Chapter VII

Applications

INTRODUCTION

Any process which involves mechanical positioning or measurement is a potential application for the products discussed in the previous six chapters. Therefore the purpose of this chapter is to suggest a few applications not mentioned hitherto, where synchro and resolver conversion equipment has been or could be used successfully. These examples have been deliberately chosen to illustrate the wide spectrum of potential applications for these products.

APPLICATIONS

Synchronising the phase of high speed shafts

There are many cases in industrial control and manufacturing industry where rotating shafts, positioned remotely from each other, must be controlled in phase as though they were coupled by gears. Examples of this occur in the control of propellor speed in ships to reduce vibration and in the printing industry where very precise indexing is required.

Fig. 7-1 shows how this control system can be implemented by the use of synchro control transmitters on the shafts together with a synchro to digital converter and a solid state control transmitter (SSCT1621).

The choice of the most suitable synchro to digital converter will depend upon the speed of the shafts and the accuracy of control required. The 400Hz option of the 12 bit SDC1700,

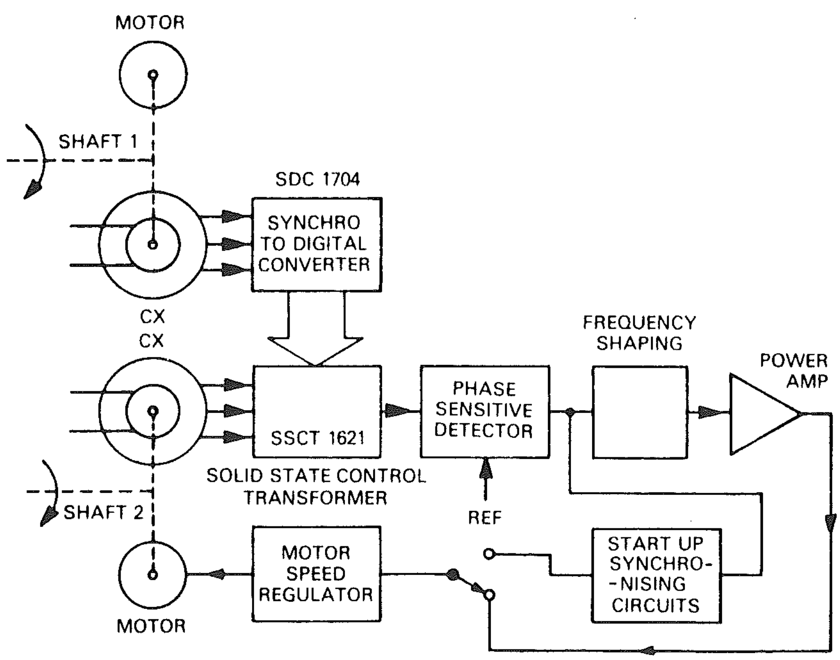

Fig. 7-1 Loop for controlling the phase of rotating shafts.

has a resolution of 5.3 Arc Mins and is capable of tracking at speeds of up to 2160 RPM while the 400Hz option of the 14 bit SDC1704 has a resolution of 1.3 Arc Mins and is capable of tracking at speeds of up to 720 RPM. The full accuracy of the converters at their maximum speed will only be obtained if suitable care has been taken to avoid reference phase shifts. (See Appendix D). In most industrial applications, the speeds are slow compared with these maximum figures and no special precautions need to be taken to get the required dynamic accuracy.

Referring to Fig. 7-1 the range of angular difference over which the output from the Solid State Control Transformer is linear is ±12.5 degrees, beyond this the output will limit for differences in angle up to ±90 degrees and beyond this, i.e. with large angular differences, the error signal can reverse. This means that the simple arrangement in Fig. 7-1 is not capable of correcting large angular errors or synchronising from differing speeds. In the case of differing speeds, the error signal will swing from one limit to the other at a frequency depending upon the speed difference. This can be made the basis of the start up control to bring the shafts to the same speed before switching to the fine control.

An alternative system, shown in Fig. 7-2, uses two synchro to digital converters with a Micro-Processor to produce the digital error signal.

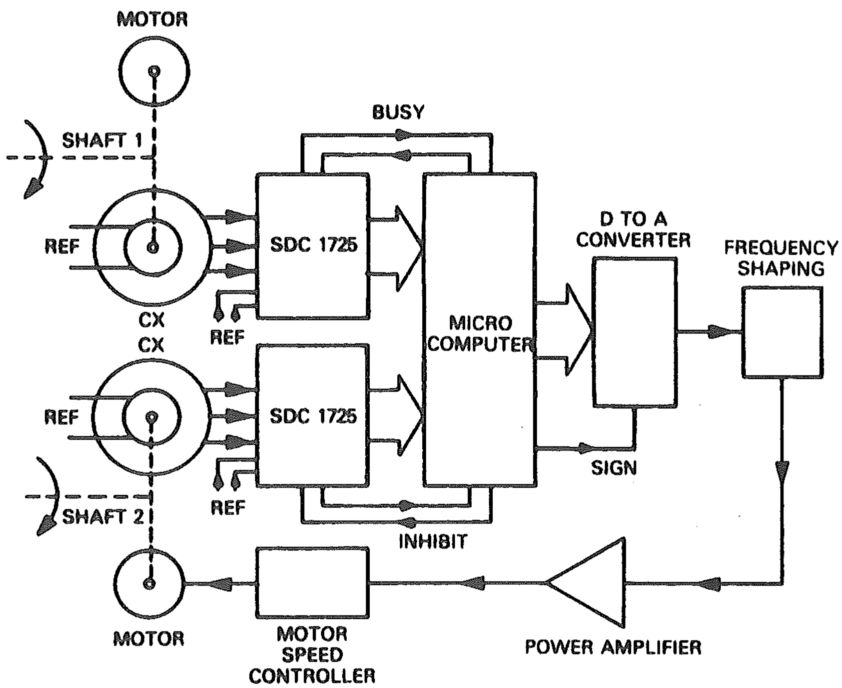

Fig. 7-2 Loop for controlling the phase of rotating shafts using two synchro to digital converters.

The type of control loop shown in Fig. 7-2, simplifies the hardware start up circuit because the most significant bits (MSB's) from the converters can be used to get the speeds into synchronism before switching to phase control.

Precision control of the difference of speed between rotating shafts

There are many applications in engineering where shafts rotating with precise but controllable differences in speed are required. Examples are in steel rolling mills, wire drawing, paper making etc. where there is a continuous elongation of the product during its manufacture. In such processes, the speed of the shafts down stream have to be controlled in order to be related to the feed speed. Very often the type of product being produced will vary from day to day and will require differing relationships between the speeds of the shafts.

Fig. 7-3 shows how this problem can be controlled by a control system using Synchro Control Transmitters and Synchro Conversion units.

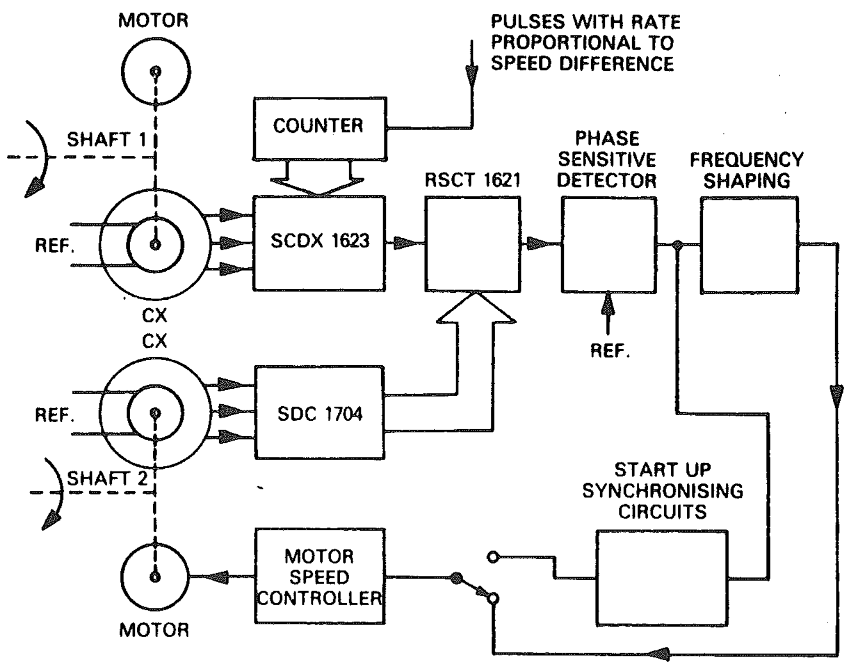

Fig. 7-3 System for producing a controllable difference in speed between shafts.

Fig. 7-4 shows an alternative method of making use of a microcomputer to produce the required pulse rate for the velocity difference.

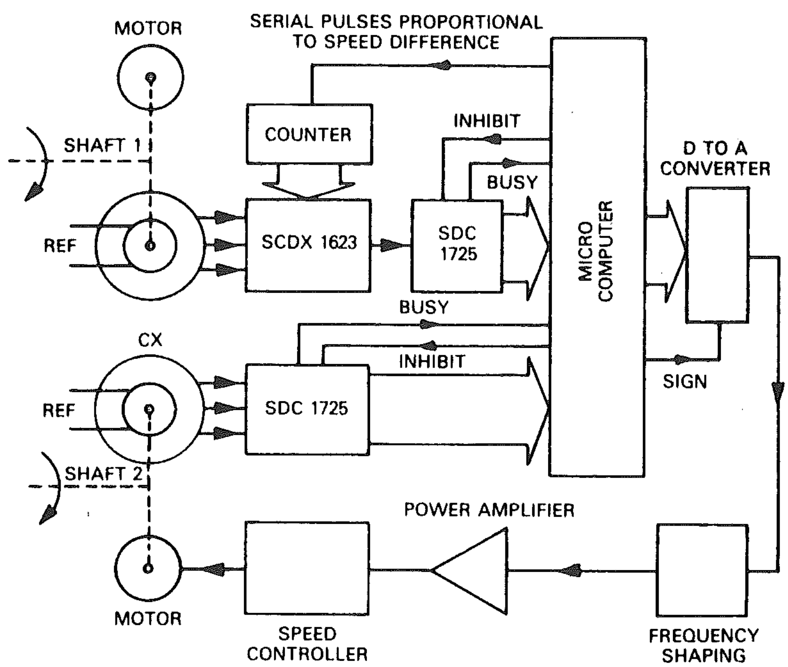

Fig. 7-4 System using a microcomputer and synchro to digital converter to control the speed difference between rotating shafts.

With both systems there are special precautions necessary during start up but in these control loops this problem is simplified by the fact that the Solid State Differential Transmitter (SCDX1623) can be fed with digital inputs from the counter to produce a stationary output. As the motor pulls in to the required speed difference, the pulse rate can be modified to give the desired difference of speed.

Both increasing and decreasing speed may be obtained with each of the systems. For a reduced speed in shaft 2, the SCDX1623 is arranged to add the digital angle. These differences can be obtained by reversing the synchro input wires S1 and S3 to the SCDX1623. Alternatively the up-down control on the counter can be used to cause the added angle to be an increasing or decreasing angle.

Changing the speed of rotation of Synchro or Resolver format signals

By interconnecting synchro (or resolver) to digital converters, digital to synchro (or resolver) converters and SCDX modules, it is possible to alter the speed of rotation of the synchro or resolver format signals.

Fig. 7-5 shows a simple example of this where an SDC is connected to a DSC to cause the output synchro signals to rotate at four times the speed of the signals on the input. (n is taken at 2).

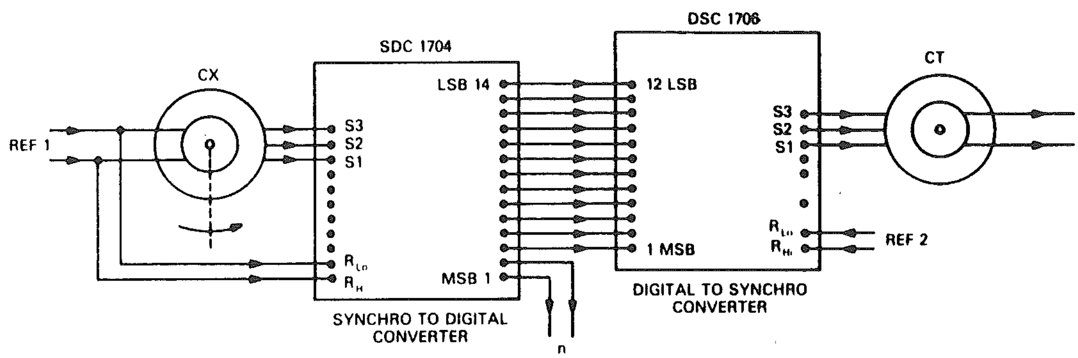

Fig. 7-5 A step up in speed of 4:1 using an SDC and a DSC.

Other possible arrangements are shown in Figs. 7-6 through 7-9. It is worth noting that in the systems shown in Figs. 7-5 and 7-6, the SDC and DSC do not have to be connected to the same reference voltage and frequency system. This provides a good method of converting from one reference system to another, the convertors being connected with a 1:1 gearing if necessary. (For 60Hz outputs, external transformers would be required for the DSC.).

Fig. 7-6 shows the interconnections to give a step down ratio of 2^n where n is the shift in the interconnections between the modules. In this case the output angular movement is limited to:

$$\frac{360}{2^n} \text{ Degrees}$$

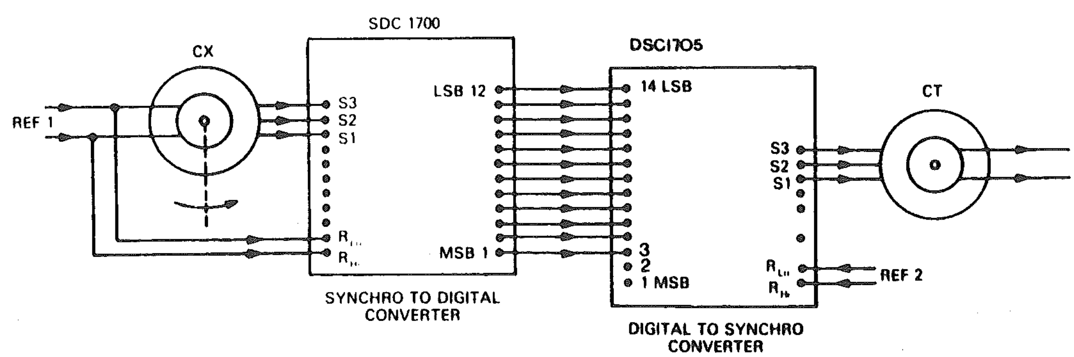

Fig. 7-6 A step down in speed of ratio 4:1 using an SDC and a DSC.

Fig. 7-7 uses an SCDX 1623 module and an SDC to give non binary step up ratios of the form (1 ± 2^n) where n is the shift in interconnections and the sign depends upon the method of connecting the input and the output of the SCDX.

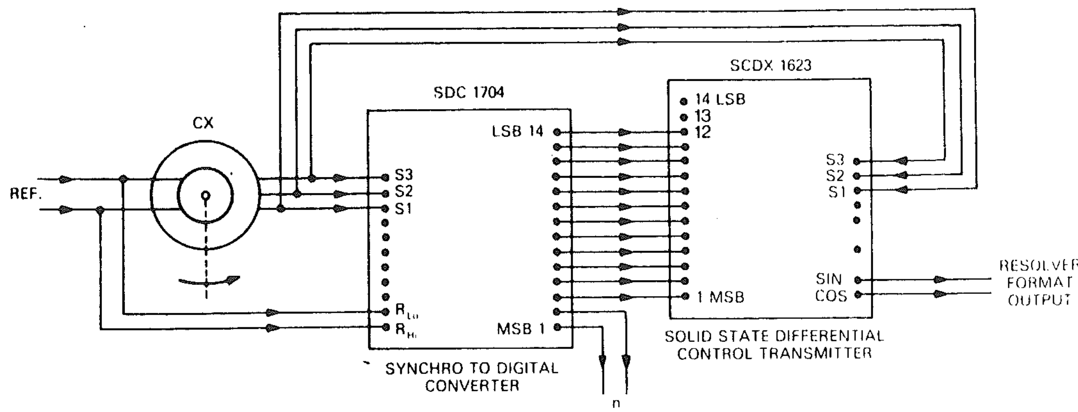

Fig. 7-7 A non binary step up speed ratio of the form 1 ± 2^n.

Fig. 7-8 uses an SCDX 1623, an RCDX1623 (Resolver Output) and an SDC. This arrangement gives a much wider range of gear ratios of the form $1 \pm 2^n \pm 2^m$ where n and m are the shifts in the interconnections and the plus and minus signs can be determined independently by the methods of connection of the SCDX's. With this arrangement for n and m up to 3, all the odd ratios from 3:1 to 17:1 are possible and the non binary ratios of 6:1 and 10:1 are obtained with $n=0$ and $m=2$ and 3.

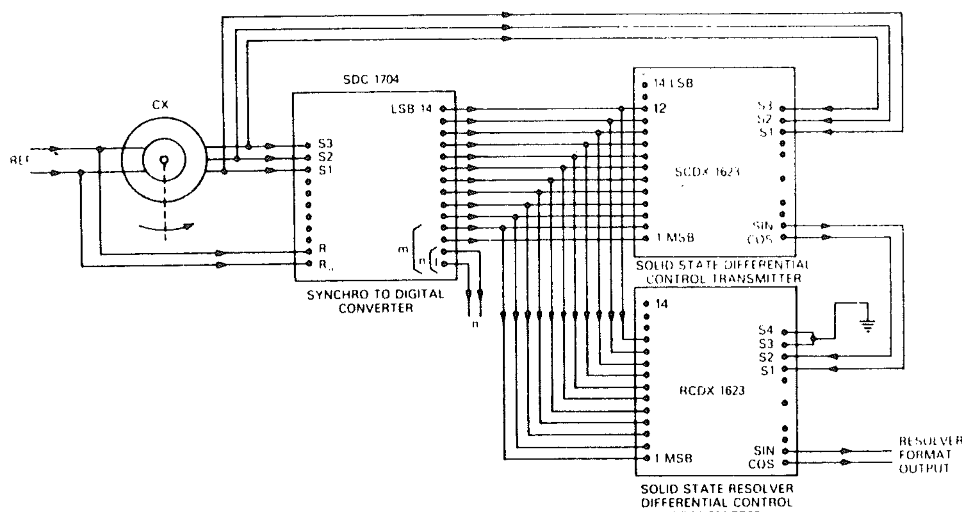

Fig. 7-8 Method of obtaining all the odd speed ratios from 3:1 to 17:1 as well as 6:1 and 10:1.

Reduction gearing can be obtained by using step up techniques in the feedback loop of SDC systems. See Fig. 7-9.

In the type of system shown in Fig. 7-9, however, there are dangers of instability unless special digital smoothing is used around the loop. The usual requirement is for the inclusion of a dominant lag (the digital equivalent to simple smoothing). This however can give rise to an output which is equivalent in operation on the input by:

$$\frac{(1 + sT)}{(sT + 1 + N)}$$

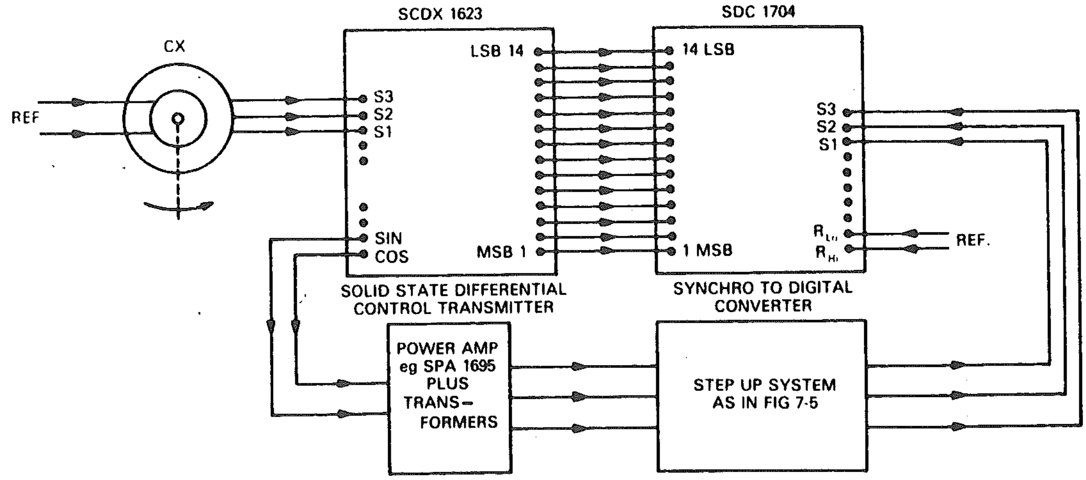

Fig. 7-9 Reduction gearing by using step up techniques in the feedback loop of an SDC system.

This would not be acceptable for many applications.

Fig. 7-10 shows how the synchro changes of speed can be used to artificially increase the angular velocity to give a better scaling from the velocity output of a synchro to digital converter. Such scaling increases the signal to noise ratio on the velocity signal.

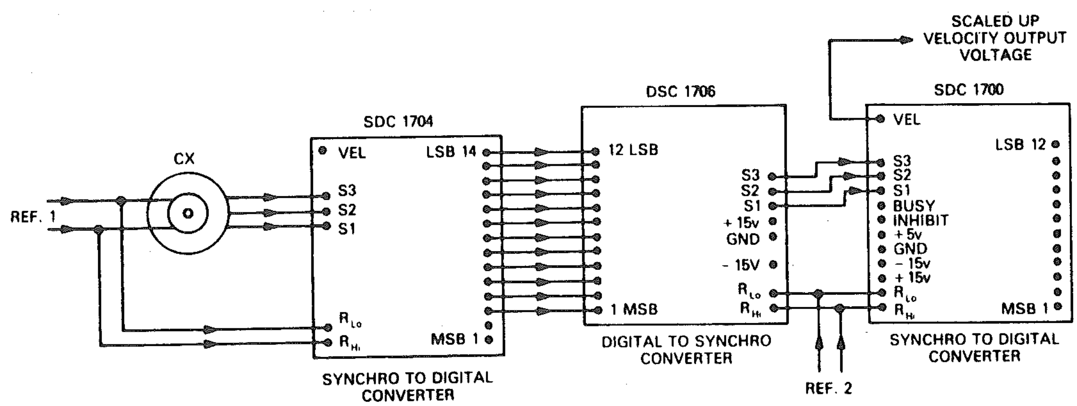

Fig. 7-10 A four times speed increase to alter D.C. velocity output scaling of an SDC.

Solid State Synchro Retransmission Systems

In complex systems, it is often necessary to distribute a common variable to a multitude of equipments. For example in a ship, the ship's gyro angular information may be needed at many different points within the ship and it may be needed for equipment requiring synchro information at different reference frequencies and speed ratios. The pitch and roll of the ship are other examples of angular data which will need to be distributed.

The traditional method of solving the retransmission problem is to produce a servo controlled shaft to which control transmitters of different frequencies can be coupled. Often, two speed systems with differing speeds are required and in this case geared shafts are the traditional solution to this problem.

Fig. 7-11 shows a simple electromechanical retransmission system. See also Fig. 6-35.

In practice, retransmission systems are generally much more complicated than a single two speed change, sometimes running up to 50 or more outputs in different forms all generated from a single input. In such cases the common shafts give simplifications whereas in solid state retransmission systems the method has equivalent common shafts but they are now the digital bus systems.

A simple solid state retransmission system going from a single speed to a two speed output

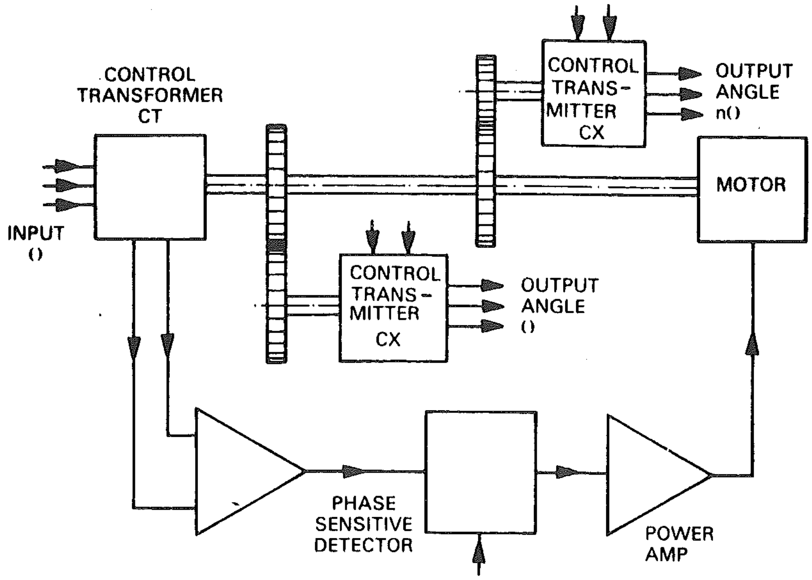

Fig. 7-11 A simple electromechanical retransmission system.

and including a reference frequency change is shown in Fig. 7-12.

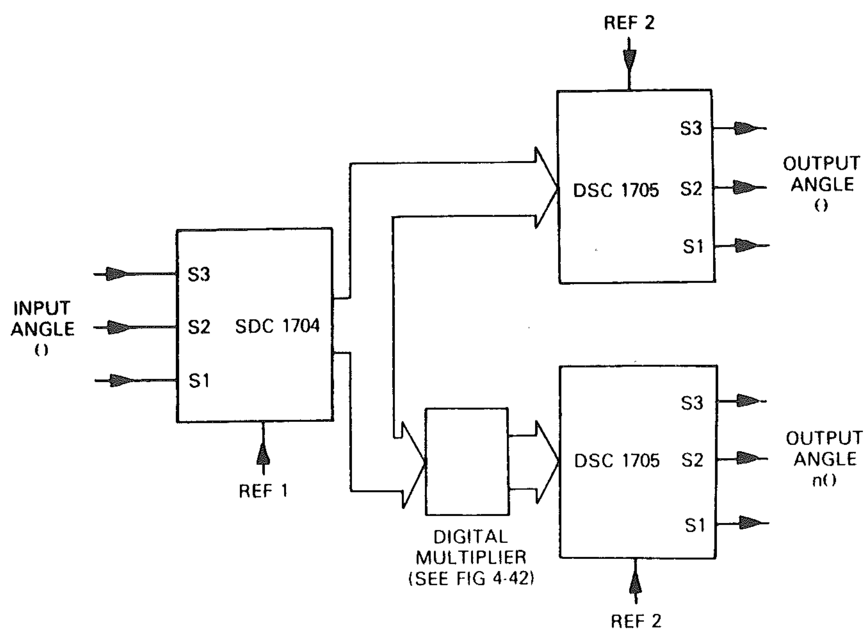

Fig. 7-12 A simple solid state retransmission system — single to two speed with reference frequency change.

An important advantage of the solid state retransmission system is that the speed of response of the SDC's is very much faster than that of the electromechanical loop.

The lack of moving parts is also a big advantage and the MTBF of the solid state method is very high.

While catastrophic failure of the electromechanical system is low, the continuous operation of the gear trains as the ship rolls and pitches means that the maintenance costs are high. The solid state system requires no maintenance.

Data Transmission by Synchro Format Signals

Although the synchro is an angle measuring or control device, the data which is transmitted in synchro format is by no means limited to being angular. In radar systems it is common for range information to be transmitted in synchro form. In ships the speed is often transmitted in synchro form as is the altitude in aircraft. In such cases as these where the data being transmitted is not fundamentally angular data, it is necessary to choose the scaling. For example it might be convenient to use 300 degrees to represent 60 knots.

According to the accuracy required it may be sufficient to use a single speed transmission or for higher accuracy, such as might be required for radar range information, two speed transmission can be used. Accuracies for single speed transmission could be typically 5 Arc Mins, but for two speed systems it could be a few seconds of Arc. In terms of ratios the 5 Arc Minutes of a single speed system when used over 360 degrees gives 1 part in 4320. In a two speed system, say 20 Arc seconds in 360 degrees gives one part in 64,800 which is adequate for such applications as radar range and altitude.

Fig. 7-13 shows some of the variables which will be transmitted in synchro format to many stations in a ship. Some are transmitting angular data but others have been transduced into synchro form to give a unified data transmission system.

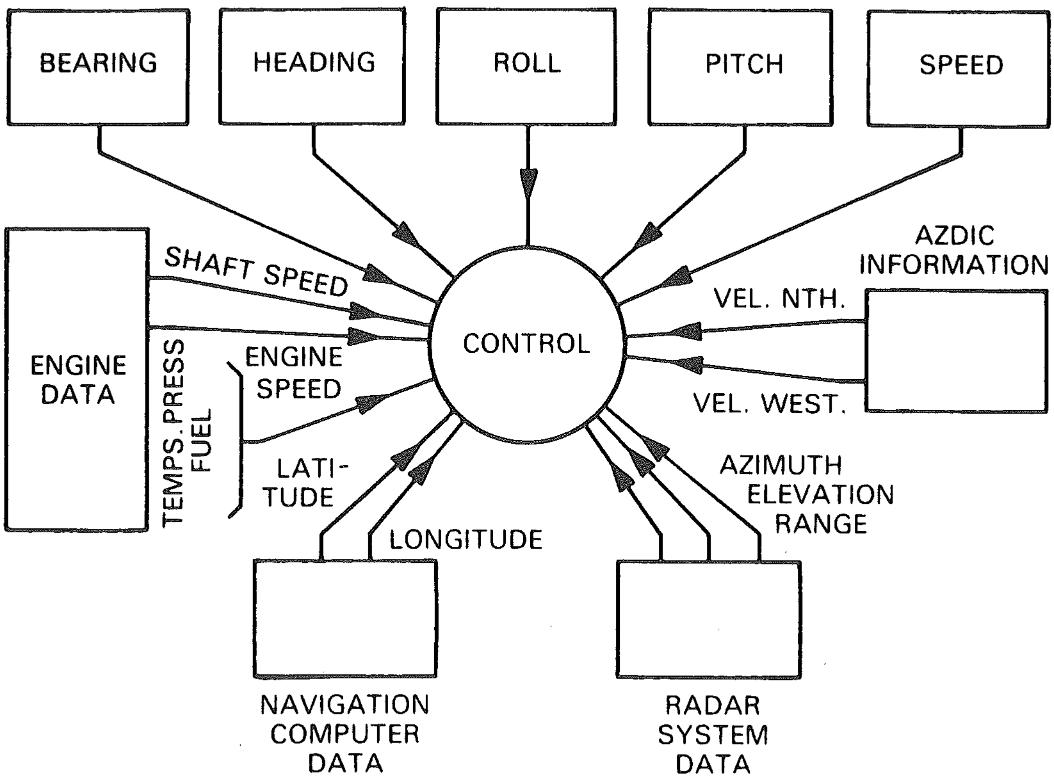

Fig. 7-13 Parameters on a ship which will be transmitted in synchro format.

Laser Theodolite angle measurement

Lasers are now used extensively in theodolite applications. The angular information provided by the theodolite may have to be sent to a central data processing station remote from the theodolite. Examples of this are on missile testing stations and in surveying.

The two speed synchro angle measuring method is ideally suited for this application as the synchro format signals can be carried by cable over distances of up to 100 metres or more and because of the relatively high noise immunity, the data will be transmitted with a very high integrity. With high coarse/fine ratios the final angular accuracy can be within a few seconds of arc.

The rotary multiple inductosyn is also suitable for this application but its requirement for higher reference frequencies means that special cable is required for transmission of the resolver form voltages over long distances. In non-mobile installations a retransmission system may be used to reduce the reference frequency. Alternatively the data can be converted to digital data and transmitted digitally using redundant codes to retain the integrity. Because the rotary inductosyn is not a truly absolute device, it will be necessary to transmit a coarse indication of the inductosyn position.

The use of Synchros or Resolvers for the positioning of reflectors in solar energy systems.

With the recent recognition of the need to find alternative sources of energy, the problem of reflecting and focussing the sun's radiation onto suitable energy converters is receiving considerable attention. Some schemes proposed simply have fixed arrays of solar cells but with other proposals, the sun's radiation is reflected by movable mirrors which focus the radiation onto a thermal converter. Other proposals involve the movement of flat arrays of cells to keep them normal to the sun's rays.

For such systems to be economic they will be required to function for many years with negligible servicing, possibly in very remote installations. The high reliability of synchros, resolvers and the digital converters make such systems an ideal choice for this type of application.

In schemes involving many mirrors a servo system incorporating a synchro or resolver can be fitted onto each axis of each mirror. Because the rotation rates are very low it is possible to use a single multiplexed successive approximation converter e.g. SSD1625 to control the movement in both axis of all mirrors in the system. It is also possible in this case to dispense with the usual sample and hold and peak detector units and multiplex all the channels into a single pair of phase sensitive rectifiers followed by smoothing, in order to provide the invariant sine and cosine inputs required by the SSD1625. The output of the SSD1625 can be fed into a microcomputer which can then individually provide each axis of each mirror with its appropriate control signal. Such a system is shown in Fig. 7-14.

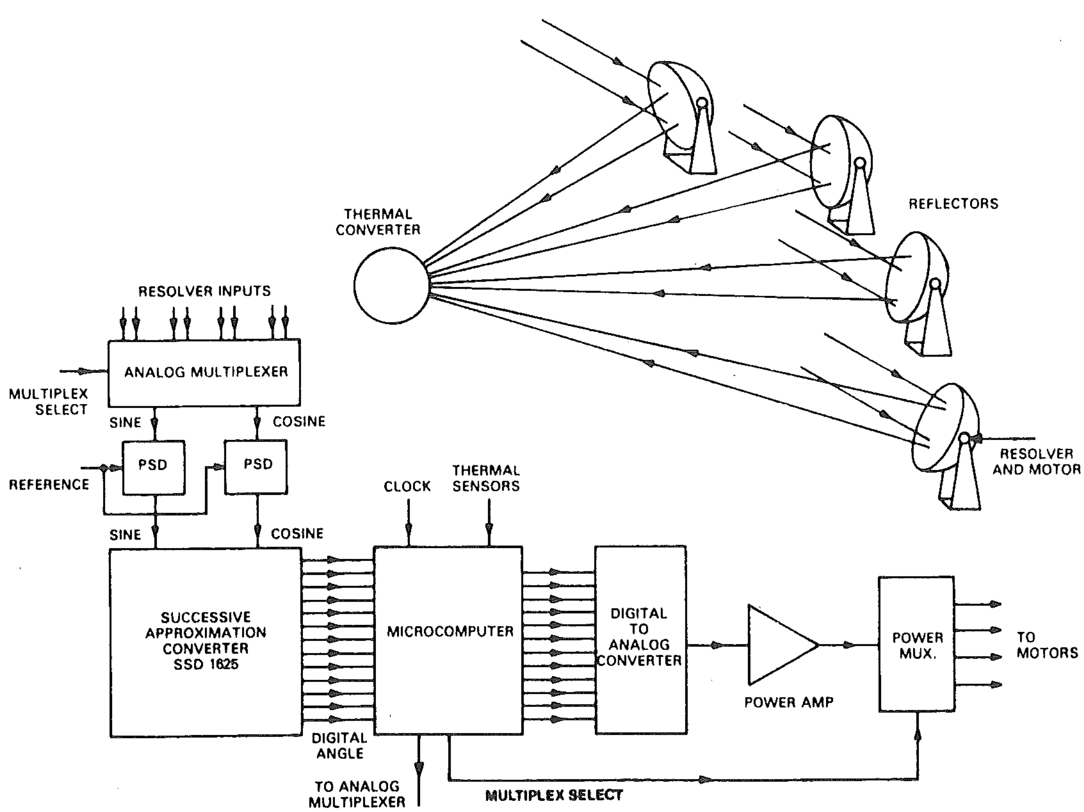

Fig. 7-14 A successive approximation converter being used to position the mirrors in a solar energy system.

In systems involving large arrays which have to be positioned normal to the sun's rays, tracking converters can be used.

Such a system is shown in Fig. 7-15.

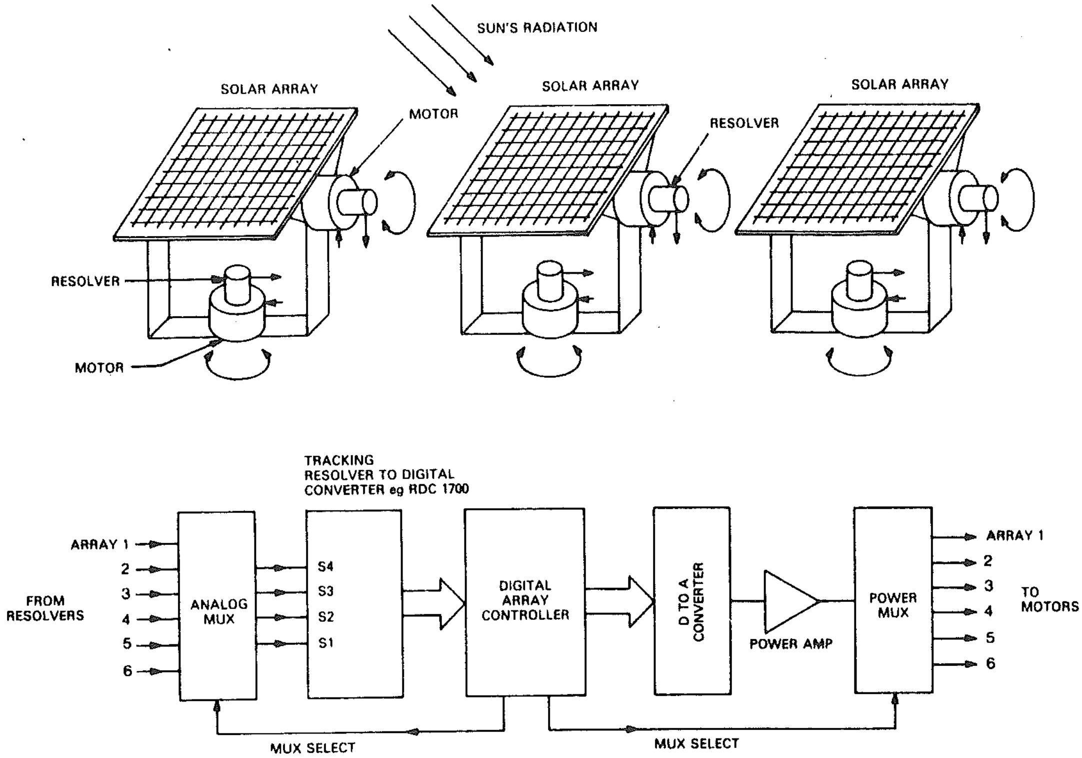

Fig. 7-15 System for the angular control of solar cell arrays.

Plan Position Indicator (PPI) waveform generation in radar systems

Fig. 7-16 shows how a Digital Vector generator (DTM1716) and a synchro to digital converter can be used to generate the waveforms required for radar PPI displays.

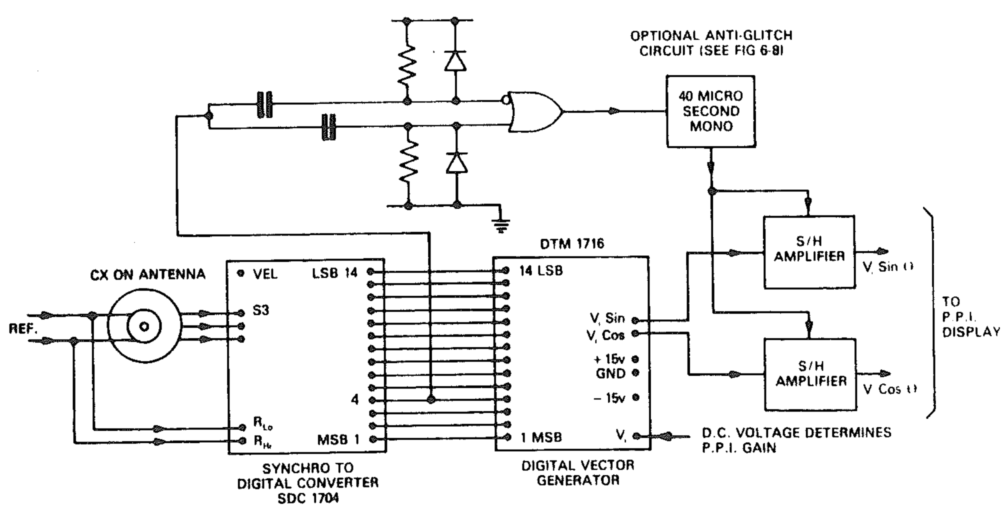

Fig. 7-16 A synchro to digital converter and a digital vector generator used to provide the voltages for a P.P.I. radar display.

The synchro (or resolver) signal representing the radar antenna angle is converted to a binary word by the synchro (or resolver) to digital converter. This digital angle is applied to the digital input of the DTM1716. A DC voltage is applied to the DTM1716 analog input which controls the radius of the displayed raster. The outputs of the DTM1716, which are proportional to the Sine and Cosine of the antenna angle, are then used to provide the voltages required by the X and Y time base of the PPI display.

Plan Position Indicator (PPI) waveform generation in radar systems where only the geared up synchro information is available

In the "Coarse-Fine Synchro and geared systems" section in Chapter 1, Fig. 1-28 showed an example of a synchro data transmission method, commonly encountered in older radar systems, where only the geared-up or fine synchro information is transmitted. The advantage of such an electromechanical system is to reduce the errors due to load torque.

Because many of these older equipments are being updated, it is now often necessary to digitise the geared-up synchro information in order to produce, without ambiguity, a single digital word representing the antenna angle. This function can be performed by the use of a special unit called the DDM1684 Digital Divide Module which uses the digitised synchro signal as well as the "North-Marker" signal in order to produce an unambiguous 14 bit representation of the antenna angle. The gear ratio of the system is selected on the DDM1684 and the function of the unit is to divide the digital input by this ratio.

Fig. 7-17 shows such a system also utilising the DTM1716 Digital Vector Generator which produces the sine and cosine signals required for the radar display.

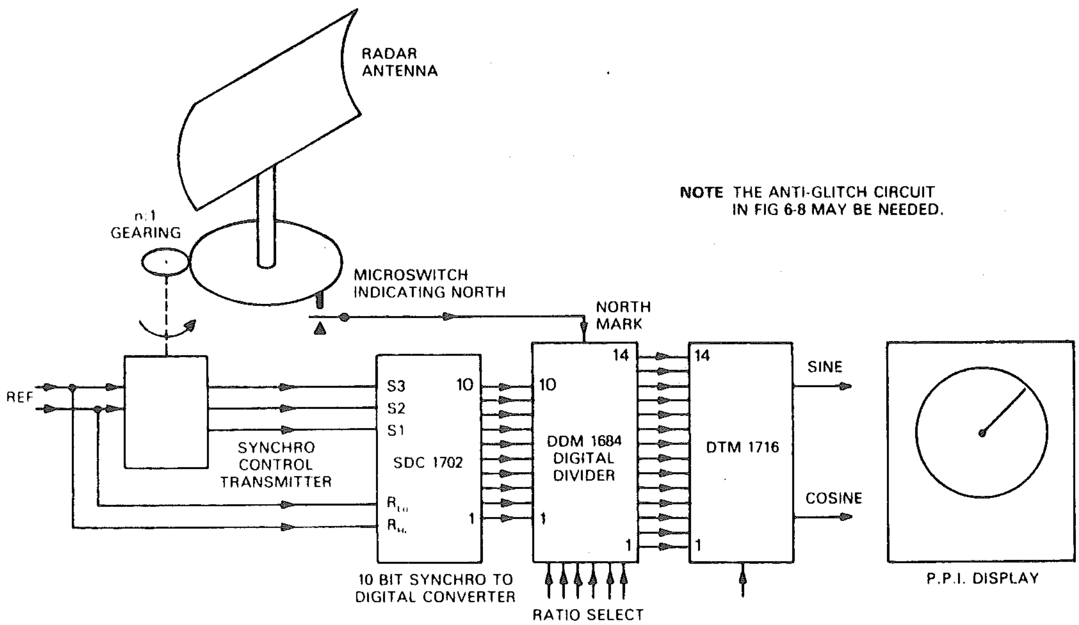

Fig. 7-17 Obtaining the sine and cosine waveforms for a P.P.I. display from a synchro system where only the "fine" synchro information is transmitted.

It is important in applications such as this to ensure that a synchro to digital converter is chosen which can track the geared-up synchro information at the speed required.

Plan Position Indicator (PPI) waveform generation in radars from two speed synchro systems

Many radars have two speed synchro systems on the antenna in order to transmit the turning information. This two speed information often has to be digitised in order to provide an input to the radar processing equipment or to produce the sine and cosine signals required by the PPI display.

Fig. 7-18 shows an example of such an application where the coarse fine gear ratio is 36:1. Note that the DTM1716 Digital vector generator can only utilise 14 Bits of the word supplied by the TSL1612 Two Speed Logic unit.

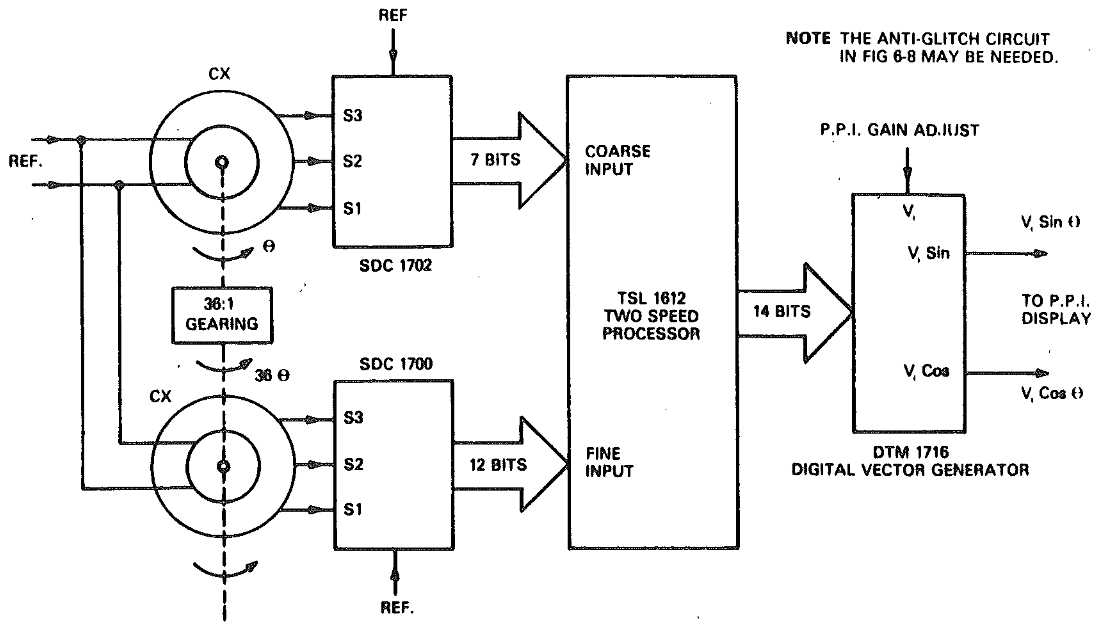

Fig. 7-18 Digitising the output of a coarse/fine synchro system to provide the sine and cosine voltages required for the P.P.I. display.

Conversion of Azimuth Change Pulses (A.C.P's) in radar systems into D.C. Sine and Cosine voltages for PPI displays

Radar turning information is sometimes transmitted in serial digital form from the antenna to the processing equipment. This method is used for example in the case of microwave transmission of the data. At the receiving end, it may be required to convert these Azimuth Change Pulses (A.C.P's) which usually number 4096 per revolution, into D.C. Sine and Cosine voltages for the PPI display. The ACP's are usually accompanied by an Azimuth Rotation Pulse (A.R.P.) which occurs once per revolution of the antenna and is equivalent to the "North Marker". Such a system is shown in Fig. 7-19.

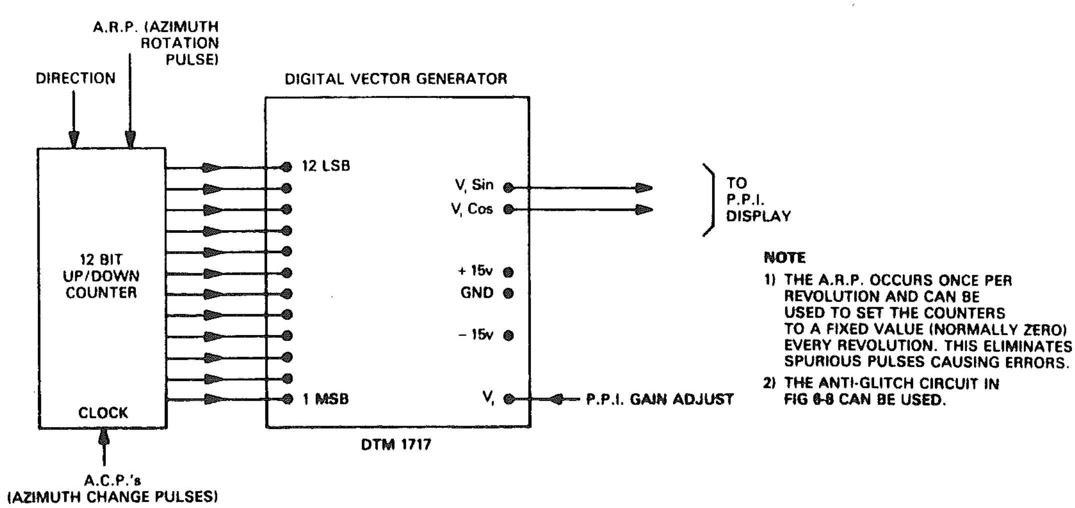

Fig. 7-19 Conversion of Azimuth change pulses into D.C. Sine and Cosine for a P.P.I. display.

Note that in the above system the ARP resets the counter to zero every revolution in case any spurious pulses have occurred during the previous revolution. Also note should be taken of the simple method described in chapter 6 of eliminating any glitches likely to occur during the update of the DTM1717.

Conversion of Azimuth Change Pulses (A.C.P's) in radar systems to Synchro or Resolver format

A method similar to that described above is shown in Fig. 7-20 for converting the Azimuth Change Pulses into Synchro or Resolver format. Note that the inclusion of the SPA1695 amplifier gives the system a 5VA drive capability.

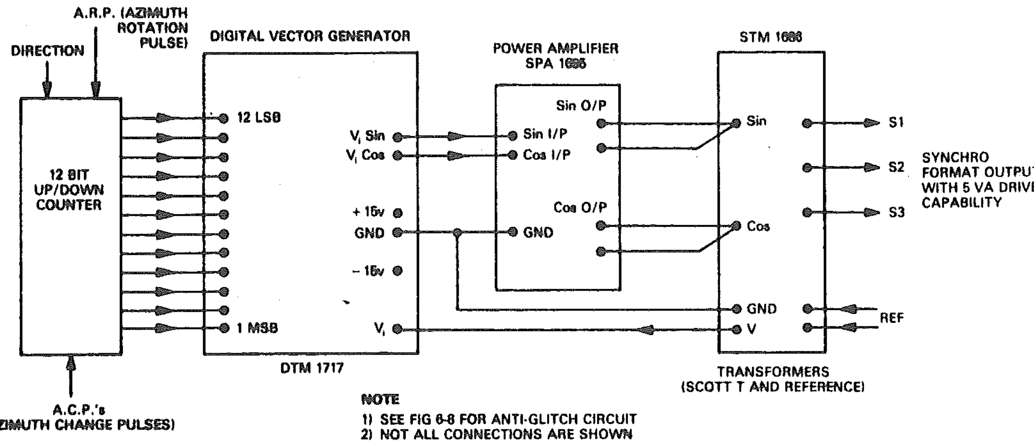

Fig. 7-20 Conversion of Azimuth Change Pulses into synchro format.

Synchro or Resolver to Binary Coded Decimal Conversion (B.C.D.) Applications

Very often angular information from synchros and resolvers has to be visually displayed. For example in repeating master compass information in ships where the same angular data has to be available usually at several stations remote from the compass.

In such cases, units such as the SBCD1752 and SBCD1753 synchro/resolver to BCD converters can be used.

The displays used sometimes contain their own B.C.D. decoders and in such cases the B.C.D. data can be fed directly into the display. An example of this is shown in Fig. 7-21.

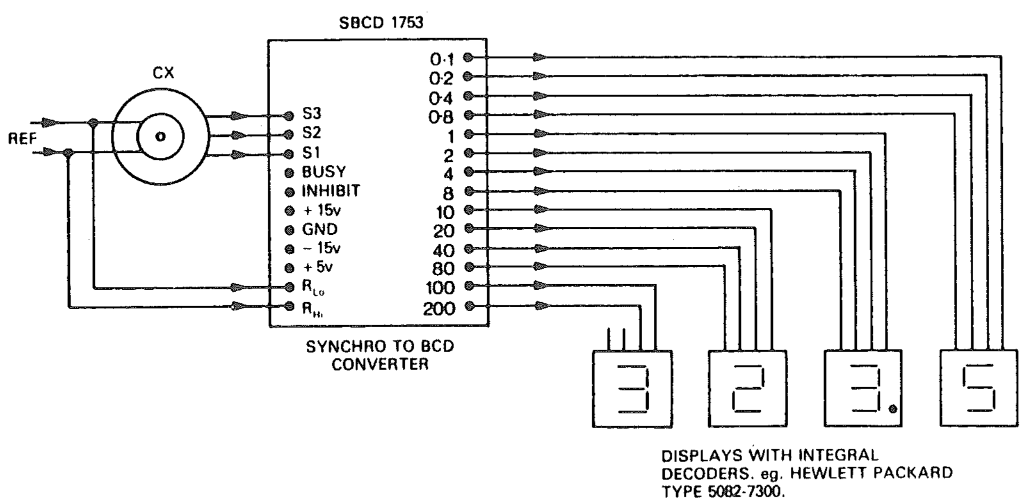

Fig. 7-21 Synchro data displayed using displays with integral B.C.D. decoders.

In cases where external seven segment decoders are required, and the angular data is changing slowly, suitable TTL packaged decoders are SN74246, SN74247, 74LS247, SN74248, SN74LS248, SN74249 and SN74LS249. These decoders have no latches.

In cases where external decoders are required and the angular data is changing quickly, data must be latched to avoid flicker. Fig. 7-22 shows the general arrangement in which the displays are fed in parallel.

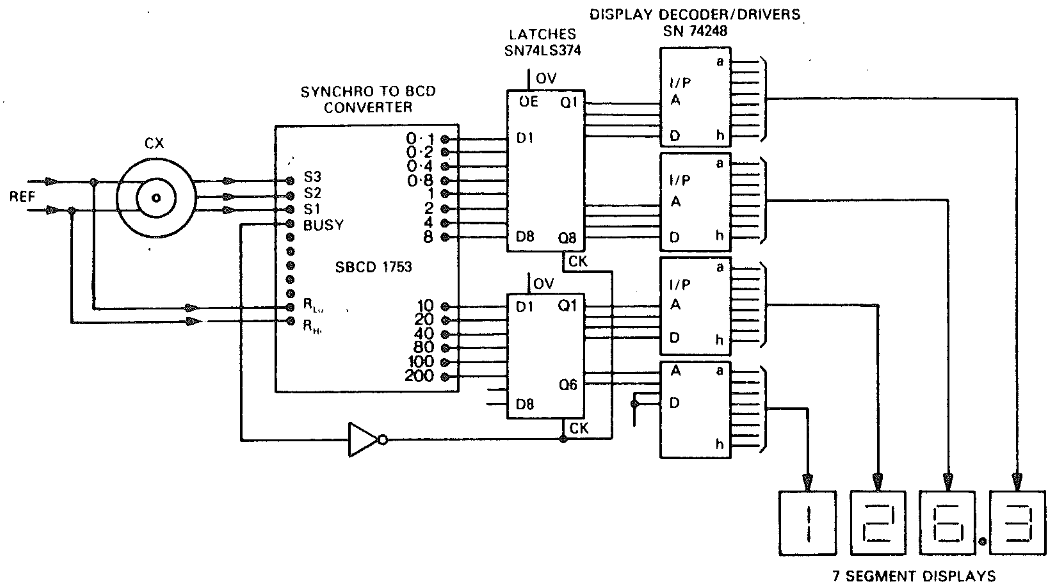

Fig. 7-22 Synchro data displayed using seven segment displays and external decoders and latches.

Sometimes it may be more convenient to sequence the displays in which case three-state latches can be used on to a seven wire bus with the three-state enables being sequentially enabled in synchronism with the display scan.

In some applications it is required to have the synchro or resolver angular information available in binary form as well as BCD. Fig. 7-23 shows how this can be accomplished using a synchro or resolver to digital converter and a binary to BCD converter.

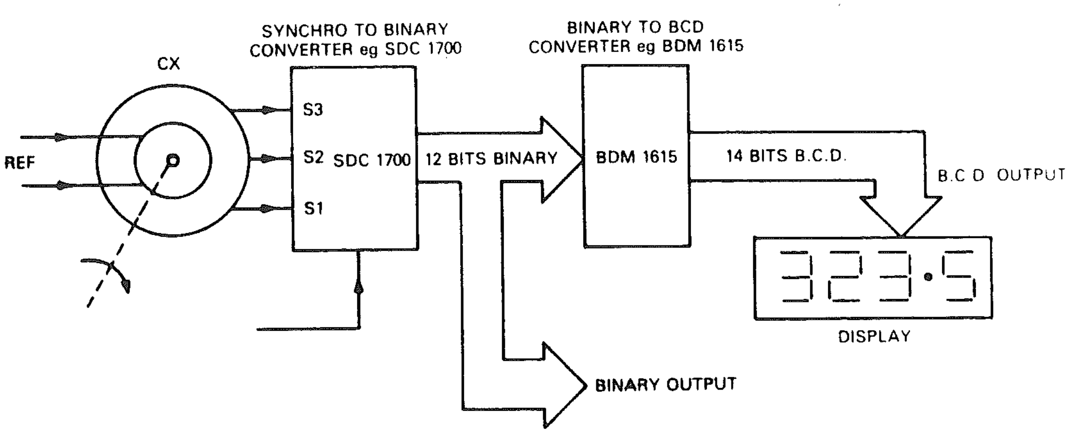

Fig. 7-23 Obtaining the Binary and BCD Digital representation from a synchro.

True bearing to relative bearing conversion

A very common requirement in ships navigation is the conversion from true bearing to relative bearing. The true bearing input will be obtained from the radar information and the ships heading relative to its compass is available from the master compass. The true bearing may be available as an analog voltage while the heading will be available in synchro form.

Fig. 7-24 shows how the relative bearing of, for example, another ship, is obtained from the analog and synchro inputs.

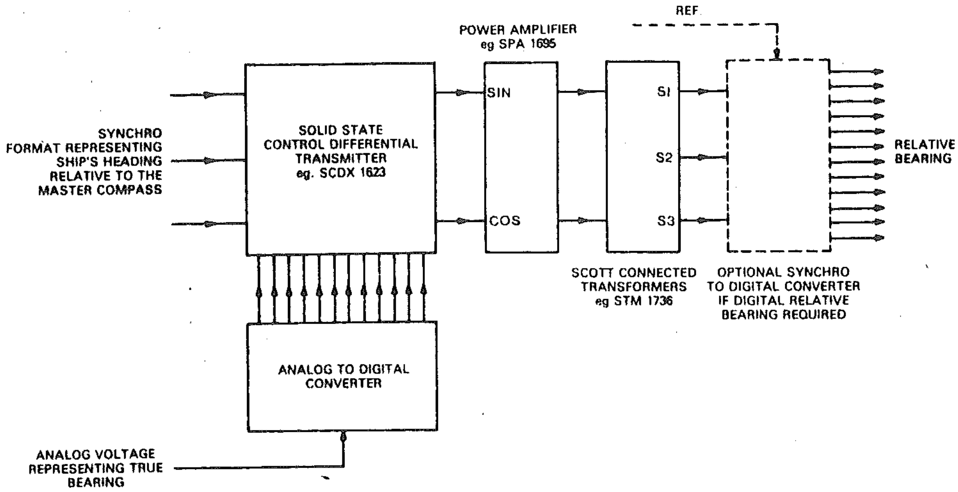

Fig. 7-24 True bearing to relative bearing conversion.

Synchro and Resolver to digital converters in avionic equipment

A large amount of avionic equipment requires the processing of synchro or resolver inputs. Very often these signals have to be converted into digital form and the method which is traditionally used is a successive approximation technique where the resolver format voltages are held on the peak of the reference with sample and hold amplifiers and an Analog to Digital converter used to convert these voltages to a digital Sine and Cosine. The digital processor in the equipment then either uses the Sine and Cosine of the angle in its calculations or it uses a look up table to determine the angle θ. This method is shown in Fig. 7-25 and it should be noted that it differs from the successive approximation method described in Chapter 3 in so far as the equipment processor and *not* the converter determines the value of θ. Thus the method shown in Fig. 7-25 requires a considerable amount of hardware and software in order to calculate the angle θ from the sine and cosine inputs.

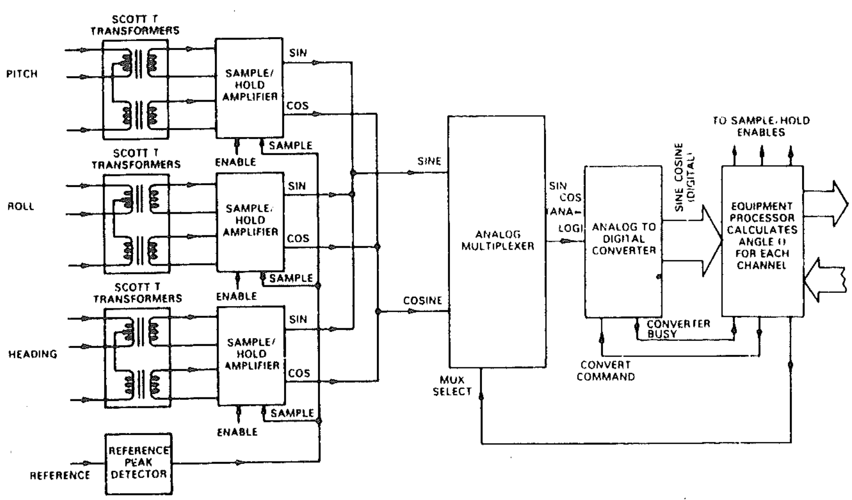

Fig. 7-25 Traditional method of processing synchro and resolver information in avionic equipment.

The disadvantage of the method shown in Fig. 7-25 is that it suffers from the stale data problems described in Chapter 3, i.e. because the signals can only be accurately converted at the peak of the reference waveform, a delay of 2.5mS may be required in a 400Hz system before this condition arises.

A much more satisfactory method is to use an individual tracking synchro or resolver to digital converter for each channel of information. The hybrid tracking converters type SDC1741 and 1742 are ideal for this situation as they are of very small size (1.74× 1.14× 0.25 inches), have *internal* transformers and latched three-state digital outputs. They also provide the synchro or resolver angle directly in digital form and the data is always fresh and readily available, i.e. there are *no stale data problems.* Such a system is shown in Fig. 7-26.

Note also that because each hybrid converter is a complete subsystem, they can each operate from different reference frequencies, and voltages. The internal transformers provide a balanced input regardless of what other equipment may be using the same synchro data.

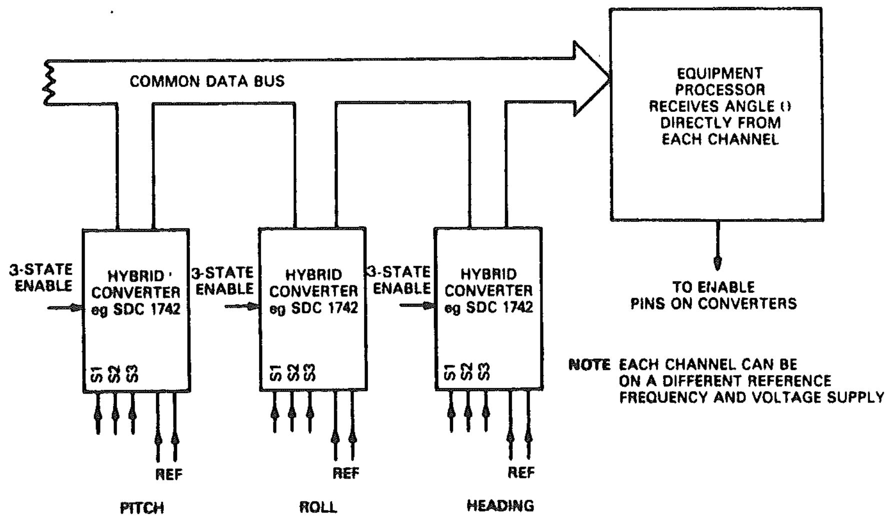

Fig. 7-26 Processing of synchro information in avionic equipment using hybrid converters with internal transformers.

Systems such as that shown in Fig. 7-26 find wide applications in all types of avionic equipment including jet engine controllers.

Plotting Tables

To assist in naval navigation, the chart of the area through which the ship is sailing is placed

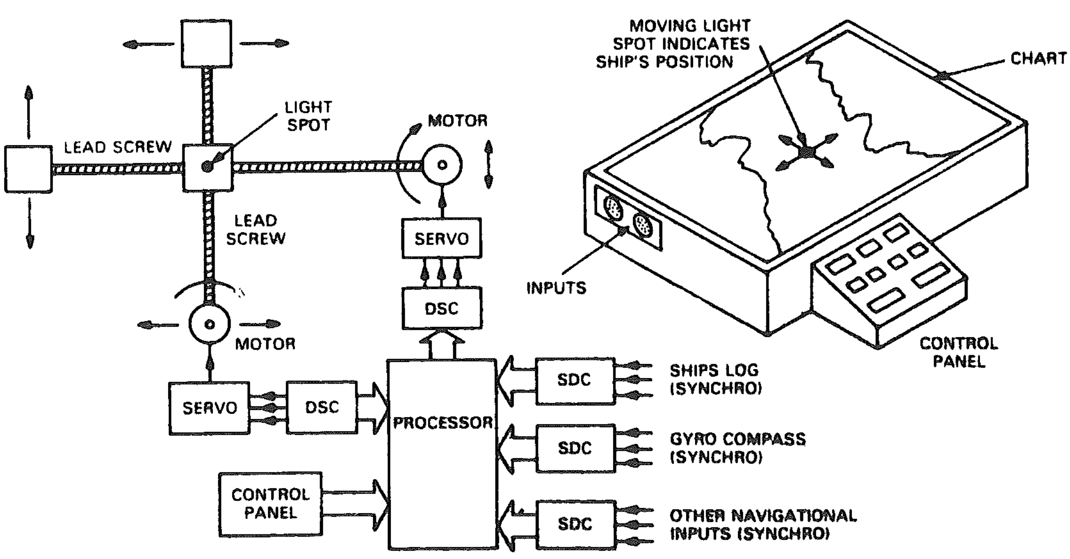

Fig. 7-27 A microprocessor controlled plotting table with synchro inputs.

on a flat table called a plotting table and a spot of light is generated by the equipment in the table to indicate on the chart the ship's or another ship's position. Many of these plotting tables take inputs in synchro form from the ship's navigation equipment in order to drive the equipment which positions the light spot. Because many of the latest plotting tables have microprocessor controlled X and Y drives for the light spot, it means that synchro to digital converters are essential equipment. The actual drive mechanisms are sometimes driven by stepping motors or in some cases by servos which require synchro format inputs. In the latter case digital to synchro converters are required. See Fig. 7-27.

Stitching machines

An application similar to the plotting table example is to be found in industrial stitching equipment. Many of the latest generation of stitching machines are microprocessor controlled and output digitally to the X and Y drives on the stitching head. In some cases the table as opposed to the head is driven in two axes. The X and Y drives are normally on lead screws and resolvers can be attached to them which in conjunction with resolver to digital converters can transmit the X and Y position back to the processor in order to complete the closed loop of the servo drive system. The stitching head itself can be driven by stepping motors or as in the case of the plotting table by servo mechanisms requiring synchro or resolver inputs. See Fig. 7-28.

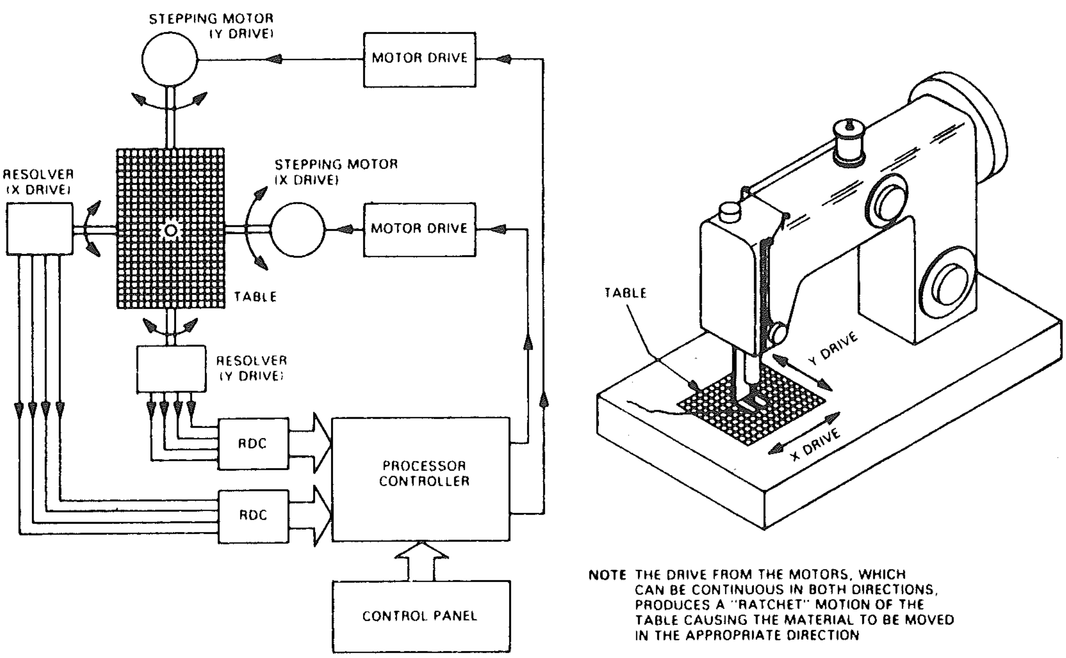

Fig. 7-28 A stitching machine using resolvers on the X and Y drives.

Bending Machines

There are many cases where the bending process of a pipe or a rod has to be performed on a mass production basis. A classic example of this is in the manufacture of car exhaust pipes. Special machines have been developed for this purpose and because a variety of different pipes have to be produced by the same machine, it is desirable that the machine is programmable. For this reason modern bending machines are microprocessor controlled and require digital positional information back from each of the bending mechanisms in order to close each servo loop. Once again this is an example where resolvers and resolver to digital converters have proved to be very reliable under the most extreme environmental conditions. See Fig. 7-29.

Wind direction and windspeed indicators

Although it is a very simple application, resolvers and converters have been used very

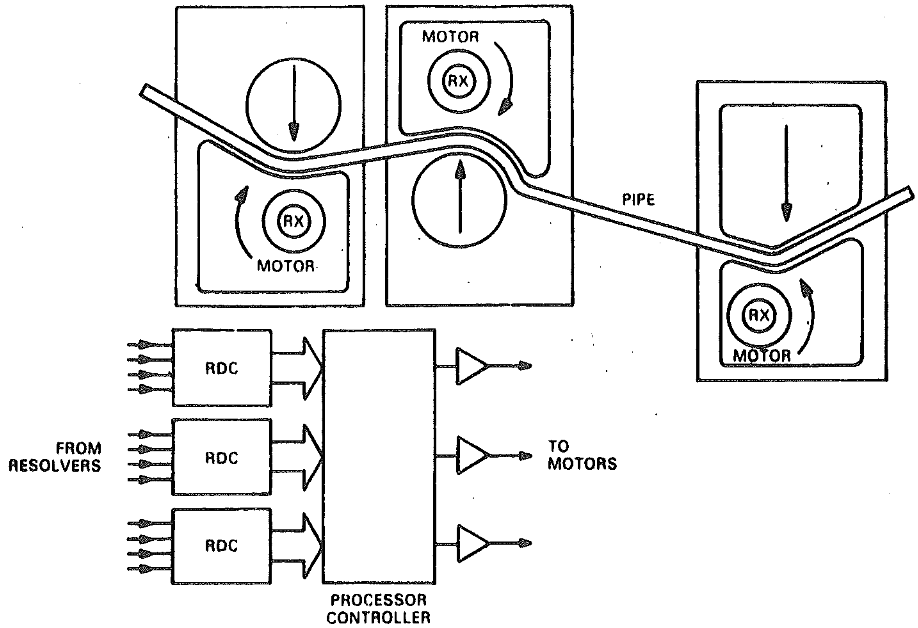

Fig. 7-29 A microprocessor controlled bending machine using resolvers as the tellbacks in the servo system.

successfully in wind direction indicators. The weather vane itself is connected to a resolver and an associated converter converts the position of the vane into either BCD format for a display or into binary for a processor. An advantage of using a synchro or resolver is that the information can be sent considerable distances with total noise immunity.

Very often a time constant needs to be incorporated into the system to eliminate the minor variations in wind direction. This is best achieved using a synchro to D.C. concerter and a Digital panel meter. See Fig 7-30.

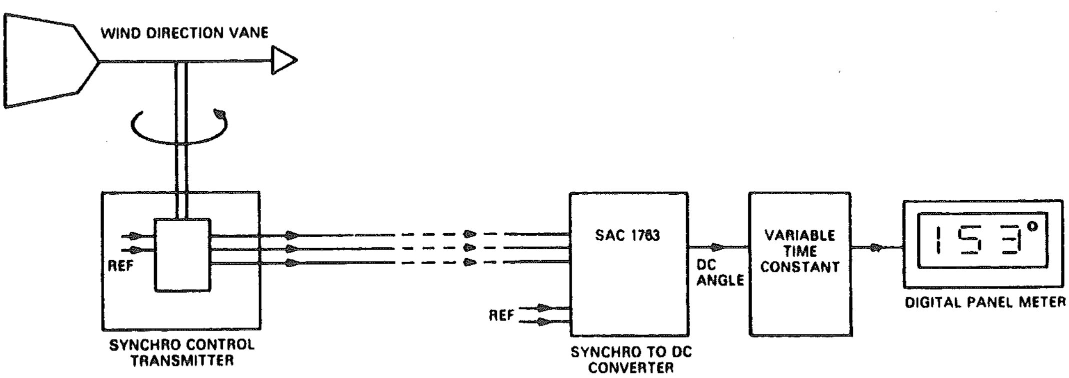

Fig. 7-30 Transmitting wind direction information using a synchro.

Rotating anemometers can also be used in conjunction with resolvers and converters where the D.C. velocity output of the converter will be proportional to the rate of rotation of the anemometer.

Fire control systems

Modern military fire control systems often consist of a processor which accepts signals, often in synchro format, and produces outputs, usually in coarse/fine synchro format, in order to position the missile launcher or gun. Tracking synchro to digital converters can be used to process the synchro inputs and a special two speed digital to synchro converter and power amplifier, type DSC1710, is ideally suited to provide the coarse/fine synchro output data.

The DSC1710 accepts a 16 bit digital input word and produces both a coarse and a fine synchro output each accurate to 14 bits. The whole system is mounted on a single card and the 5VA output amplifiers have current and voltage sensing which in the event of fault conditions or overload cause TTL flags to be set. The card is available for any coarse/fine ratio between 2:1 and 255:1.

A typical naval fire control system showing some of the inputs and outputs is shown in Fig. 7-31.

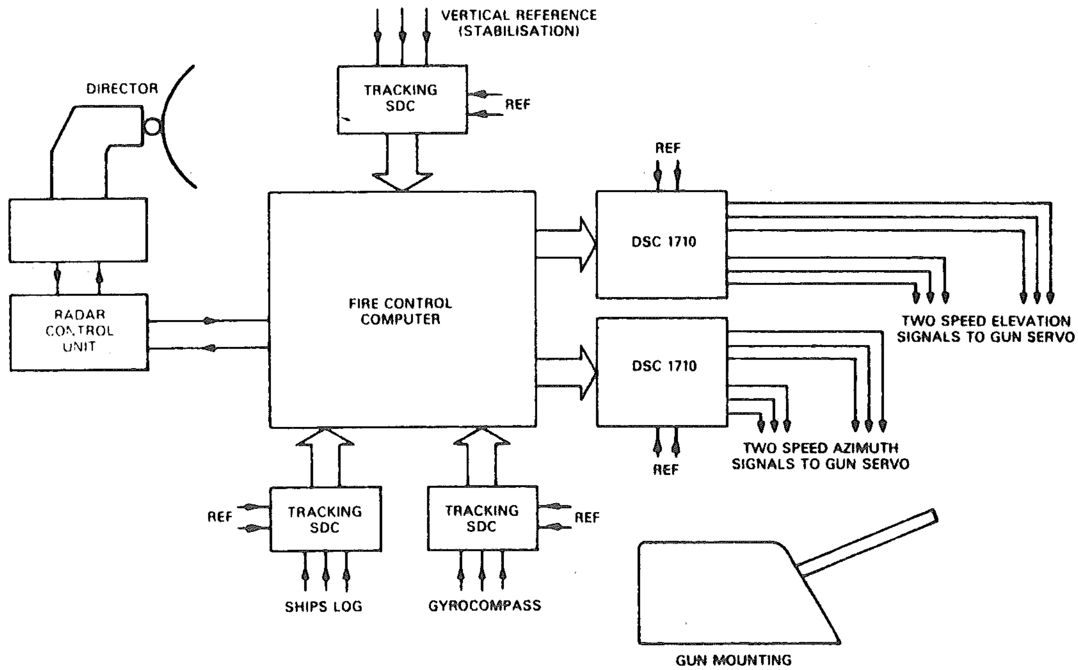

Fig. 7-31 Synchro inputs and outputs from a naval fire control system.

Synchro or resolver to digital tangent conversion

In problems associated with mechanical linkages such as are used in robots, the controlled and measured variables are usually angles between the rods forming the linkage. The output to be controlled is usually a displacement and not an angle. In the computation of these displacements from the angles, the tangents of the angles are often required. An example of this is the well known Peaucellier linkage which is shown in Fig. 7-32.

The linkage is made from 7 rods which are formed from 2 equal length rods l, 4 equal length rods k and the rod OC which has a length equal to one half of the distance AB. With this linkage, the locus of the point P is a *straight line*.

Such linkages could be very useful in Robot type of control. The angle α cannot be directly measured since there is no rod connecting A to C, however, the angle ϕ is equal to 2α and a synchro or resolver could be positioned at this pivot point to measure 2α.

The required distance to be controlled is the displacement S which is given by:

$$S = d \operatorname{Tan} \frac{\phi}{2}$$

Since d is fixed and is a simple scaling, no multiplication need be carried out providing care is taken in the overall design. Modules for providing the required digital representation

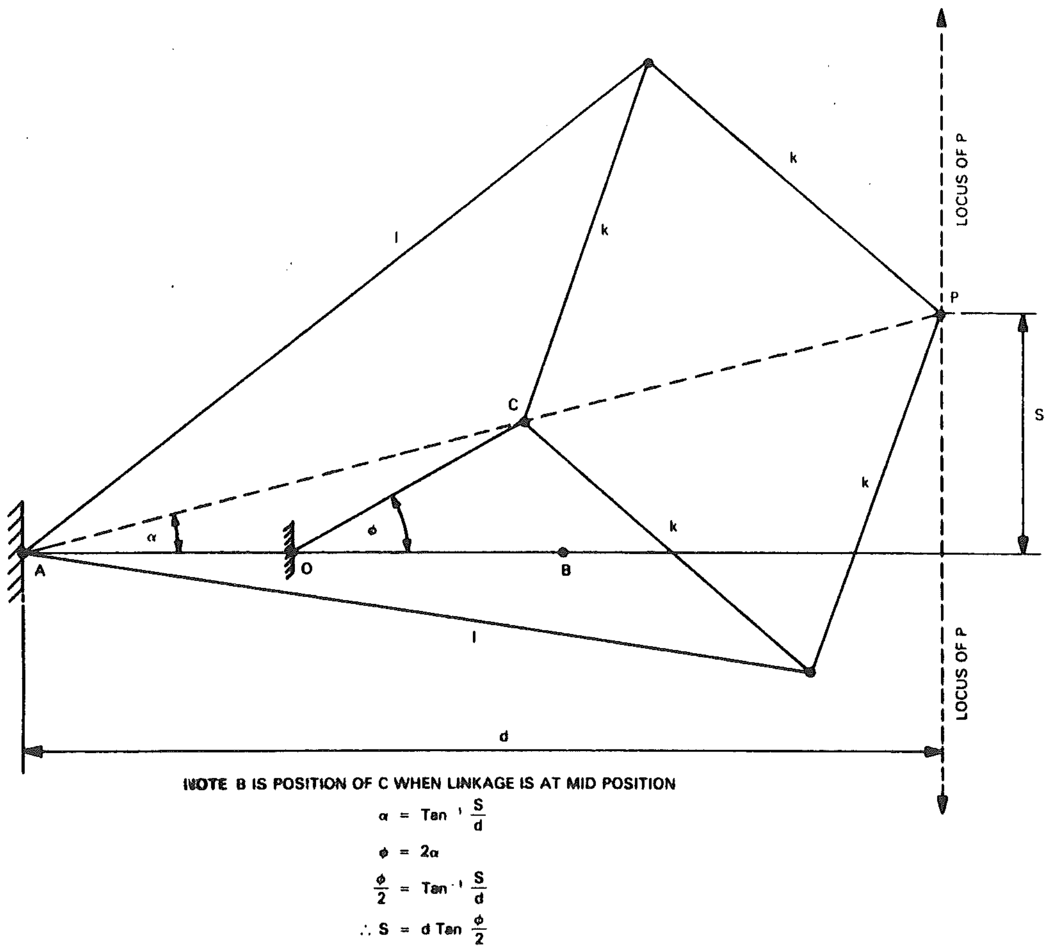

Fig. 7-32 The well known Peaucellier linkage.

of Tan ϕ have been developed using a technique similar to the tracking synchro or resolver to digital converter. See Fig. 7-33.

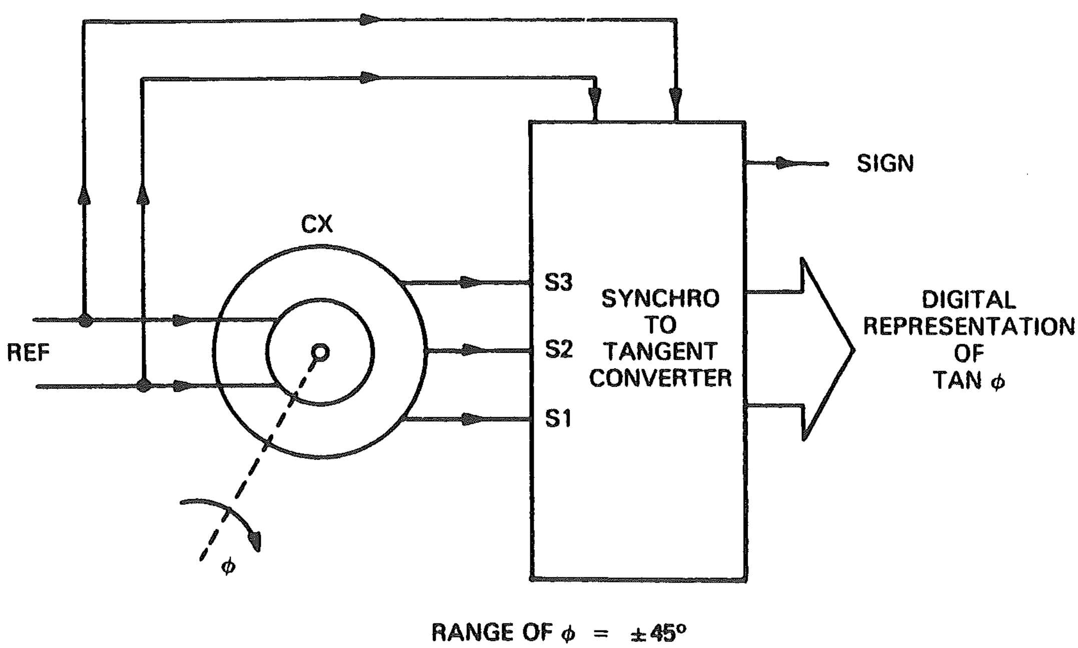

Fig. 7-33 Synchro or resolver to digital tangent conversion.

Elbow linkage

If instead of using the Peaucellier linkage for obtaining the straight line, a simple elbow arrangement is used with two angles being controlled and measured, the required computations still require angle to tangent conversion. The system being considered is shown in Fig. 7-34.

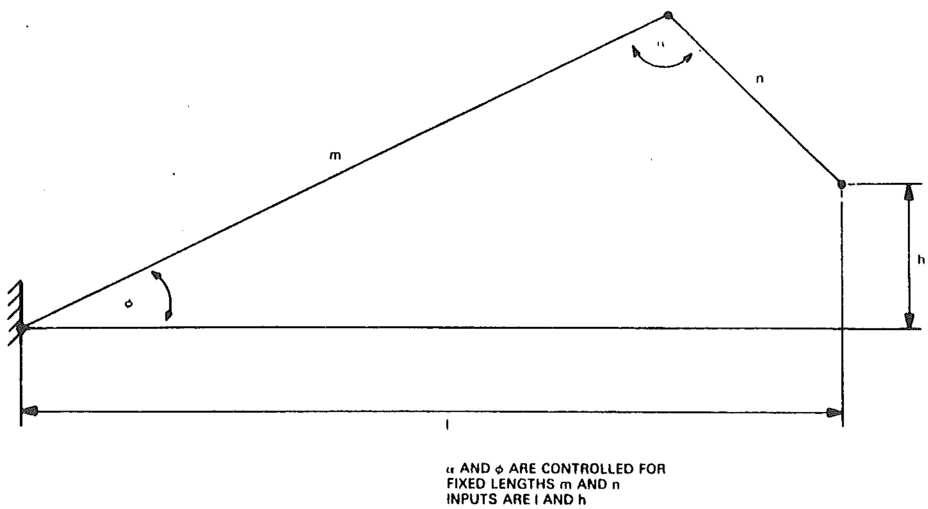

Fig. 7-34 Elbow type linkage.

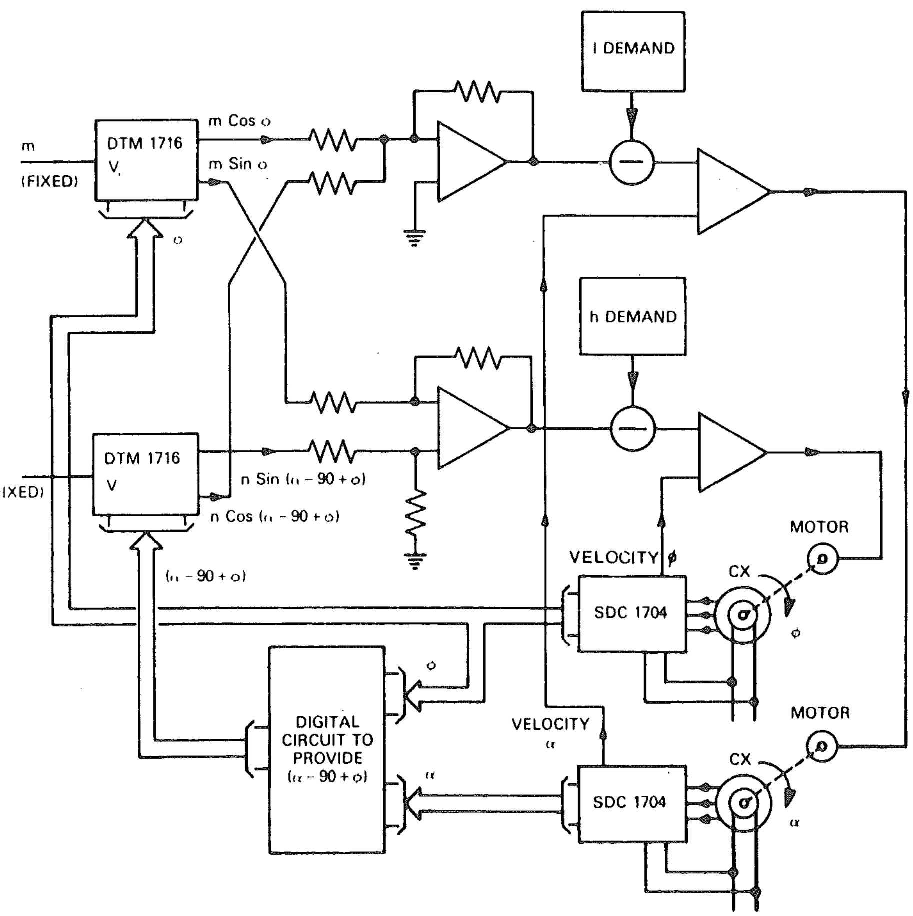

Fig. 7-35 Control loop for controlling the angles in a robot elbow.

In Fig. 7-34 the equations relating the input variables h and l and the fixed lengths m and n to the controlled angles ϕ and α are

$$l = m \cos \phi - n \sin (\alpha - 90 + \phi)$$
$$h = m \sin \phi + n \cos (\alpha - 90 + \phi)$$

A closed loop control method of implementing the solution to these equations using the DTM1716 and SDC1704 is shown in Fig. 7-35.

Conversion of invariant Sine/Cosine DC voltages to synchro or resolver format signals

Applications sometimes arise where invariant Sine and Cosine DC signals are available as inputs and either synchro or resolver format AC voltages are required as outputs. The inputs are:

$$V_s = V \sin \theta$$
$$\text{and } V_c = V \cos \theta$$

and the outputs required are:

$$V \sin\omega t \sin \theta$$
$$V \sin\omega t \sin (\theta + 120°)$$
$$V \sin\omega t \sin (\theta + 240°)$$

when in synchro format, and

$$V \sin\omega t \sin \theta$$
$$V \sin\omega t \cos \theta$$

when in resolver format.

The simple approach to the problem is to use analog multipliers in conjunction with an SPA1695 amplifier and a transformer such as shown in Fig. 7-36.

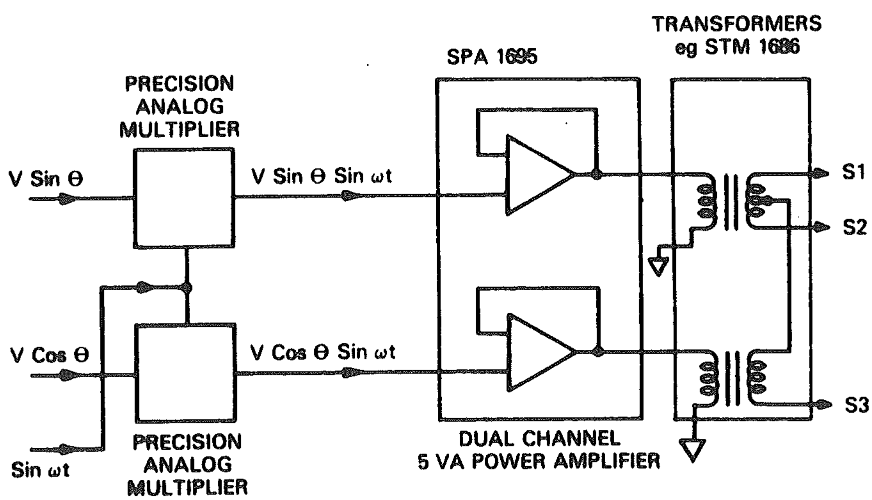

Fig. 7-36 Invariant sine/cosine to synchro or resolver conversion.

This method is satisfactory for lower accuracy applications. The accuracy will be limited by the inaccuracy of the multiplier at the carrier frequency. (A gain error of 1% will give angular errors of 0.28 degrees.)

A more accurate method is provided by using a conversion from invariant Sine and Cosine to digital representation of θ and then using a digital to synchro or resolver converter as shown in Fig. 7-37.

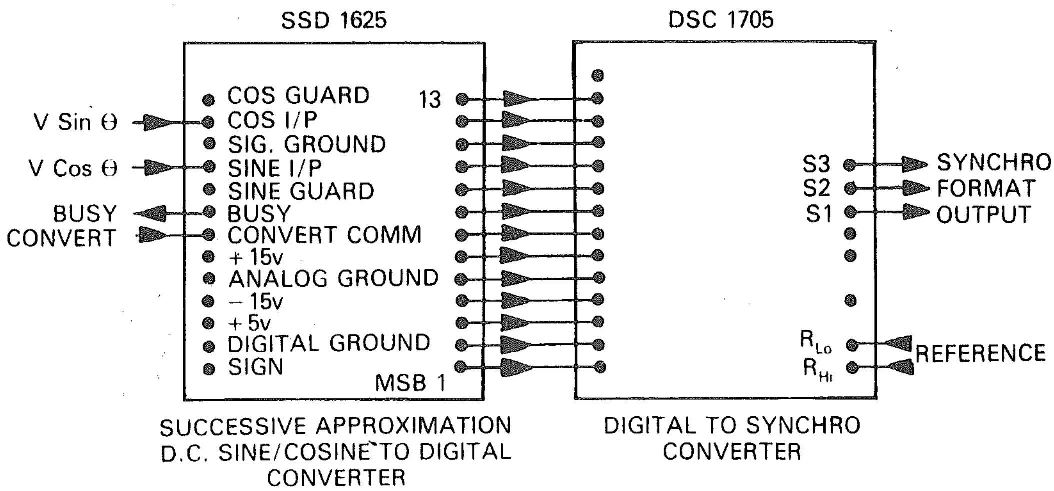

Fig. 7-37 High precision invariant sine/cosine to synchro or resolver conversion.

Relation between gimbal angles and the direction cosines in axis transformation

In the control of missiles and aircraft and also in the control of robots in engineering, it is necessary to be able to convert coordinates in a rotated set of axes. Such problems occur also in many other branches of engineering. As is explained in Chapter 6, the Digital Vector generators, DTM1716 and 1717 can be used to produce this axis rotation.

In almost all mathematical texts dealing with the rotation of one set of axes relative to another, the solution is given in terms of the direction cosines of the angles between the coordinate systems. There are nine direction cosines between the two sets of orthogonal axes which have been rotated relative to each other. The direction cosines are the cosines of the angles between the original and the rotated axes.

If two sets of orthogonal axes are skew to each other it requires only *two* rotations of one set of the axis to cause all the axes to overlap. These two angular rotations could be those obtained with a gimbal system. It is these gimbal angles that are available to the engineer. The angles required for the direction cosines are not normally available directly.

The formulae below give the relations between the three direction cosines for a straight line through the origin in terms of the two gimbal angles required to move the line from being superimposed on one of the axes to its new orientation. This line can be considered to be the first axes of a rotated coordinate system and the other two axes can be dealt with in the same way. Fig. 7-38 shows the line through the origin and the angles involved.

$$\text{Cos}\ \gamma_x = \text{Cos}\ \phi\ \text{Cos}\ \alpha$$

$$\text{Cos}\ \gamma_y = \text{Sin}\ \alpha$$

$$\text{Cos}\ \gamma_z = \text{Sin}\ \phi\ \text{Cos}\ \alpha$$

The formulae relate the gimbal angles ϕ and α with the direction cosines Cos γ_x, Cos γ_y and Cos γ_z.

The DTM1716 can be used to obtain the direction cosines if the angles ϕ and α are available in digital form. The required gimbal angles can be obtained in digital form by use of synchro control transmitters and synchro to digital converters. Fig. 7-39 shows the required units for obtaining the direction cosines.

Interpolation of Moire Fringe displacement measurements

A technique which is sometimes used for precision measurements relies on the Moire fringe technique and is shown in Fig. 7-40.

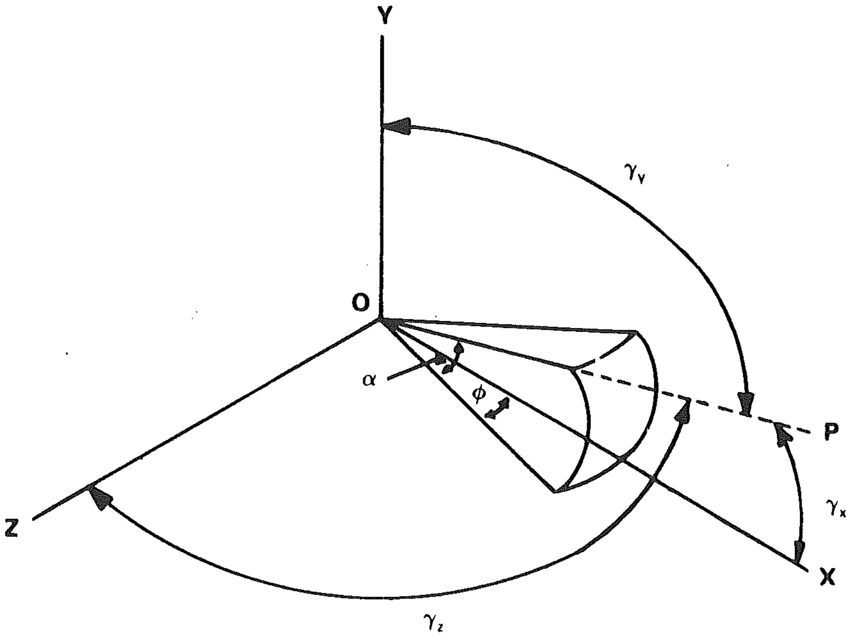

Fig. 7-38 Diagram showing the direction cosine angles for the line OP rotated through the angles α and ϕ from OX.

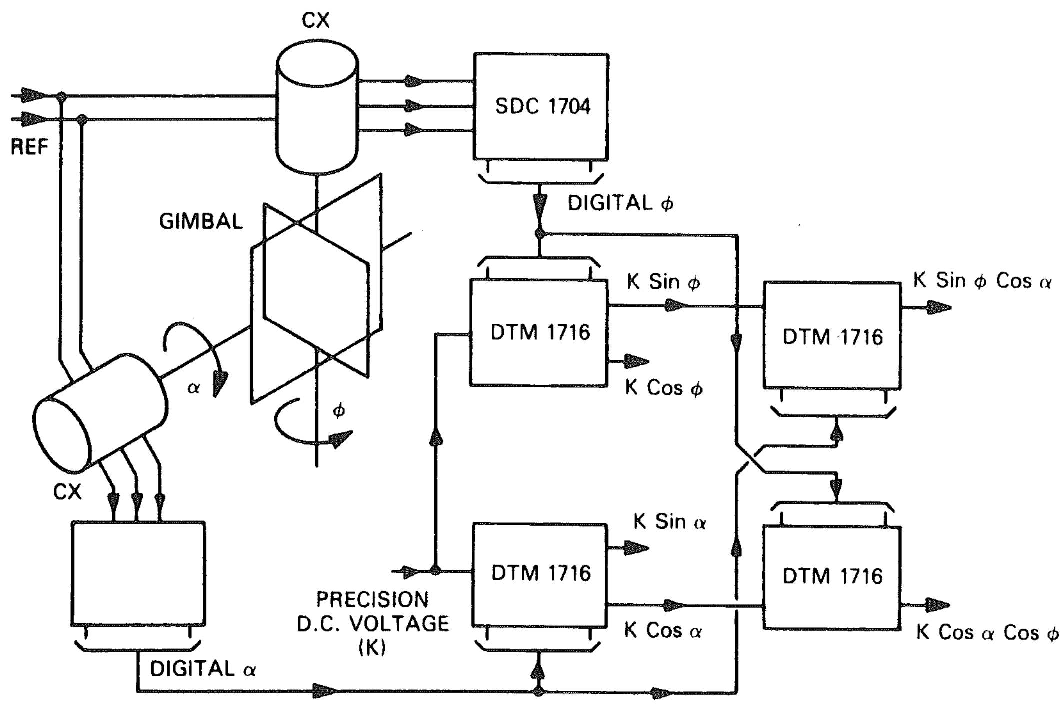

Fig. 7-39 Diagram showing how to obtain the trigonometric functions of the gimbal angles required for computation of the direction cosines.

Two optical gratings move relative to each other to produce light intensity variations which are detected by photo-cells. The usual arrangement has a long transparent strip of dimensionally stable material fixed along the line of displacement to be measured. The transparent strip is ruled with uniformly spaced black lines giving equal mark to space ratio. A smaller transparent strip of material with lines ruled at a small angular deviation from those of the first strip and of equal mark to space ratio is fixed to the traversing part of the machine in such a way that light can be shone through the two strips to the photo-detectors.

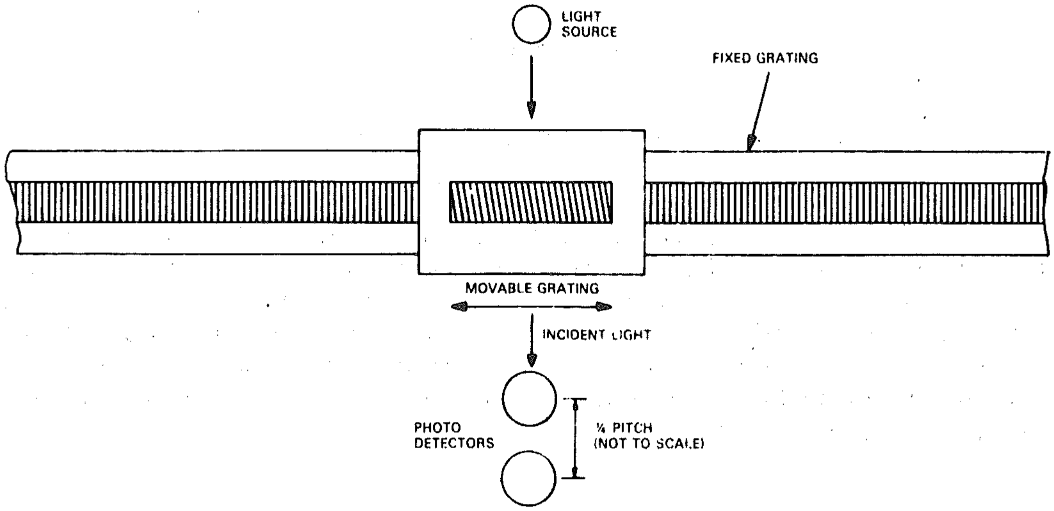

Fig. 7-40 Principle of Moire fringe measurement.

The effect of the small offset in angle is to produce bands of light and dark areas which move approximately vertically as the smaller transparent strip and the light source are moved horizontally. One band of light moves vertically for each pitch traversed in the horizontal direction. (The Moire fringe effect can be simply observed by using two combs held at a slight angle to each other and looking through them at a light background when they are moved relative to each other.)

By using two photo detectors separated by ¼ pitch, the direction of movement can be deduced.

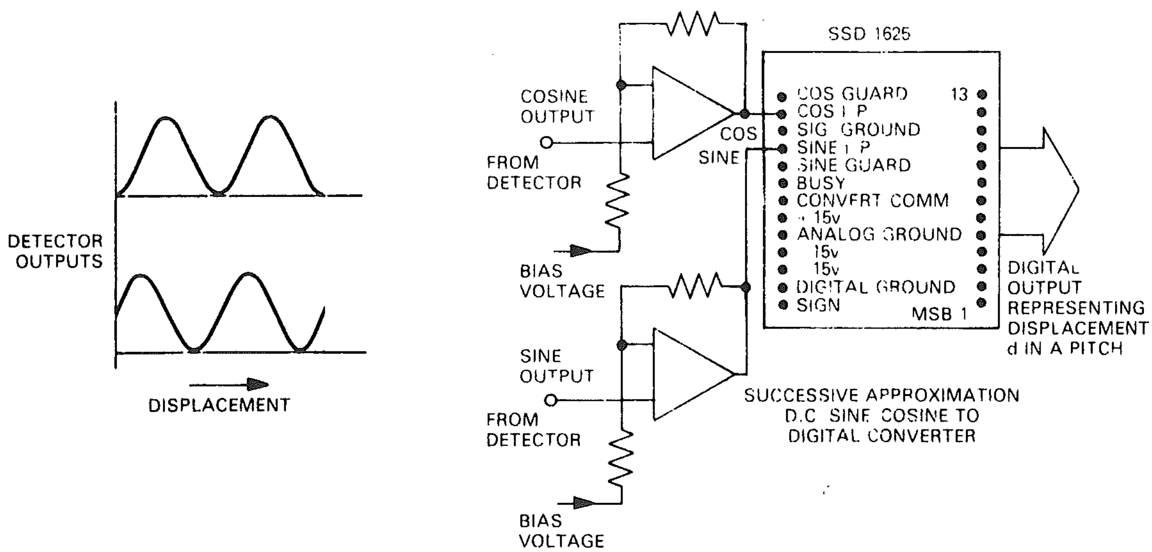

Fig. 7-41 Using the SSD1625 successive approximations converter to interpolate the output of a Moire fringe measurement system.

When suitable biases are added to the voltages obtained from the photo detectors, the output voltages approximate to:

$$V_s = V \operatorname{Sin} (360 \times \frac{d}{p})$$

$$V_c = V \operatorname{Cos} (360 \times \frac{d}{p})$$

where p is the pitch and d is the displacement within these pitches.

The successive approximations resolver to digital converter SSD1625 can be used with these voltages to produce a digital output representing the displacement d. See Fig. 7-41. Since the SSD1625 can give up to 13 binary bits accurately for accurate Sine and Cosine inputs, the limitations of this method of interpolation depend upon the amount by which the outputs obtainable from the photo-detectors vary from the sinusoidal voltages required.

As in the case of the linear and rotary inductosyn, note must be made of the number of pitches traversed (see Fig. 5-3).