic circuit was machined from a hypersil alloy transformer core. This material consists of 0.001 inch thick laminations glued together to form a monolithic block. It has a low eddy current loss at the frequency of operation (10 kc/s) and is easy to machine. It was found that standard types of audio transformer lamination could not provide the flatness and parallelism required for the pole faces when stacked in the normal manner.

The pickups are nonintercepting position sensors that operate in a manner similar to a differential transformer. The emf induced in the coil of the pickup is proportional to the x displacement of the wire from the center of the window (see Figure 1a). When the wire is in the center of the window (on the y axis) the emf's induced in the two halves of the coil are equal and opposite, the output being zero volts. An x displacement of the alignment wire produces an increased induced emf in the side of the coil closest to the wire, and a corresponding decrease in the induced emf in the side furthest from the wire. The resulting difference in the induced emfs is presented at the terminations of the coil. The two-coil pickup shown in Figure 1b operates in a manner similar to the one in Figure 1a, the difference being that the emfs are induced in separate coils that oppose (buck). In both types of pickups the phase of the output signal inverts relative to the signal on the alignment wire when the wire moves across the y axis.

The way to present the information from the pickups to the computer is to amplify and demodulate the ac signals to give dc levels. The dc levels may be sampled by the computer through an analogue to digital converter fitted with a multiplexing unit. Figures 2 and 3 show block diagrams of two feasible systems which enable the information from any number of pickups to be read almost simultaneously.

Figure 2 shows an alignment system that has an amplifier-demodulator for each pickup. The oscillator that provides the signal on the alignment wire has a demodulator drive incorporated (see Figure 6). The demodulator drive supplies a square wave reference signal that switches all of the demodulators simultaneously. It is synchronized with the 10 kc/s oscillator and has provisions to adjust the level, symmetry and delay of the square wave pulses. The delay adjustment is to compensate for the phase shift in the system between the oscillator and the demodulators. The lower portion of the circuit in Figure 6 shows the 10 kc/s oscillator and demodulator drive circuitry. As is, the demodulator drive output stage will drive 12 demodulator units, and the addition of an extra emitter-follower stage will provide enough drive for 100 units. The square wave pulses may be fed through over 100 feet of RG 196AU (50 ohm) cable to the demodulators without serious deterioration in their shape. The upper portion of Figure 6 shows the stabilized power supply and an output stage that matches the load presented by an experimental 40 foot span of alignment wire. The stabilization of the power supply was necessary to maintain a constant current level on the alignment wire with line voltage fluctuations. In this unit, the sine wave output contains less than 5 percent harmonic distortion; however, a push-pull output stage may be used for the final alignment system to reduce even harmonic distortion to a minimum. A low even harmonic distortion is advantageous because the demodulator integrates the area of either the positive or the negative halves of the sine wave for a period of 1/2f seconds, the polarity depending on the phase of the reference signal. Thus, it is necessary that the sine wave be symmetrical about its axis in order for the demodulator to present the same sensitivity when dealing with either polarity. Figure 5 shows a circuit of one of the amplifier-demodulator units for this system. The unit consists of an inexpensive operational amplifier strapped to have the desired gain and a one transistor demodulator. The demodulator functions as a shunt chopper that shorts either the positive or negative portions of the sine wave to ground depending upon the phase relationship that is given by the reference signal. The remaining half wave portions are smoothed to provide the dc level output. This dc level will be fed into the multiplexing unit on the analogue to digital converter in order to be sampled by the computer. The amplifier-demodulator units will be mounted close to the magnetic pickups and the dc level outputs may be fed to the computer or readout area by regular PVC insulated wire.

This system was constructed using one pickup and one amplifier-demodulator, and tested. The output of the demodulator was approximately 6 Mv per 0.001 inches displacement of the alignment wire and the pickup gave a linear output to 0.05 inches either side of center. The drift in the demodulator output was approximately 0.06 Mv per °C when the amplifier demodulator unit was temperature cycled between 20°C and 70°C. The long term drift is awaiting further investigation; however, a 'short' long term drift over a period of 3 days showed a change of 1.5 Mv in the output level superimposed on a reading of 30 Mv although the reliability of this test is questionable.

Unlike the experimental pickup used in the above test run the poles of the pickup described by Dr. Panofsky are not divided by a 0.007 inch slit. In order to calculate the sensitivity of this pickup from Eq. 5 (page 2) an experimental correction factor of 3 must be included because of the increased sensitivity provided by the slit.

The output of the pickup may be calculated using Eq. 5 where

$$\omega = 2\pi \times 10^4$$

$$\mu_o = 4\pi \times 10^{-7} \text{ MKS units}$$

$$x = .001 \text{ inches} = 2.54 \times 10^{-5} \text{ meters}$$

$$n = 482 \text{ turns}$$

$$i = 45 \times 10^{-3} \text{ amps}$$

$$\frac{\ell}{g} = 1$$

Correction factor = 3

$$\text{Sensitivity} = 3 \times 2\pi \times 4\pi \times 2.54 \times 482 \times 45 \times 10^{-11} \text{ Volts/.001 inch}$$

$$= \underline{130\ \mu V/.001 \text{ inch}}$$

The voltage gain of the operational amplifier (Fig. 5) is the ratio of values of the feed back resistor (1 Meg) and the input series resistor (6.8k)

$$\text{Voltage gain} = \frac{10^6}{6.8 \times 10^3} = 147$$

The attenuation provided by the demodulator may be estimated in the following manner. The 1Mfd smoothing capacitor on the demodulator output (between D and ground in Fig. 5) is charged through 10.2k-ohm (the two 5.1k resistors in series) when the transistor is switched off, and discharged through 5.1k-ohm when the transistor is on. Since the charge and discharge time intervals are equal, the capacitor assumes a dc voltage that is 1/3 of the average value of the applied sine wave.

$$\text{Attenuation factor} = 1/3 \times \frac{\text{Average}}{\text{rms}} = 0.30$$

The sensitivity of the pickup, amplifier and demodulator combined is then

$$130 \times 10^{-6} \times 147 \times 0.30 = 6.12\text{Mv}/.001 \text{ inch}$$

This calculated value agrees quite well with the test results.

Figure 3 shows a system that uses an isolating amplifier for each pickup and an amplifier demodulator that is common to all of these units. The isolating amplifiers are mounted close to the pickups to convert their high impedance output to match the 50 ohm impedance of the co-ax cables, and to isolate the capacitance presented by different lengths of co-ax cable from the inductive magnetic pickups. These isolating amplifiers may be a unity gain emitter follower unit, the circuit shown in Fig. 4. This type of amplifier has the simplicity of circuit required for this application and an excellent voltage gain stability. The amplifier-demodulator and its sampling switch may be placed close to the computer, or at a point that is convenient for all of the co-ax cables coming from the isolating amplifiers to converge. Since all of the pickups are identical, and all of the isolating amplifiers are identical, it may be reasonably assumed that the phase shifts produced by them are identical. The amounts of phase shift in the various lengths of co-ax cable that connect the isolating amplifiers to the sampling switch may be considered negligible. Thus, the phase shift between the alignment wire and the demodulator may be considered equal for each of the pickup channels. One phase reference signal set to compensate for this phase shift is sufficient to drive the common demodulator.

The mode of operation of the computer is such that the dc levels that represent the movement between pickup and alignment wire must be continuously available for the computer to read. This involves storing the demodulated signal for each channel or sampling switch position until the switch rescans the positions to reestablish or modify the demodulated dc levels. If this storage is in an analogue form (a charge on a storage capacitor), a multiplexing unit and analogue to digital converter may be used in this system as well as the system shown in Fig 2. Alternatively, the output from the demodulator may connect directly into an analogue to digital converter. The digital equivalent of the demodulated signal level may then be stored with an address on magnetic disks or on suitable digital storage system, until information is required by the computer. Digital storage has the inherent advantage that the information remains until modified, whereas dc voltage level storage on a capacitor decays exponentially because it is permanently connected to the finite input resistance of the electronic multiplexing unit. DC level storage has the advantage that it is more flexible and may be used to drive remote readouts, profile monitors, servo-systems, etc. Future requirements may demand the use of these or similar instruments. The sampling switch would have to be a comparatively slow scan device because the dwell time at each position cannot be less than the time taken for the demodulator to resolve the ac signal level and present steady dc output. If a dc level storage system is used, certain compromises will have to be made concerning the demodulator output impedance the capacitor size, the maximum resistive load on the capacitors, and the scanning rate of the sampling switch.

After the capacitors have reached a steady state of charge, it may be assumed that the average load on the demodulator equals the sum of the loads across the capacitors. If there are x sampling positions and R is the resistance of the load across each capacitor, then the total resistance 'seen' by the demodulator = R/x ohms.

The size of the capacitor depends upon the maximum tolerable drop in charge due to its resistive load during the period of one scan of the sampling switch.

If t_1 seconds is the time taken for one scan of the sampling switch and y is the percentage drop in charge for t_1 seconds, the value of storage capacitor is given by:

$$C \simeq \frac{100\, t_1 \times 10^6}{Ry} \text{ micro-farads}$$

Ideally, the sampling switch would spend all of its time dwelling upon the sampling positions, but, in practice, a non-contacting time exists between consecutive contact positions because the switch would have to be a break-before-make type.

If Z is the fraction of the time that the switch is contacting, the charging time for each capacitor is given by:

$$\frac{Zt_1}{x} \text{ seconds}$$

and to match the loads, the demodulator output resistance is given by:

$$\frac{RZ}{x} \text{ ohms}$$

The following is a numerical example using some typical values:

100 sampling positions	$x = 100$
Scan time 0.5 seconds	$t_1 = 0.5$
Fraction of dwell time 0.8	$Z = 0.8$
Maximum tolerable voltage drop on storage capacitor for time t_1 seconds is 0.25 percent	$y = 0.25$
Load on each capacitor is 25,000 ohms	$R = 25,000$

Size of capacitor:

$$C = \frac{100 \times 0.5 \times 10^6}{25000 \times 0.25}$$

$$= \underline{8000 \text{ micro-farads}}$$

To match the load, the output resistance of the demodulator must be:

$$\frac{25000 \times 0.8}{100} = \underline{200 \text{ ohms}}$$

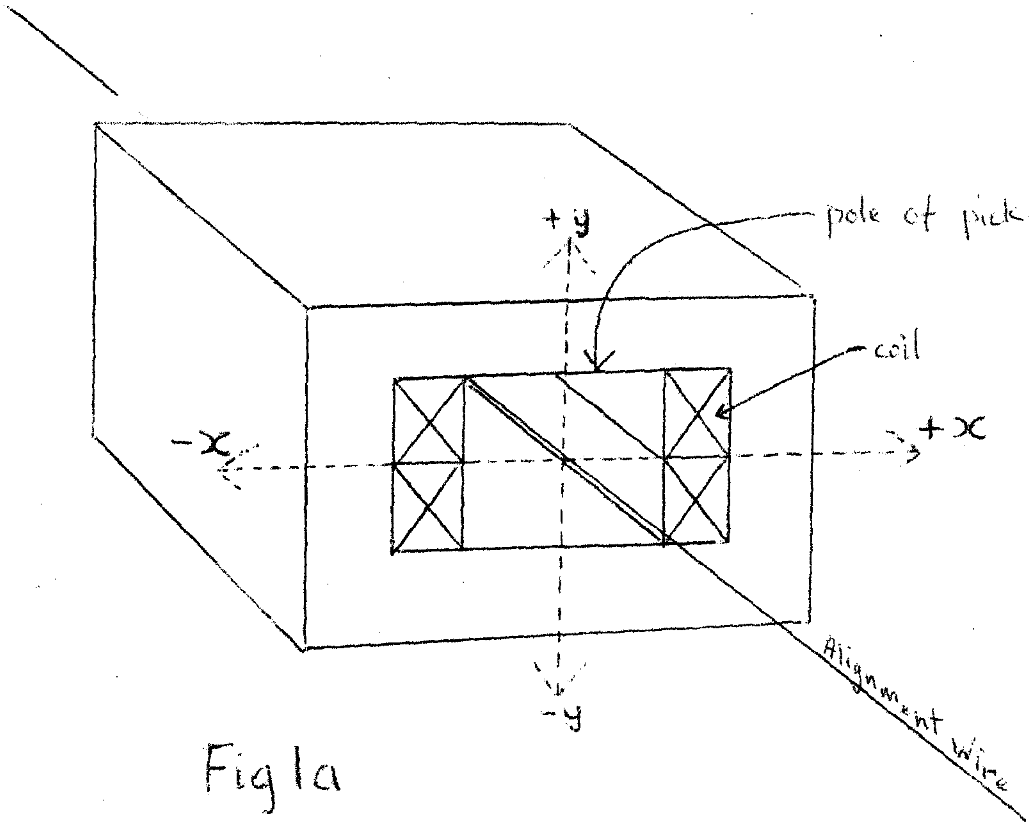

Fig 1a

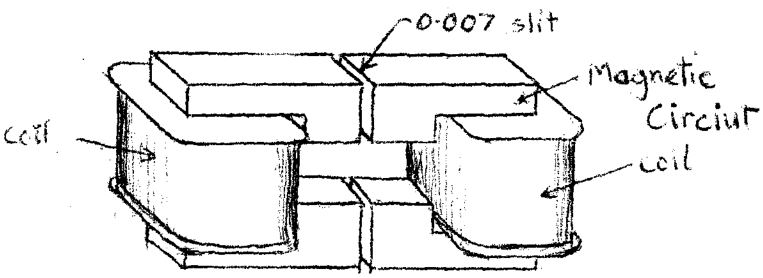

Fig 1b Experimental Magnetic Pickup

WTM

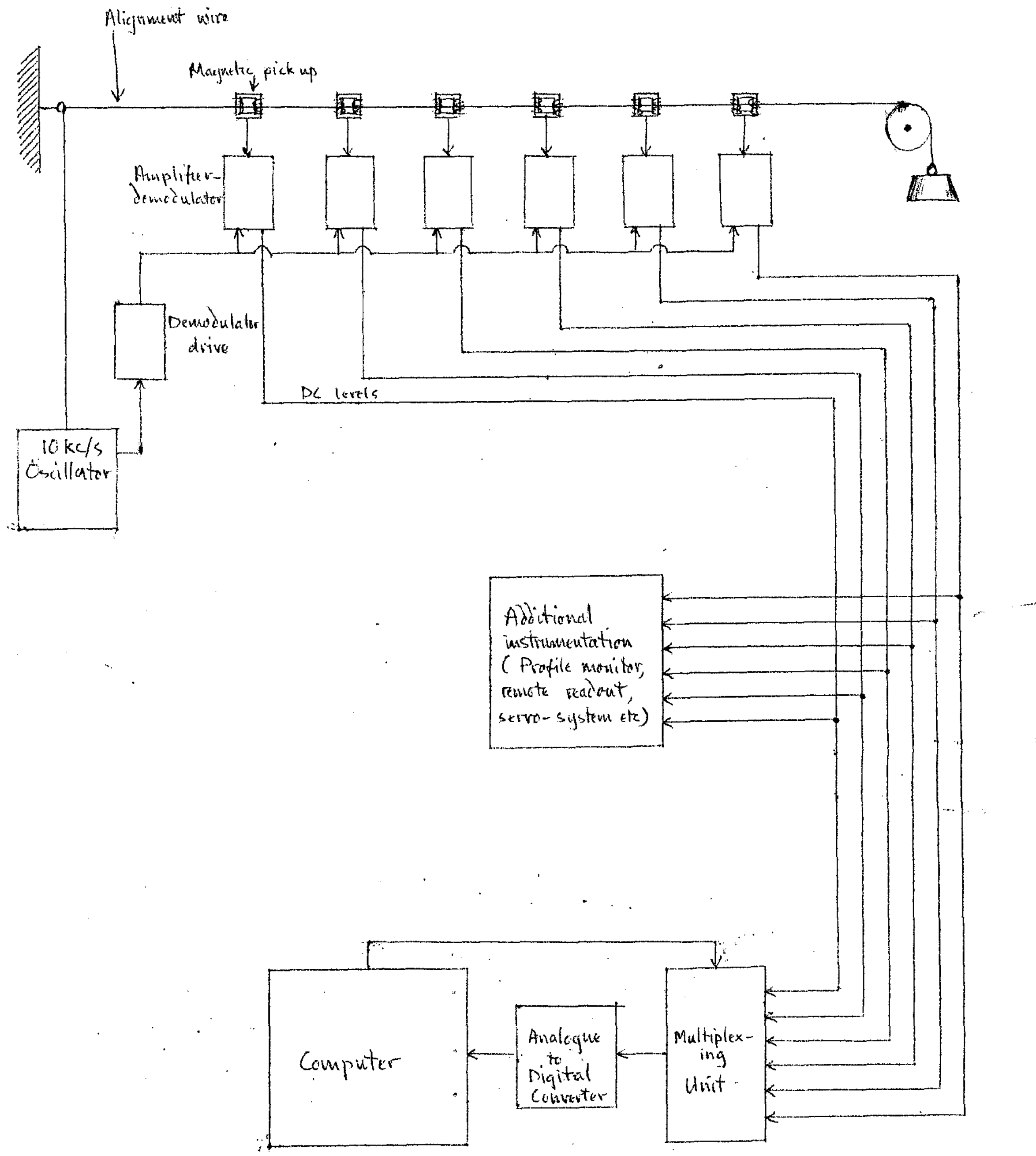

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Fig 2 System using an amplifier-demodulator for each pick-up

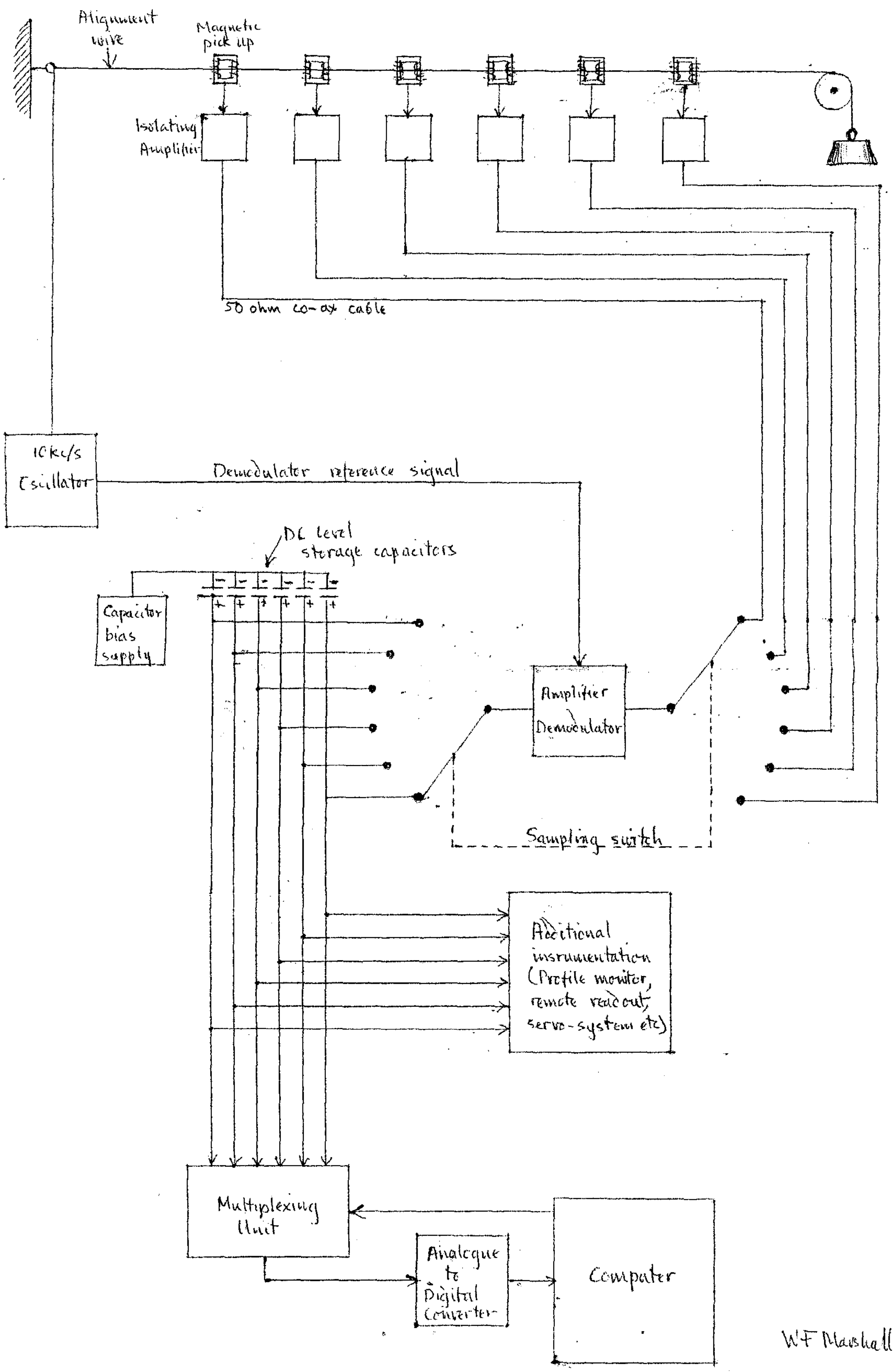

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Fig 3 System using one amplifier-demodulator and sampling switch

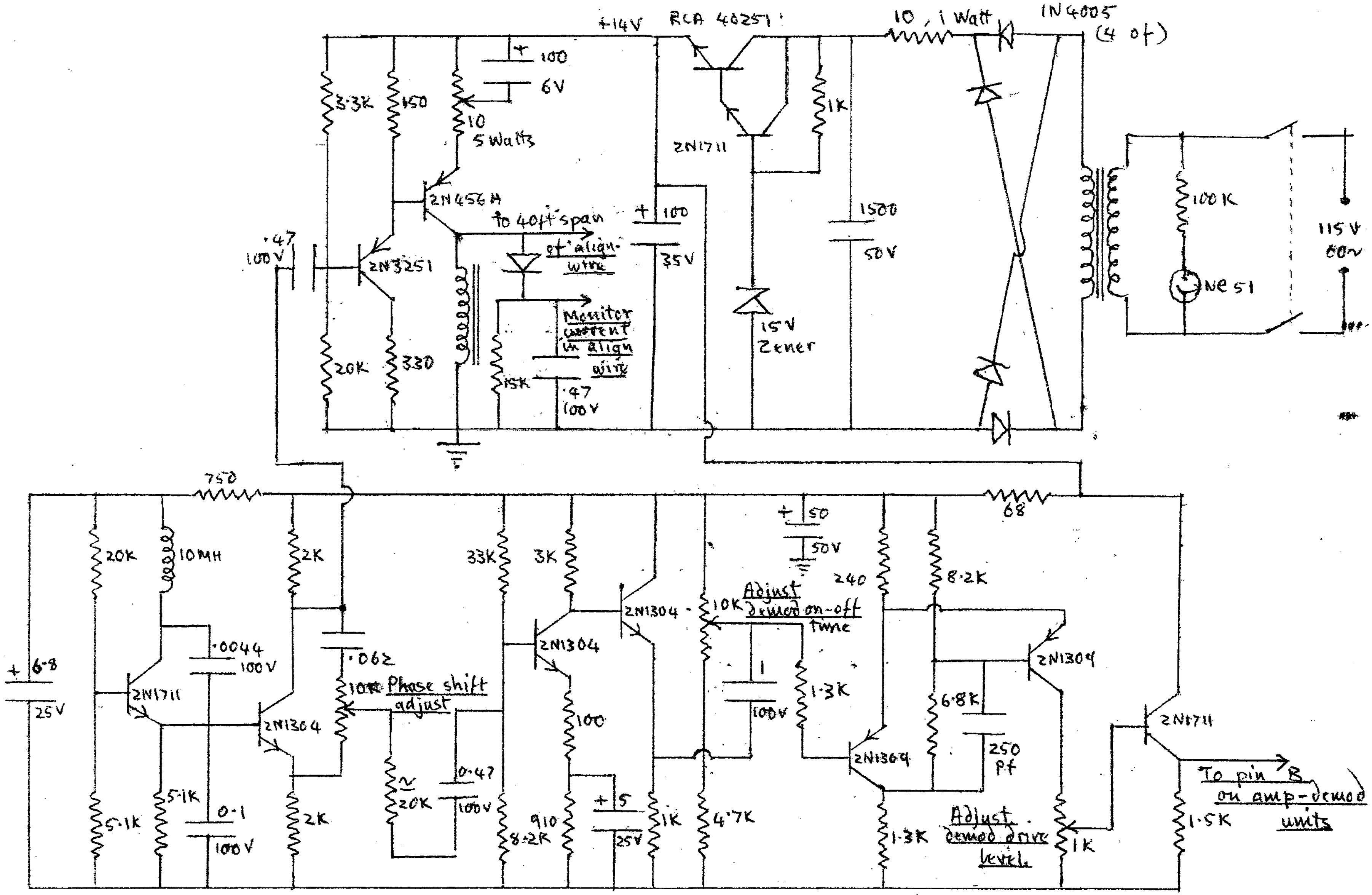

Fig 6 Oscillator, power amplifier & demodulator drive

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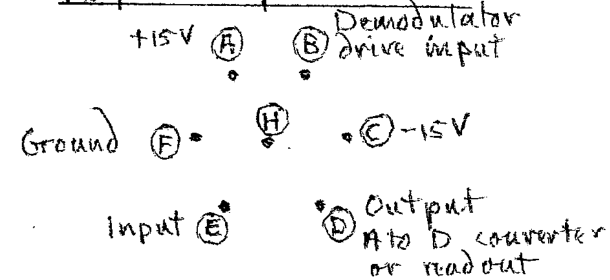
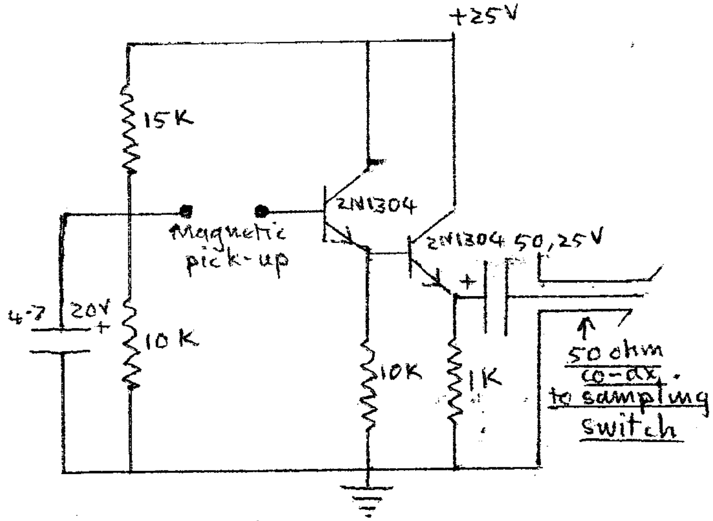
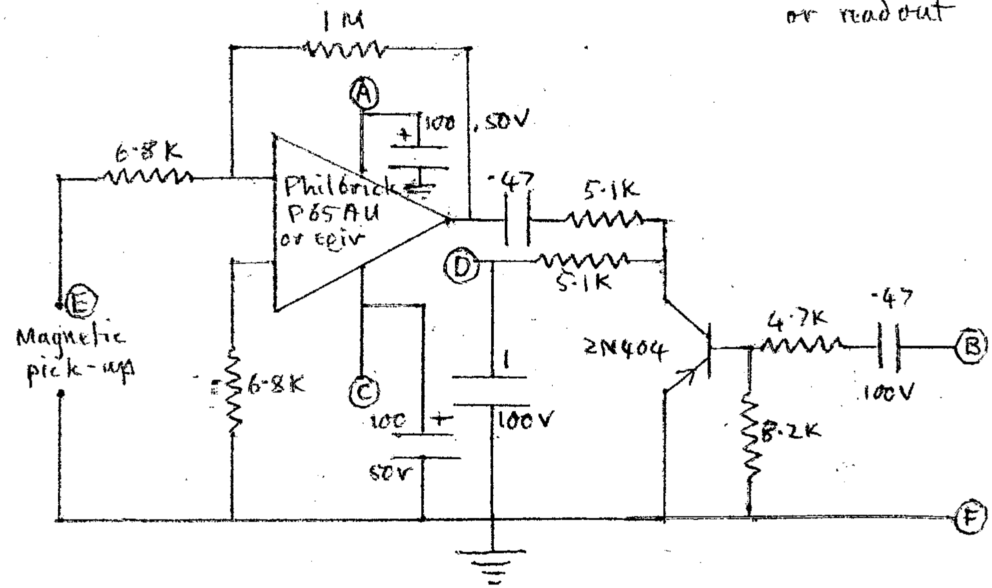
Amphenol 7pin connector





Isolating amplifier

Fig 4



Amplifier - demodulator for system in fig 2

Fig 5

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