Chapter IV

Digital to Synchro/Resolver conversion

INTRODUCTION

Function of DSC's and DRC's

Digital to Synchro/Resolver converters are used to interface digital systems to Synchro or Resolver angular control systems.

The units take digital inputs in parallel natural binary form representing the angle and produce outputs in either Synchro or Resolver format at any of the standard frequencies and voltages. The output of the converter normally includes a 1.3VA amplification stage which gives the unit the capability of driving certain electromechanical loads. In cases where this drive capability is not sufficient, additional external amplification needs to be used.

Digital to Synchro and Resolver converters normally drive into the following loads which are listed in order of occurrence:

Control Transformers (CT)

Torque Receivers (TR)

Control Differential Transmitters (CDX)

Torque Differential Transmitters (TDX)

By far the most common use is for driving into Synchro or Resolver control transformers which are the feedback elements in electromechanical servo control loops.

Fig. 4-1 shows such a control loop being driven from a Digital to Synchro converter.

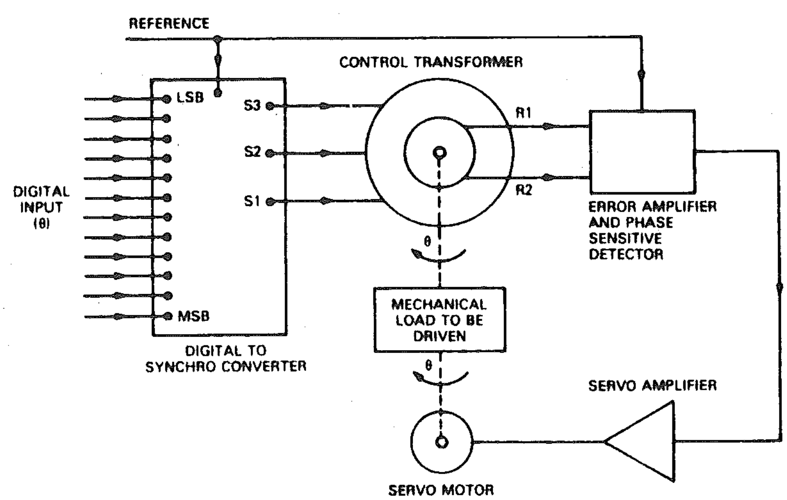


Fig. 4-1 The use of a Digital to Synchro converter to drive a simple (type 1) control loop.

PRINCIPLE OF OPERATION OF DSC'S AND DRC'S

The general arrangement of a digital to Synchro converter is shown in Fig. 4-2 and a digital to Resolver converter in Fig. 4-3.

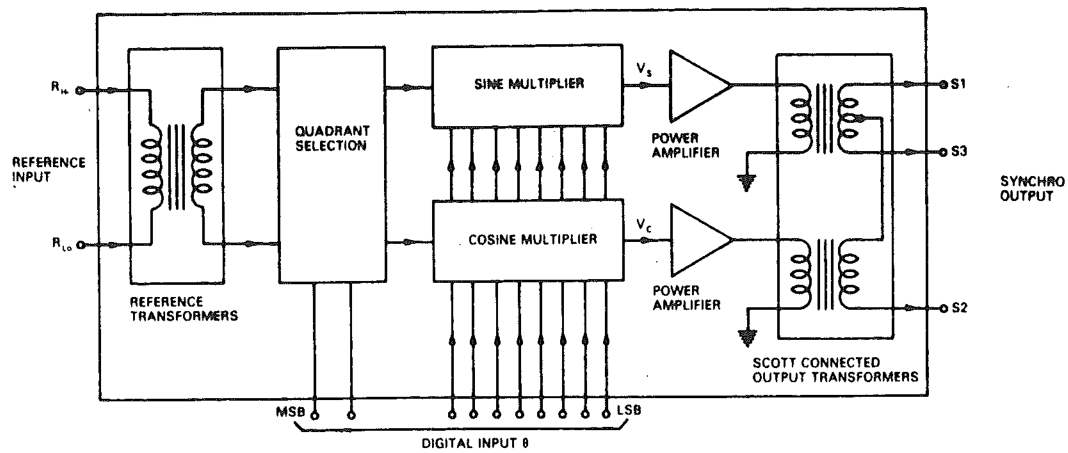


Fig. 4-2 Principle of operation of a digital to Synchro converter.

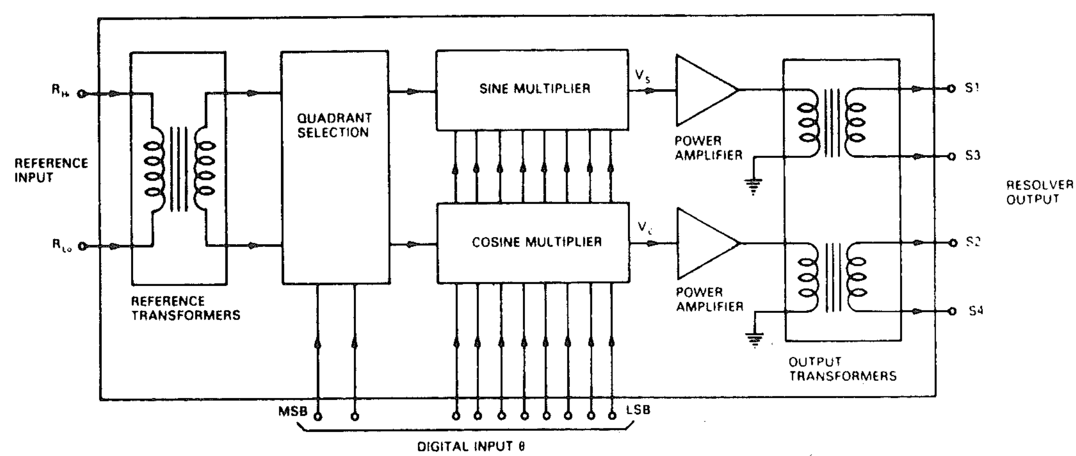


Fig. 4-3 Principle of operation of a digital to Resolver converter.

The above two diagrams show that the only difference between a digital to Synchro converter and a digital to Resolver converter is the configuration of the output transformers, the Synchro converter having them Scott connected and the Resolver converter having them connected in an isolation mode. All of the converters work internally with Resolver format signals.

As can be seen in the above diagrams, the converter consists of Sine and Cosine multipliers which are basically multiplying digital to analog converters incorporating Sine and Cosine laws. These are similar to those used in tracking Synchro and Resolver to digital converters. (See Chapter III section "Tracking Synchro and Resolver to digital converters" and Appendix E).

The basic method of conversion multiplies the reference input voltage V Sin ωt by Sine θ and Cosine θ to produce the Resolver form voltages:

$$V_S = E \sin \omega t \sin \theta$$

$$\text{and} \quad V_C = E \sin \omega t \cos \theta$$

where θ is the shaft angle applied in digital form to the Sine and Cosine multipliers.

These voltages are fed directly into the power amplifiers and isolation transformers in the case of a digital to Resolver converter. In the case of a digital to Synchro converter, the voltages are fed into the power amplifiers and then into the Scott connected transformers to produce:

$$V_{S1\text{-}S3} = E \sin\omega t \sin\theta$$
$$V_{S3\text{-}S2} = E \sin\omega t \sin(\theta + 120)$$
and $$V_{S2\text{-}S1} = E \sin\omega t \sin(\theta + 240)$$

which are the required Synchro format voltages. (S1-S3 means the voltage appearing between terminals S1 and S3 etc.)

DSC AND DRC PACKAGING

Most of the converters, which have integral power amplifiers of the order of 1.3VA drive capability, are in modular form.

400 Hz option converters of the above type usually contain integral transformers while the 60 Hz converters, although having internal power amplifiers, usually require an external transformer module. This module contains the output transformers as well as the reference isolation transformer. A 60 Hz converter and external transformers are shown in Fig. 4-4.

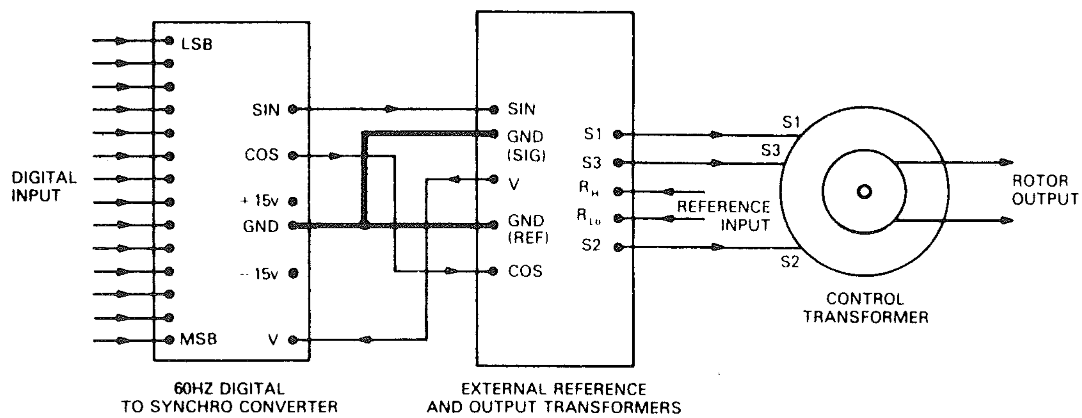


Fig. 4-4 A 60 Hz option digital to Synchro converter with external output and reference transformer module.

Where the converter amplifier is not sufficiently powerful to drive a particular load, external amplifiers and transformers will be required. This subject is dealt with later in the section "Driving Loads greater than 1.3VA".

TRANSFORMATION RATIO OR RADIUS VECTOR VARIATION

Although all DRC's and DSC's work on the principle shown in Fig. 4-2 and 4-3, they do fall into two types i.e. those where the transformation ratio (or radius vector variation) is significant i.e. $\pm 7\%$ and those where it is not significant i.e. $\pm 0.1\%$. The meaning of radius vector variation is explained below.

Consider the Resolver and Synchro format outputs. In these equations, in the ideal case, E is a constant equal to the peak value of the maximum AC output voltage. Consideration of the working of the control transformer shows that the loop being controlled will null at the correct angle independently of the value of E. Variation in the value of this peak voltage will give rise to a gain variation in the CT control loop but other than that, the loop will function normally.

Now in certain converters the Sine and Cosine multipliers do not follow exactly the Sine and Cosine laws, but vary from them by about $\pm 7\%$ and consequently the value of E is a function of the angle θ. Consequently if a digital to Resolver converter of this type were used to drive the X and Y plates of a P.P.I. radar display or produce a circle on an oscilloscope, the result would be as shown in Fig. 4-5.

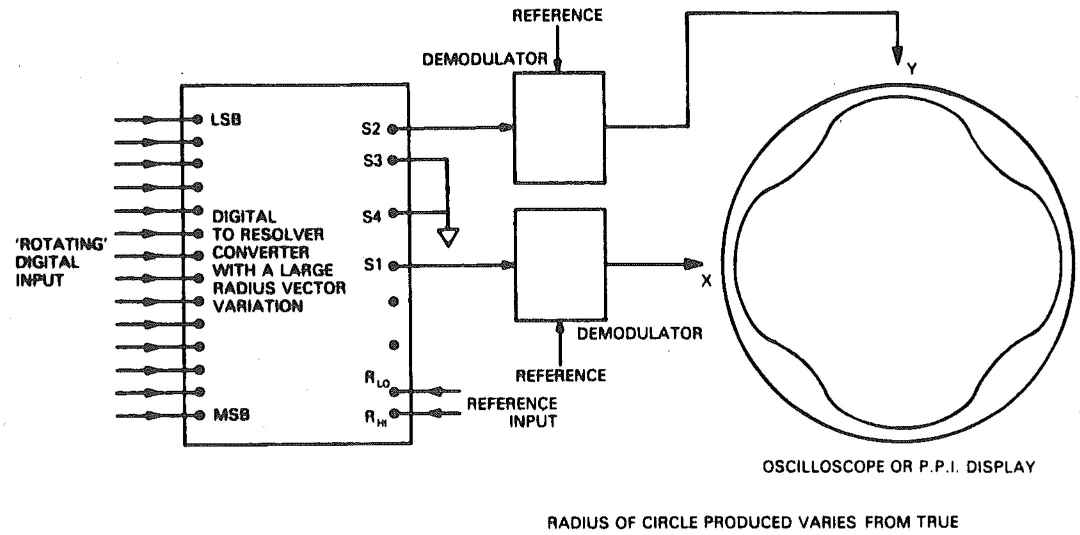


Fig. 4-5 Driving a P.P.I. radar display or the X and Y plates of an oscilloscope with a Digital to resolver converter with a large radius vector variation.

However the important point about converters with a high radius vector variation is that the ratio of the Sine and Cosine, i.e. the Tangent, is accurate to the rated accuracy specification of the converter, and that is what is important when driving electromechanical loads.

Converters of this type tend to be of an older design but have been successfully used for a number of years. The only disadvantage of them, if any, in addition to being unsuitable for P.P.I. waveform generation, is that the loop gain changes can in some rare instances cause detrimental effects in the servo system being driven. This is more likely to be noticeable in the simpler type 1 servo loops than in the more sophisticated type 2 loops.

In the latest design of converter, for example the DSC 1705 and DSC 1706, this radius vector variation has been reduced to $\pm 0.1\%$ and consequently no problems can arise when driving into an electromechanical servo system. They can also be used to provide the waveforms required for P.P.I. displays. See Fig. 4-6.

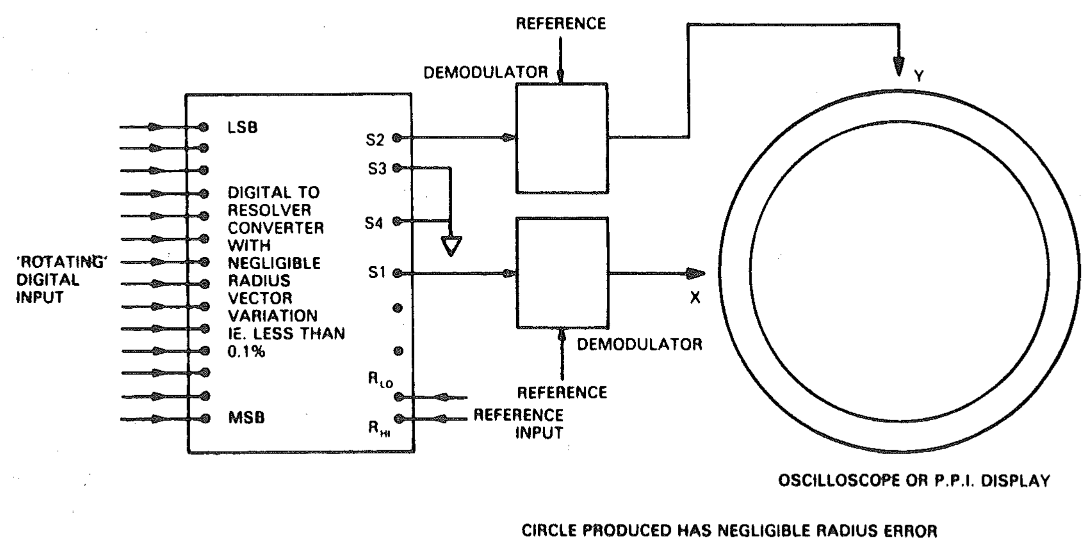


Fig. 4-6 Driving a P.P.I. radar display or the X and Y plates of an oscilloscope with a Digital to resolver converter with a radius vector variation of less than $\pm 0.1\%$.

APPLYING DIGITAL TO SYNCHRO AND RESOLVER CONVERTERS

Connecting the Converter to the device to be driven

Digital to Synchro and Resolver converters are extremely simple to use. A DRC connected to a Resolver control transformer is shown in Fig. 4-7 and a DSC connected to a Synchro control transformer is shown in Fig. 4-8.

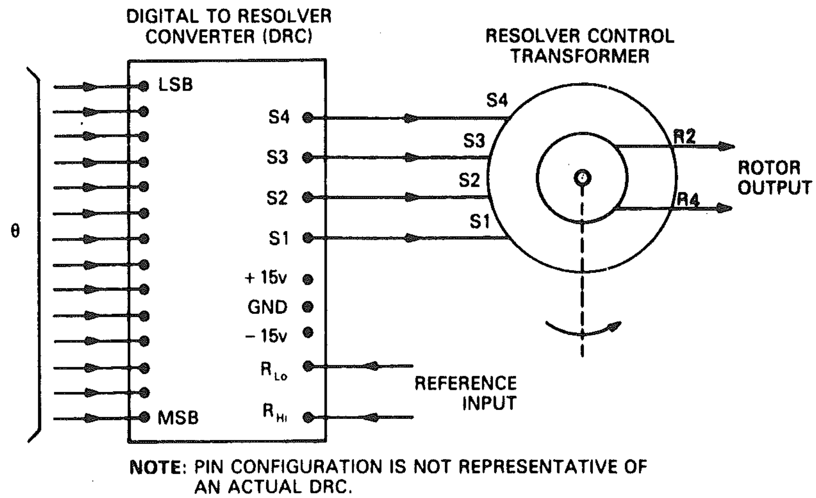


Fig. 4-7 A Digital to Resolver converter connected to a Resolver control transformer.

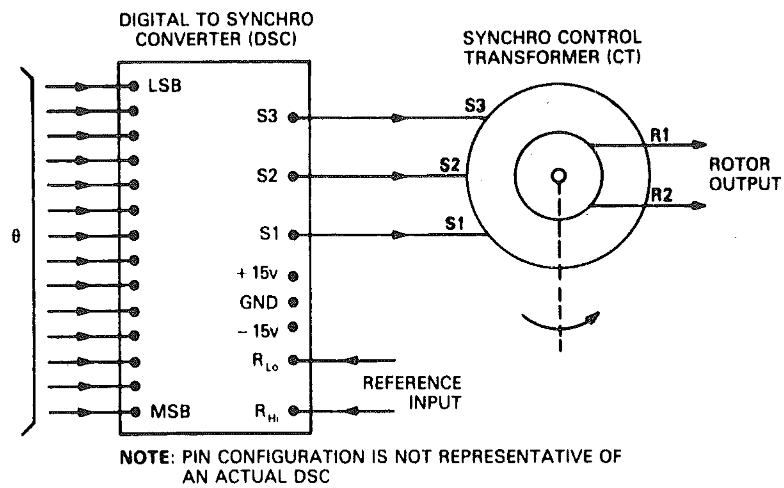


Fig. 4-8 A Digital to Synchro converter connected to a Synchro control transformer.

The above diagrams show 400 Hz systems. In the case of 60 Hz systems, external output and reference transformers are usually required and the method of connecting these is normally given in the converter data sheet.

Although the converters are simple to use, certain questions often arise and these are answered below.

1) The signal and reference connections should be made to the converter and Synchro according to the convention given in Chapter II under the heading "Synchro and Resolver connection conventions". However if they are not connected correctly, Figs 4-9 thru 4-19 show the results of all the possible changes in connection between the output nulled angle β and the digital input angle α.

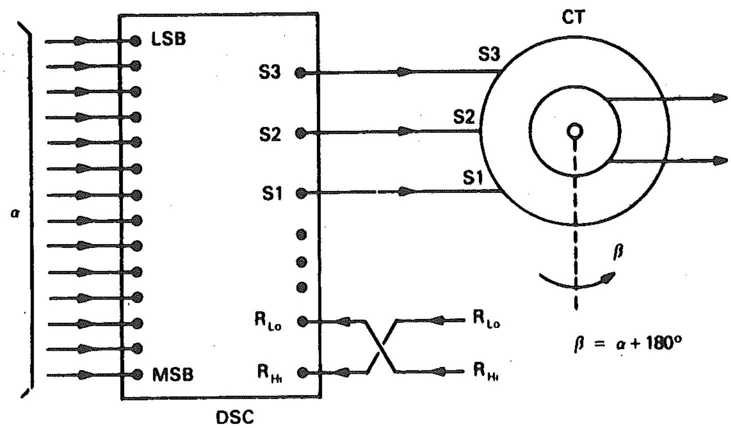


Fig. 4-9 Reversed reference.

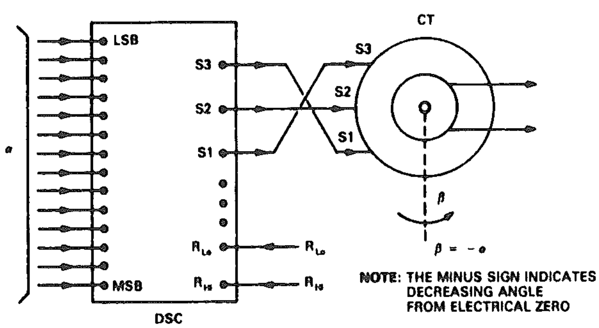


Fig. 4-10 S1 and S3 reversed.

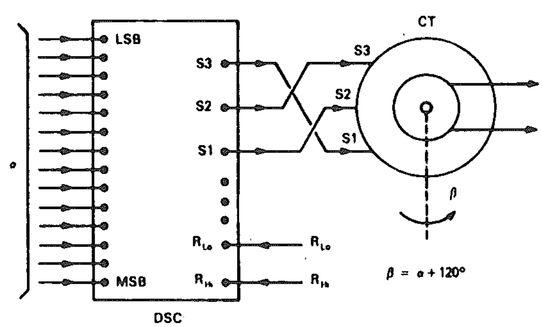


Fig. 4-11 Wires rotated. S1→S2, S2→S3, S3→S1.

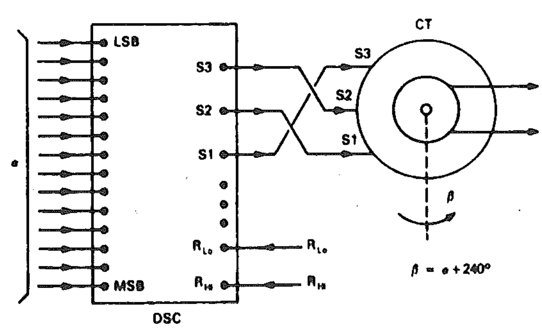


Fig. 4-12 Wires rotated S1→S3, S2→S1, S3→S2.

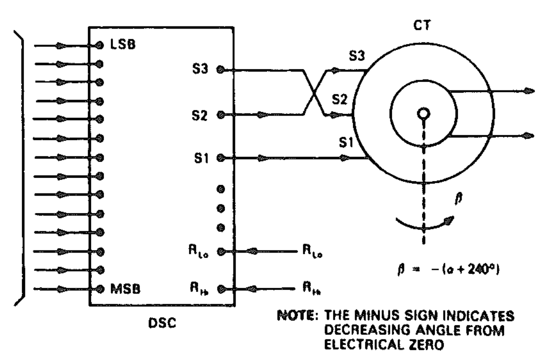


Fig. 4-13 Wires S2 and S3 reversed.

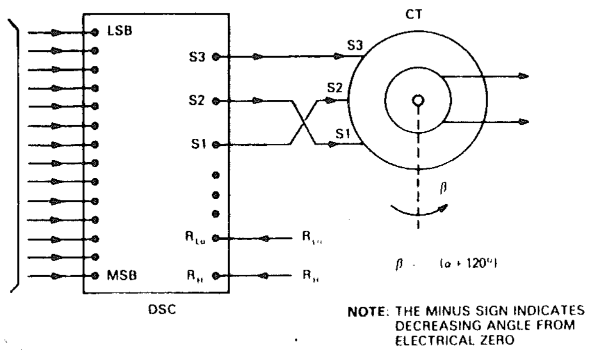


Fig. 4-14 Wires S1 and S2 reversed.

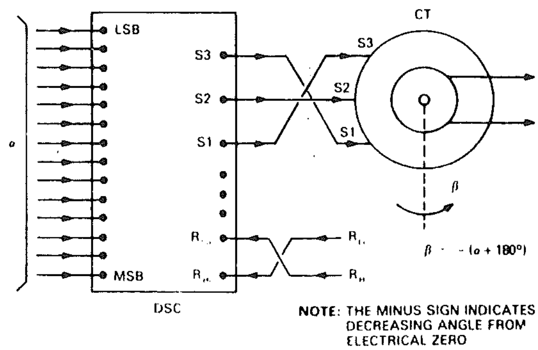


Fig. 4-15 Reference reversed, S1 and S3 reversed.

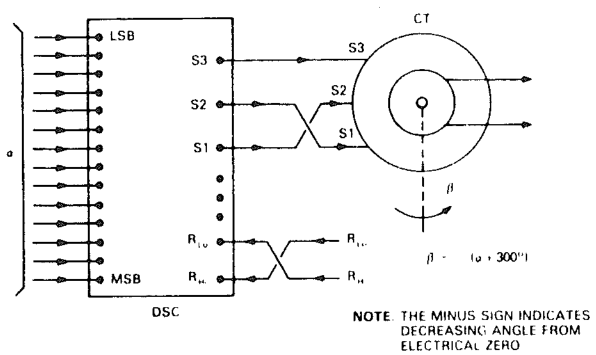


Fig. 4-16 Reference reversed, S1 and S2 reversed.

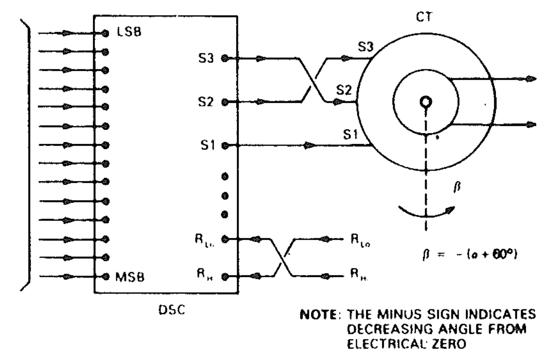


Fig. 4-17 Reference reversed, S2 and S3 reversed.

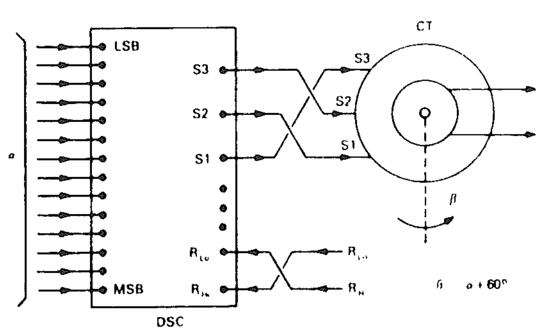


Fig. 4-18 Reference reversed, wires rotated S1→S3, S2→S1, S3→S2.

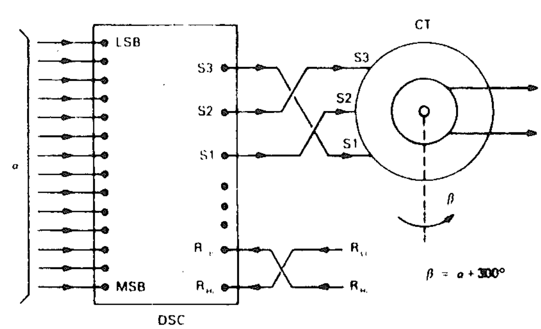


Fig. 4-19 Reference reversed, wires rotated S1→S2, S2→S3, S3→S1.

2) For distances up to 20 feet, the connection between the Synchro or Resolver and the converter may be made with ordinary wire preferably twisted. For greater distances it is preferable to use individually shielded multicore low capacitance cable.

3) It should be ensured that the converter is the correct option as far as the signal and reference voltages are concerned. Failure to ensure this may result in damage.

4) It is advisable that the signal and reference voltages should not be routed through the same wiring harness as the power supplies and digital data.

5) Damage may occur to the converter if the Synchro or Resolver load is connected to the converter along with the reference for any length of time with only one of the power supply rails being present.

Considerations when connecting the Power Supplies

Generally the converters are powered from ± 15 volts. The power supplies may be switched on and off in any order. The only proviso concerning the ± 15 volt lines is that the converter should not be powered with + 15 volts without the − 15, or − 15 volts without the + 15 for sustained periods. The prolonged absence of either line, with the other being connected, can cause overheating of the modules.

The data sheets describing the particular DSC's give the line currents taken under loaded and unloaded conditions. Two figures are sometimes given for the loaded currents i.e. "mean with full load" and "peak with full load". The "mean with full load" is the current averaged over one or more periods of the carrier frequency with the converter working at the angle which requires the highest current (45 degrees). The "peak with full load" is the peak current during the carrier cycle again for the converter working at the worst angle. If current limits are set on the power supply this peak current must be allowed for unless local electrolytic capacitors are employed to average out the current required from the power supply.

Variations of accuracy and performance with reference frequency

DSC's and DRC's are designed to work at specific reference frequencies usually 60 Hz or 400 Hz with tolerances (as given in the data sheets) over which they will operate to their full accuracy. These frequencies are generally conservative and a DSC designed for 60 Hz is likely to work at 400 Hz with negligible degradation in performance. Similarly a 400 Hz converter will work at 800 Hz with only small additional errors. The converse however is not true. Converters designed for 400 Hz operations are not suitable for use at 60 Hz. This limitation is because the 400 Hz converters contain internal transformers which will saturate if lower reference frequencies are used. To obtain satisfactory operation of a 400 Hz converter at 200 Hz, the AC references voltage into the converter would need to be halved, this reduction of input will cause reduced outputs in proportion.

Though it is difficult to generalise over the whole range of DSC's Fig. 4-20 shows a typical degradation in performance for the DSC1705 60 Hz converter over the range 50 to 800 Hz. Fig. 4-21 shows a similar curve for the DSC1705 400 Hz version used over the range 400 Hz to 3 KHz.

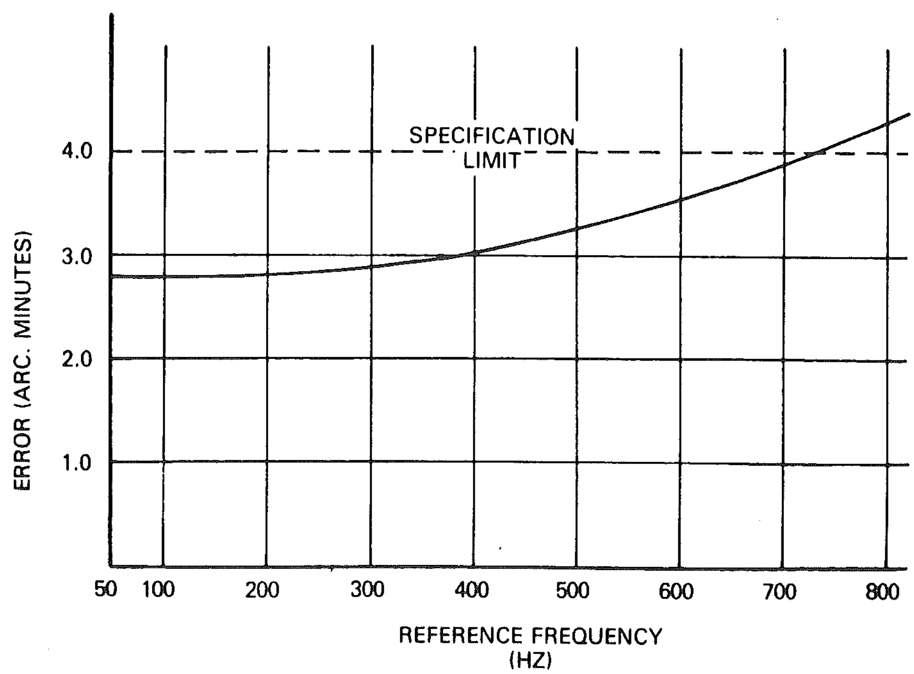


Fig. 4-20 Typical performance of the 60 Hz option DSC1705 over 50 Hz to 800 Hz.

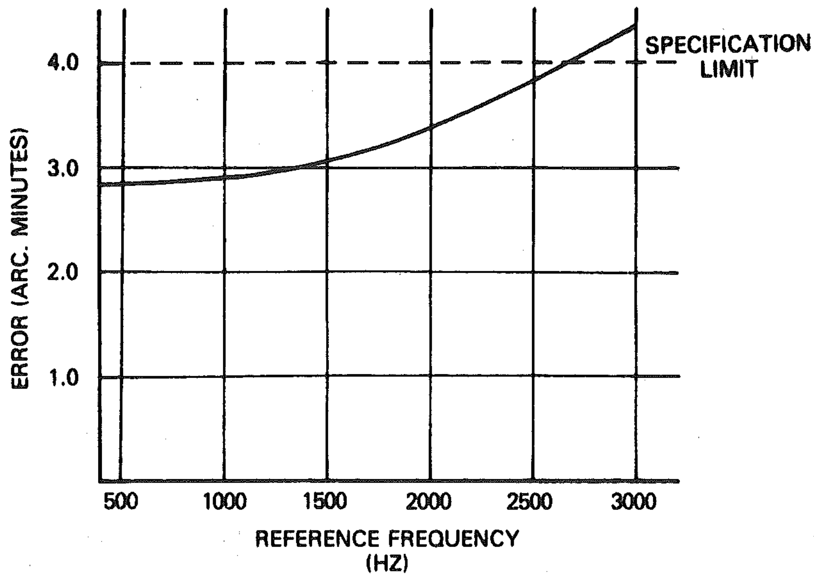


Fig. 4-21 Performance of the 400 Hz option DSC1705 over 400 Hz to 3 KHz.

Loading the Converters

Synchro Control Transformer Loads

The most common use of DSC's and DRC's is for driving Synchro or Resolver control transformers. The rotor of the CT is almost invariably connected to the input of an amplifier, which is followed by a phase sensitive detector. The input impedance of the amplifier will be high, usually 20 K ohms or more, and from the loading point of view therefore the CT secondary load can be neglected and the relevant impedance will be the Z_{SO} of the CT (see Chapter I Section "Synchro and Resolver Parameters" heading 'Impedances'). See Fig. 4-22.

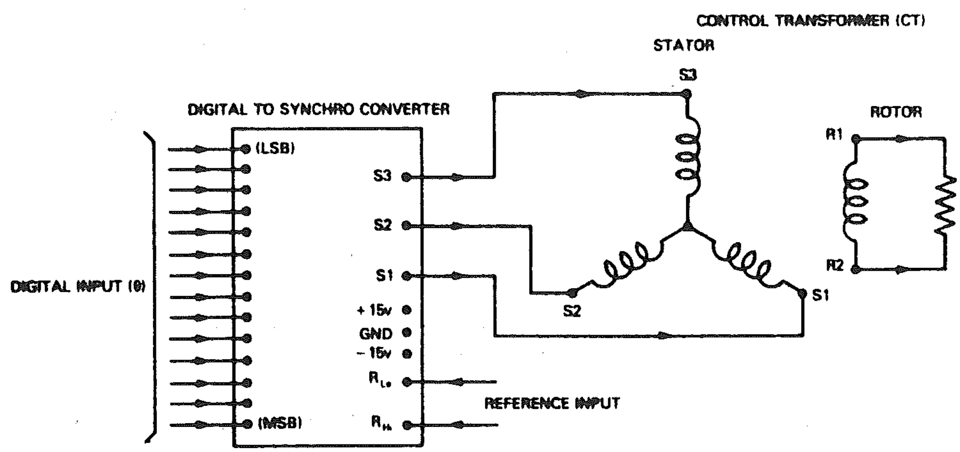


Fig. 4-22 A Digital to synchro converter connected to a control transformer (CT).

The following is a brief explanation of the VA considerations in the converter output circuits.

The output of the converter is basically in Resolver format and is converted to Synchro format by Scott connected transformers.

The Resolver outputs from the amplifiers are:

$$V_o \operatorname{Sin} \omega t \operatorname{Sin} \theta$$
$$\text{and} \quad V_o \operatorname{Sin} \omega t \operatorname{Cos} \theta$$

First for simplicity, we assume equal resistive loads, R, on each output.
The total power into the loads as a function of θ is:

$$\frac{(V_o \operatorname{Sin}\omega t \operatorname{Sin}\theta)^2}{R} + \frac{(V_o \operatorname{Sin}\omega t \operatorname{Cos}\theta)^2}{R} = \text{Total Power}$$

or

$$\frac{V_o^2 (\operatorname{Sin}\omega t)^2}{R} \cdot (\operatorname{Sin}^2\theta + \operatorname{Cos}^2\theta) = \text{Total Power}$$

or

$$\frac{V_o^2 (\operatorname{Sin}\omega t)^2}{R} = \text{Total Power}$$

i.e. The total power into the loads does not change with the angle θ. The load is usually not resistive, it is complex, but the same argument holds with R being replaced by Z and power replaced by VA.

Since at 90 degrees ($\theta = 90$) the VA from the Sine channel is maximum and is a minimum in the Cosine channel, the maximum total load VA is equal to the power provided by one of the output amplifiers.

To relate the maximum VA available from each resolver channel to the permissible Synchro loading, it is necessary to find the impedances (due to the synchro load) reflected into the sine and cosine channels through the Scott connected transformers.

Since the control transformer is for all practical purposes unloaded the relevant impedance is Z_{SO}. Fig. 4-23 shows the star connected equivalent control transformer.

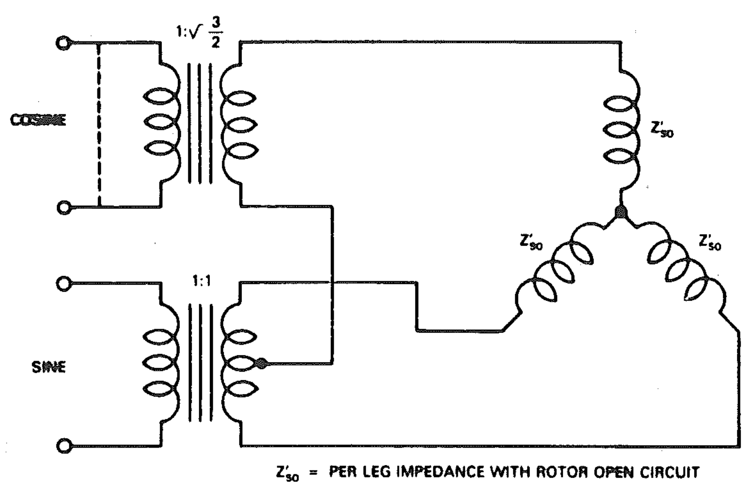


Fig. 4-23 The equivalent output condition when the sine channel is at maximum and the cosine channel at zero power.

To determine the impedance as seen looking out of Sine transformer terminals, we must short the Cosine channel to simulate the low output impedance of the converter output amplifier driving the terminals.

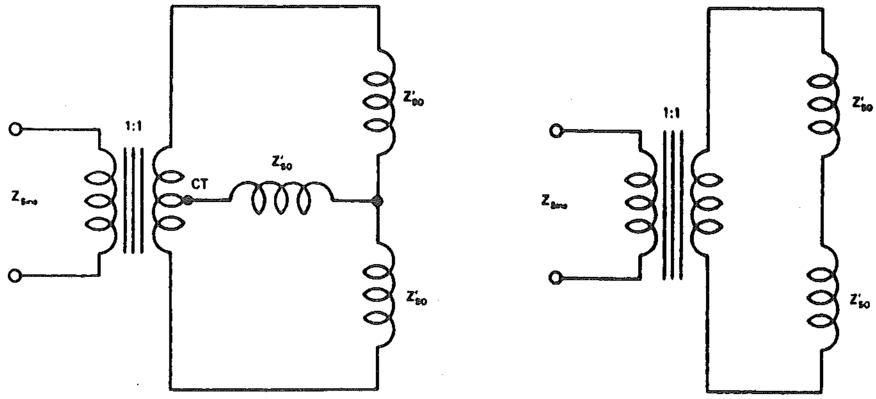
Z_{SO} is the impedance between one of the three stator wires and the other two shorted together with the rotor open circuit. Z_{SO} is therefore equal to:

$$Z'_{SO} + \frac{Z'_{SO}}{2} = \frac{3}{2} Z'_{SO}$$

(See Fig. 1-34 Chapter I for definition of Z'_{SO}).

The equivalent circuit of Fig. 4-23 with the Cosine channel shorted out is shown in Fig. 4-24 from which it is seen that:

$$Z_{sine} = \frac{4}{3} Z_{SO}$$



$Z_{Sine} = 2.Z'_{SO} = \frac{4}{3}.Z_{SO}$

Fig. 4-24 The equivalent circuit showing the impedance loading on the resolver outputs due to the synchro load.

Similar reasoning, but with a different equivalent circuit shows:

$$Z_{Cosine} = \frac{4}{3} Z_{SO}$$

The minimum impedance on the outputs of the Resolver format amplifiers is determined by the voltage swing and the maximum output VA.

Since $V_{LL} = V_{Sine} = V_{Cosine}$

$$Z_{Cosine}(min) = Z_{Sine}(min) = \frac{V_{LL}^2}{(VA)_{max.}}$$

$$\text{or} \mid Z_{SO} \mid (min) = \frac{(V_{LL})^2}{(VA)_{max.}} \cdot \frac{3}{4}$$

Where V_{LL} is the output line to line voltage and $(VA)_{max.}$ is the output VA capability of the converter.

For example:

1) If (VA) max = 1.3 and V_{LL} = 11.8 volts

$$\mid Z_{SO} \mid (min) = \frac{11.8^2}{1.3} \times \frac{3}{4} = 80.3 \text{ ohms.}$$

2) If (VA) max = 1.3 and V_{LL} = 90 volts

$$\mid Z_{SO} \mid (min) = 4670 \text{ ohms.}$$

Conversely, if we have a Synchro CT with a $\mid Z_{SO} \mid$ of 4949 ohms, and a line to line voltage of 90 volts, the minimum power required will be:

$$(VA)_{(min)} = \frac{90^2}{4949} \times \frac{3}{4} = 1.23$$

An important point to remember in loading calculations is the effect of the reference voltage. For example in the above example, we can assume that the 90 volt line to line signal voltage was produced as a result of a 115 volt reference supply to the converter.

Suppose that the reference supply increased fractionally to say 120 volts.

$$\text{Then } V_{LL} = 90 \times \frac{120}{115} = 94 \text{ volts}$$

$$\therefore (VA)_{min} = \frac{94^2}{4949} \times \frac{3}{4} = 1.34$$

i.e. A small increase in the reference voltage and consequently in the line to line voltage produces a relatively large change in the power required to drive the C.T..

The table in Fig. 4-25 shows the typical impedances for various sizes of Synchro control transformer.

Size	Z_{SO}	Z_{SS}	$\|Z_{SO}\|$	$\|Z_{SS}\|$	Frequency	Voltage
08	100+j506	140+j53	515	149	400	11.8
08	64+j332	—	338	—	400	11.8
11	20+j128	27+j13.8	129	30	400	11.8
11	700+j4900	900+j515	4949	1036	400	90
15	1020+j8330	1500+j982	8392	1792	400	90
15	1140+j6240	2280+j836	6343	2428	60	90
18	1360+j12600	1240+j1250	12700	1760	400	90
18	1690+j4800	2830+j848	5088	2954	60	90
23	1230+j14300	1100+j1360	14310	1749	400	90
23	1380+j4790	2370+j791	4984	2498	60	90

Fig. 4-25 Table showing the impedances of some common synchro control transformers.

Resolver Control Transformer Loads

Generally speaking, Resolver control transformers present higher impedances than Synchro control transformers and are therefore easier to drive.

In a Resolver, Z_{SO} is the impedance of one stator winding with the rotor open circuited and Z_{SS} is the impedance of one stator winding with the rotor short circuited and turned to the angle of maximum coupling. When driven from digital to Resolver converters, the Resolver outputs will generally be connected to high impedances, and in this condition, the impedance which is relevant is Z_{SO}.

The power required to drive a Resolver control transformer load $(VA)_{(min)}$ is:

$$\frac{(V_{LL})^2}{(Z_{SO})}$$

The table in Fig. 4-26 gives the Z_{SO} and Z_{SS} values for typical computing and data transmission resolvers.

Size	Voltage	Z_{SO}	$\|Z_{SO}\|$	Z_{SS}	Frequency	Type	$V^2/\|Z_{SO}\|$
08	5–26	250+j790	828	420+j140	400	C	0.82
08	5–26	220+j420	474	—	400	C, DT	1.426
08	11.8	45+j168	173	81+j28	400	DT	0.80
08	11.8	230+j955	982	—	400	DT	0.14
11	0–40	350+j2220	2247	600+j279	400	C	0.71
11	0–26	170+j860	876	270+j110	400	C	0.77
11	5–40	620+j2440	2517	—	400	C	0.63
15	0–60	510+j3200	3240	514+j315	400–1000	C	1.11
15	0–60	300+j1400	1431	365+j145	400–1000	C	2.51
15	5–26	200+j1060	1078	—	400–1000	C	0.63
23	26	58+j575	577	—	400	C, DT	1.17
23	0–90	360+j2830	2852	—	400	C, DT	2.8

C = Computing DT = Data transmission

Fig. 4-26 Table showing impedances of some common resolver control transformers.

Tuning Synchro and Resolver Control Transformer Loads

Capacitors can be used to reduce the problem of Synchro and Resolver loading on the converter. These are matched capacitors whose values are chosen to tune out the reactive current required by the Synchro or Resolver.

In the case of Synchros, tuning is carried out by means of 3 capacitors across the Synchro lines as shown in Fig. 4-27.

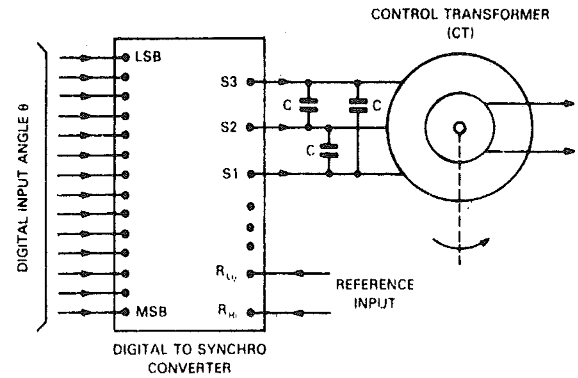


Fig. 4-27 Tuning the output of a Digital to synchro converter.

The values of the capacitors are given by:

$$C = \frac{X_{SO}}{4\pi f\,(R_{SO}^2 + X_{SO}^2)}$$

For example in the case of an 11CT4C,

$$Z_{SO} = R_{SO} + jX_{SO} = 700 + j4900$$

Therefore:

$$C = \frac{4900}{4 \times \pi \times 400 (245 \times 10^5)}$$

$\therefore$ $\underline{C = 40\text{ nF}}$

The power required after tuning will be:

$$(VA)_{untuned} \times \frac{R_{SO}}{Z_{SO}}$$

In the above example

$$(VA)_{untuned} = \frac{V_{LL}^2}{|Z_{SO}|} \times \frac{3}{4} = \frac{90^2}{\sqrt{700^2 + 4900^2}} \cdot \frac{3}{4} = 1.23$$

$\therefore$ Power required after tuning is

$$1.23 \times \frac{700}{4950} = \underline{0.17\text{ VA}}$$

The tuning of Resolver loads is illustrated in Fig. 4-28 and the calculation is the same as for Synchros.

There are however precautions to be taken when tuning the outputs of the converters.

1) The capacitors must be AC voltage rated.
2) If the capacitors are not carefully matched, phase shifts will occur which will give rise to quadrature signals. The quadrature signals may be tolerable in many systems but could cause saturation of the servo system error amplifiers and asymmetrical limiting which may cause errors. The presence of quadrature will make phase shifts on the reference more critical. (See section in this chapter on "Quadrature errors and reference phase shift".)

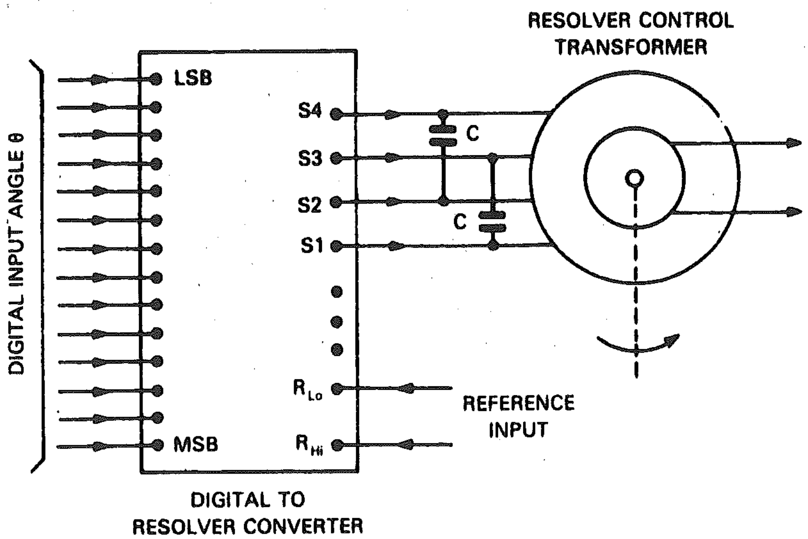


Fig. 4-28 Tuning the output of a Digital to Resolver converter.

3) It must be remembered that if the Synchro or Resolver is disconnected leaving the tuning capacitors still connected to the converter, then the capacitors will present a heavy load to the converter.

Torque Receiver Loads

Torque receivers generally have much lower impedances than control transformers. The table in Fig. 4-29 gives the Z_{SO} and Z_{SS} for some typical devices.

Size	Voltage (r.m.s.)	Frequency (Hz)	Z_{SO} (Ohms)	Z_{SS} (Ohms)	$\|Z_{SS}\|$ (Ohms)
11	26	400	3.1+j19.4	3.3+j1.3	3.54
11	115	400	175+j1090	191+j76	205
15	115	400	65+j493	48+j33	58.2
15	115	60	301+j1400	501+j106	512
18	115	400	16+j180	12+j12	16.9
23	115	400	7.5+j98	5.1+j5.0	7.1

Fig. 4-29 Impedances of some typical Torque receivers.

Fig. 4-30 shows how the Torque receiver (TR) and Torque transmitter (TX) are connected in the electromechanical arrangement. Torque receivers and Torque transmitters of the same size are usually electrically identical.

Fig. 4-31 shows a Digital to Resolver converter (or a Digital Vector Generator e.g. DTM 1717), power amplifier SPA1695 and Scott connected transformers driving a torque receiver.

Looking at Fig. 4-30, it is clear that in the null condition, i.e. when the angles of the TR and TX are the same, no circulating currents will flow in the stator windings. This is because the voltage produced by the transformer action of the TR exactly balances the voltage produced by the transformer action of the TX.

Considering the perfect system, where in the null condition, the voltages exactly balance, a deviation of the angle of the receiver relative to the transmitter of θ degrees, will give rise to an inequality in the voltages, which will give rise to a restoring torque. Fig. 4-32 shows how the torque and current will vary with angle.

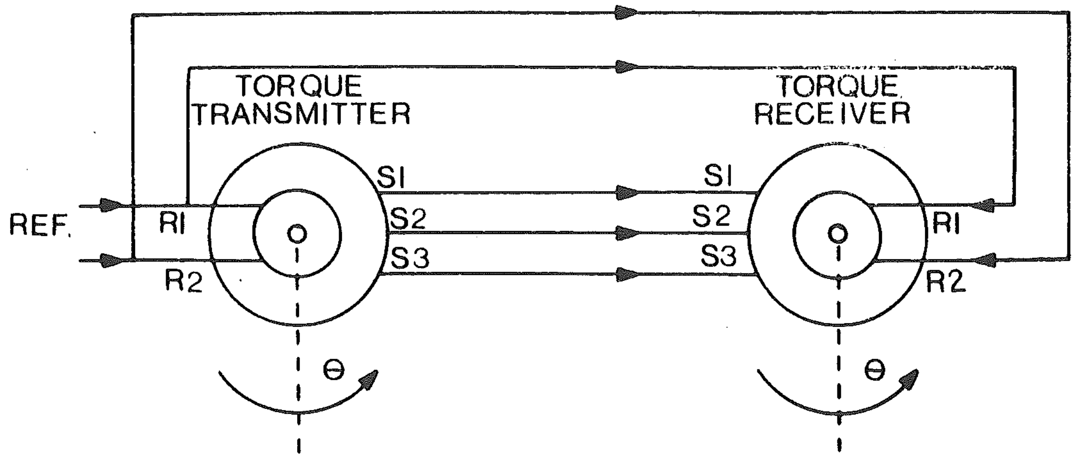


Fig. 4-30 Torque transmitter — Torque receiver electromechanical coupling.

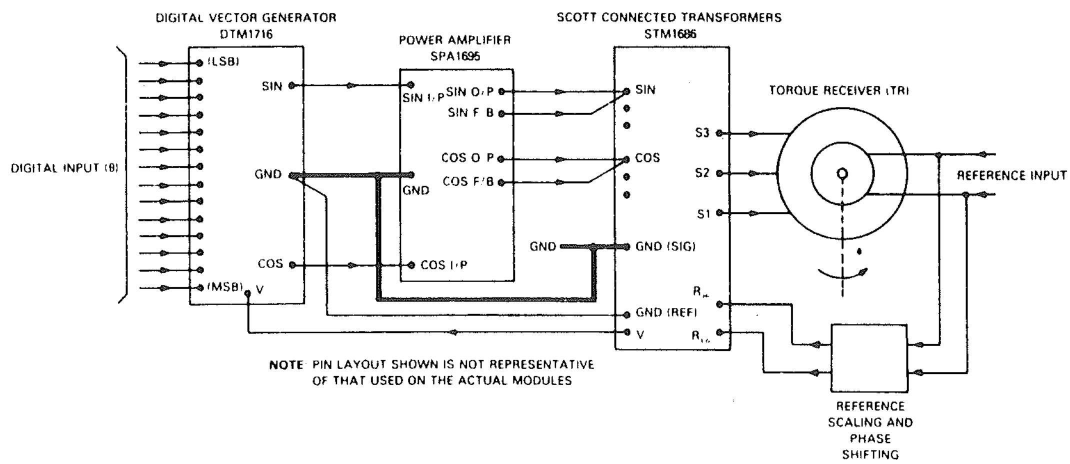


Fig. 4-31 Using a Digital Vector Generator, external power amplifier and transformers to drive a torque receiver.

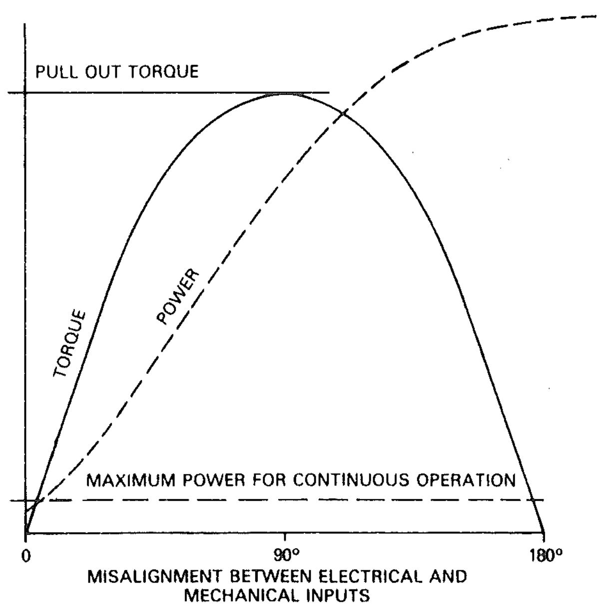


Fig. 4-32 Torque and power requirement variation with angle in a torque receiver.

The maximum torque, called the "Pull out torque" occurs at 90 degrees difference in angle. The current however continues to increase up to a maximum for 180 degrees misalignment, the current gradient and hence torque gradient are maximum for small differences in angle.

The current due to the deviation in angle θ is given by:

$$\Delta I = \frac{(2\ V_{LL}\ \mathrm{Sin}\ \frac{\theta}{2})}{|Z|}$$

or for small values of θ

$$\Delta I = \frac{V_{LL}\ \theta}{|Z|}$$

where θ is in radians.

The Z in these equations will be $2 \times \frac{4}{3} Z_{SS}$ for the electromechanical case or:

Z_{SS} + The output impedance of the Scott transformer in the case of the TR being driven from a DRC, amplifier and Scott transformers.

The table in Fig. 4-33 shows the Z_{SS} value for various torque receivers together with the deviation in angle to use 5VA.

Type No.	Z_{SS}	$\lvert Z_{SS}\rvert$	Voltage	Angle to (θ) use 5VA*	Gram cms Torque at θ*	Torque per degree (g cms)*	VA per degree*	Torque per VA.(g cms/VA)*	Frequency
08M4K1	8.8+j1.8	8.98	11.8	36°	13.3	0.37	0.14	2.6	400Hz
26V11TR4b	3.3+j1.3	3.54	11.8	14.5°	8.84	0.61	0.34	1.76	400Hz
11TR4b	191+j76	205	90	14.4°	8.8	0.61	0.34	1.75	400Hz
15TR4c	48+j33	58.2	90	4.0°	8.99	2.20	1.25	1.79	400Hz
15TR6a	501+j106	512	90	36.0°	79.2	2.20	0.14	15.84	60Hz
18TR4b	12+j12	16.9	90	1.18°	8.49	7.20	4.23	1.69	400Hz
18TR6a	379+j81	387	90	27.2°	97.9	3.60	0.18	19.6	60Hz
23TR4b	5.1+j5.0	7.1	90	0.49°	8.8	18.0	10.2	1.76	400Hz
23TRX6a	106+j24	108	90	7.6°	65.6	8.6	0.65	13.0	60Hz

* These figures are worked out on the basis that the source impedance of the drive is equal to Z_{SS}.

Fig. 4-33 Some Torque receivers and their drive requirements.

There are some general considerations concerned with driving Torque receivers from converter systems.

Since both the power amplifier driving the Torque receiver and the Torque receiver itself are power sources which are coupled together opposing each other, removal of the reference input to one and not the other will give rise to very large currents unless precautions are taken. Simple current limiting is not the solution here since this would mean a sacrifice in the maximum torque available.

In the electromechanical case, the similarity between TR and TX means that an automatic balance is obtained between the opposing voltages in the aligned condition. Such an automatic match is not obtained when amplifiers are used to drive the torque receiver and scaling of the reference should be carried out to ensure that the aligned voltages balance. *Digital to Synchro converter systems which have a radius vector variation (transformation ratio) with angle, are not suitable for driving torque receivers.* A rule of thumb which can be used to estimate the effect of voltage scaling difference is that ±7.5% amplitude variation will use up VA in the aligned condition equivalent to the VA which would normally have been obtained with a 4.25 degree misalignment.

The voltages on the stators of TR's and TX's is phase advanced by a few degrees (2 to 8 degrees) relative to the input reference. If a TR is driven from a converter and amplifier system some phase shift should be included in the DSC reference to give the required phase balance. To get the order of things, a 26 volt size 11 torque receiver may have a Z of 3.3+j1.3. Multiplying by 4/3 to give Z_{LL} and by 2 on the basis that the output Z_{SS} of the amplifier is equal to it gives:

$$|Z| = 9.45\ \text{ohms}.$$

With a 10° phase shift in the aligned condition, a current of 220mA will flow.

Unless care is taken to balance the voltages and phase, it is likely that overheating of the TR will occur. It is dangerous to try to solve the problem by giving excessive power drive. An amplifier capable of giving a continuous power required for the pull out torque would almost certainly be capable of burning out the TR if it is locked off angle or if its reference voltage fails. A more practical solution seems to be to only permit the maximum power for a short period with repetitive re-trys in the locked up condition, where the duty cycle is chosen so as not to cause overheating of the TR. When the maximum "pull out torque" is not required, these precautions are not required and a 5 to 10 VA amplifier is adequate for the purpose in many cases.

Control Differential transmitters (CDX) as loads

A control differential transmitter (CDX) is usually driven by an electromechanical control transmitter (CX). The output of the CDX is usually fed to a control transformer (CT). The impedances for some sizes of CDX are shown in the table in Fig. 4-34.

Size	Z_{SO}	Z_{SS}	$\lvert Z_{SO} \rvert$	Voltage	Frequency	$2/3.\lvert Z_{SO} \rvert$
08	24+i108	39+j14	110	11.8	400	73
11	12.2+i75	17.5+j8.5	76	11.8	400	50
11	242+i1690	421+j211	1707	90	400	1138
15	129+i917	164+j111	926	90	400	617

Fig. 4-34 Table showing impedance values for some Control Differential transmitters.

CDX's can be worked either way round but it is usual to drive the stator, taking outputs from the rotor. The impedance looking into the stator when the rotor is connected to a CT will not be given by either Z_{SO} or Z_{SS} but will be somewhere in between due to the loading effect of the CT. The CT of similar size will have impedances Z_{SO} which are about 5 times those of the CDX and generally the CT output will be lightly loaded. The equivalent loading of the CDX therefore might be obtained by taking the Z_{SO} reduced to between $\frac{4}{5} Z_{SO}$ and $\frac{2}{3} Z_{SO}$.

As can be seen from Fig. 4-34, the impedances are considerably lower than those for CT's and therefore will require the use of external amplifiers or tuning to reduce the load.

QUADRATURE ERRORS AND REFERENCE PHASE SHIFT

Reference Phase Shift

In Synchro control systems, small reference phase shifts, say ±5 degrees usually are of no consequence. There are however cases where in high precision systems the small errors caused by reference phase shift together with quadrature voltages can cause errors, which though small may still be of significance. The design of DSC's and DRC's is such that there is negligible phase shift between the input reference and the output voltages.

On the other hand the CX, which is the device which the converter usually replaces, does have a phase shift between the input reference and the output voltage which is a phase lead of the output relative to the input of 2 to 6 degrees according to type. (Some resolvers can have up to 60°.) Control transformers also have similar phase leads.

The system should be designed so that the phase of the reference at the phase sensitive detector is the same as that of the signal on the CT rotor. DSC's give negligible phase shift and only the phase shift of the CT rotor should be allowed for.

Quadrature Errors

In the specification of the performance of Synchro Control transformers (CT's) and Synchro Control transmitters (CX's) there is a specification for the "Residual signal". See

Appendix A. For the servo design engineer, these residual signals are important because they are one of the factors which limit the performance of the control loop. Fig. 4-35 shows a CX connected to a CT. If the rotor of the CX is fixed and the rotor of the CT is turned to give a minimum signal, this minimum signal is referred to as the residual and it is caused by imperfections in the CX and the CT.

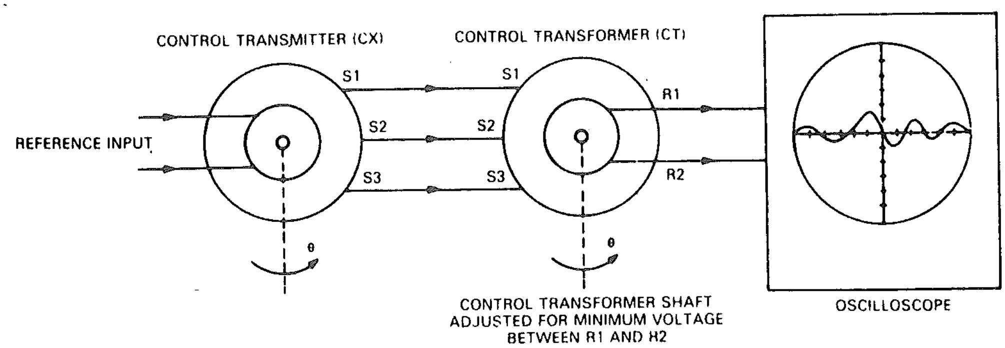


Fig. 4-35 Oscilloscope used to observe the residual signal in a CX-CT system.

The residual signal is predominantly formed from two components. They are:

a) A voltage which is at the reference frequency and 90° shifted in phase from the reference.

b) Components at twice the reference frequency and higher order harmonics.

Fig. 4-36 shows a typical residual signal on a CT rotor.

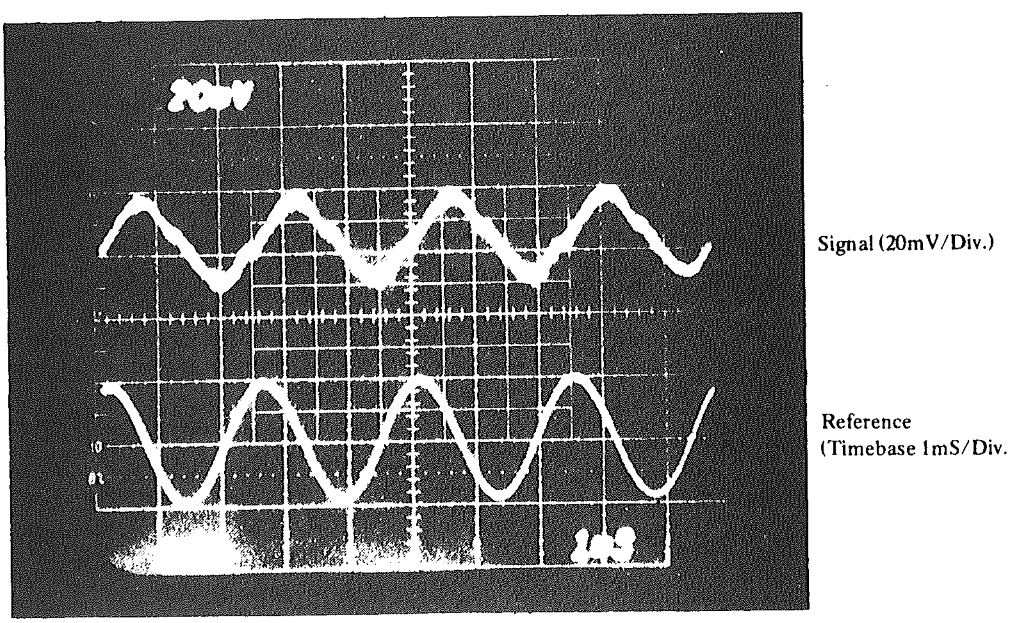


Fig. 4-36 Residual signal on a size 11 CT rotor in at the nulled condition.

The harmonic components are caused by the non-linear BH loop of the magnetic materials used in the CX and the CT.

The component at the reference frequency which is 90° shifted with respect to the reference is caused partly by small phase differences in the Synchro signal paths. This component is referred to as the quadrature voltage.

When a DSC is connected to a CT as in Fig. 4-37, and the rotor is turned to give a minimum, a similar residual signal will be formed from a quadrature signal and harmonics. Typical figures for the r.m.s. value of the residual signal are 0.1% of the line to line voltage.

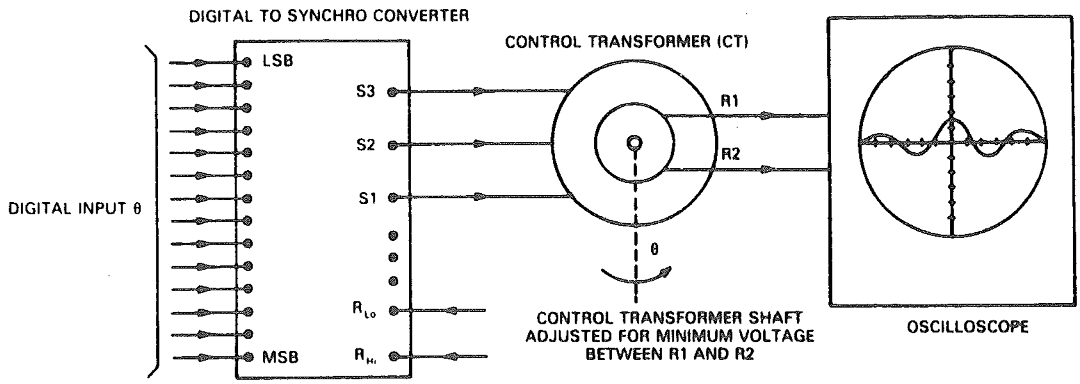


Fig. 4-37 Oscilloscope used to observe the residual signal in a DSC-CT system.

Fig. 4-38 shows the usual control loop in which the DSC-CT system is used. In such a control loop, the phase sensitive detector will not be sensitive to the second harmonic which is the dominant part of the harmonic component of the residual. Since the phase sensitive detector is not sensitive to components which are at 90° to the reference the loop will generally be insensitive to the quadrature signals, however due to the fact that the quadrature is created by small differential phase shifts between the signal, some errors can be caused and the errors are greater if the reference phase is shifted with respect to the signals as it is in many practical cases. Concerning this phase shift, it can arise due to the CT which will often have a lead of up to 5 degrees between the input and the output.

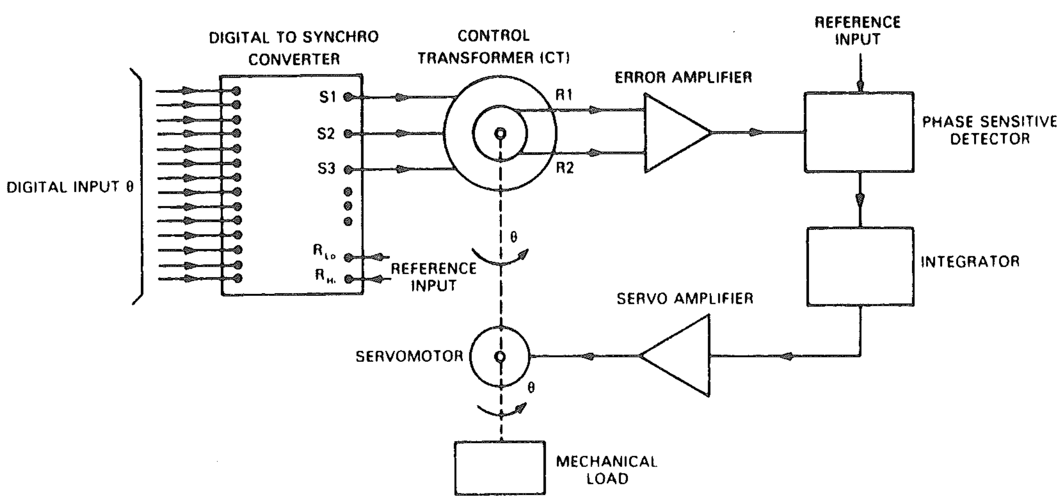


Fig. 4-38 Digital to Synchro converter driving a control transformer in a servo system.

An analysis of the errors due to quadrature signals is given in appendix F. The results of the analysis show how much quadrature residual signal is caused by a small differential phase shift in a resolver type system. It also shows the angular errors caused by this quadrature with and without phase shifts between the signal and the reference. The general results of the analysis are as below.

For a 90 volt control transformer:

(1) 0.1 degrees of differential phase shift between the Sine and Cosine signals produces 0.05 volts RMS of quadrature residual signal.

(2) If the reference and signals are in phase before the introduction of 1 degree of differential phase shift between the sine and cosine signals, the extra error introduced into the servo system due to the quadrature so caused will be 0.25 arc minutes.

(3) For 5 degrees phase shift between the reference and signals existing before the introduction of a 1 degree differential phase shift in the Resolver signal path, the extra error introduced into the servo systems with be 2.5 arc minutes.

The examples of differential phase shift of 1 degree taken in (2) and (3) above are very large and 0.2 degrees is a more typical figure. The results show therefore that for most systems, the small residual quadrature signals will not produce significant errors providing that the phase sensitive detector is of a good design. It is important that the error amplifier is designed so that no limiting can be caused by these residual signals, otherwise much larger errors may be caused.

In very small servo loops, such as those sometimes encountered in aircraft instruments, small biphase motors are sometimes used. In such systems there is no phase sensitive detector, the error signal is applied as an AC signal to the motor, while the other windings are energised by voltages in phase and also at 90 degrees with respect to the reference. These control loops are more sensitive to the quadrature signal than the usual phase sensitive detector DC control system.

DIGITAL TO SYNCHRO TWO SPEED (COARSE/FINE) SYSTEMS

Fig. 4-39 shows the digital to Synchro coarse-fine conversion requirement.

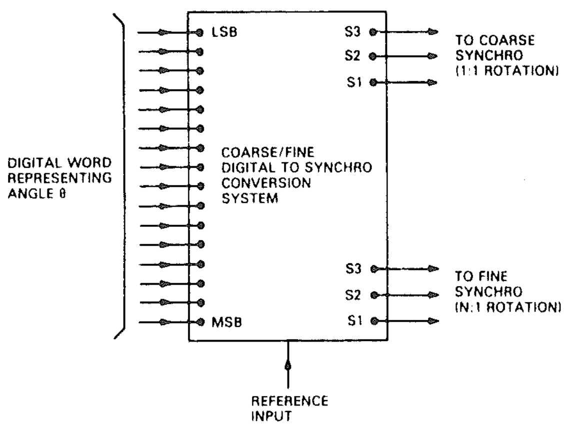


Fig. 4-39 General requirement for a coarse/fine digital to Synchro conversion system.

The input angle in digital form representing the coarse shaft angle will be the output from a digital computer or digital control system. The coarse/fine digital to Synchro conversion system takes this digital word and produces from it two Synchro or Resolver format signals for driving the coarse and fine Synchro or Resolver control transformers.

The basic units required to perform this conversion are two digital to Synchro or Resolver converters and a digital multiplier to simulate the coarse/fine gear ratio. The conversion systems for digital to coarse/fine Synchro signals are straightforward, there is none of the additional complexity equivalent to the combining logic required in the two speed Synchro to digital systems. (See Chapter 3).

Binary Gear Ratios

In the case of binary gear ratios, the multiplication becomes simply a shift in the digits used.

Fig. 4-40 shows the digital to Synchro coarse/fine system for a gear ratio of 32:1. For the ratios of 16:1 and 8:1, the shift in digits to the fine converter will be 4 and 3 respectively.

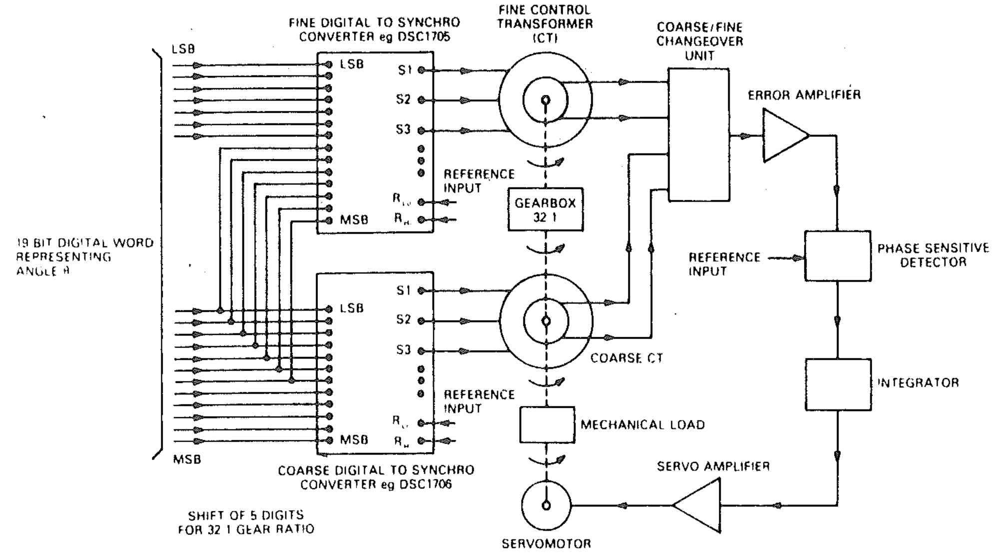


Fig. 4-40 A coarse/fine digital to Synchro system for a ratio of 32:1 driving a coarse/fine servo control loop.

In Fig. 4-40 the DSC1706 is a 12 bit Synchro to digital converter and the DSC 1705 is a 14 bit converter. If the DSC1705 is used for the 16:1 and 8:1 gear ratios, the LSB or last 2 LSB's (Least Significant Bits) in the input will not be used.

Non Binary Gear Ratios

In the case of non binary gear ratios, the multiplication becomes a shift and an add in the digits instead of the simple shift in the case of binary gear ratios.

Fig. 4-41 shows the arrangement for non binary ratios.

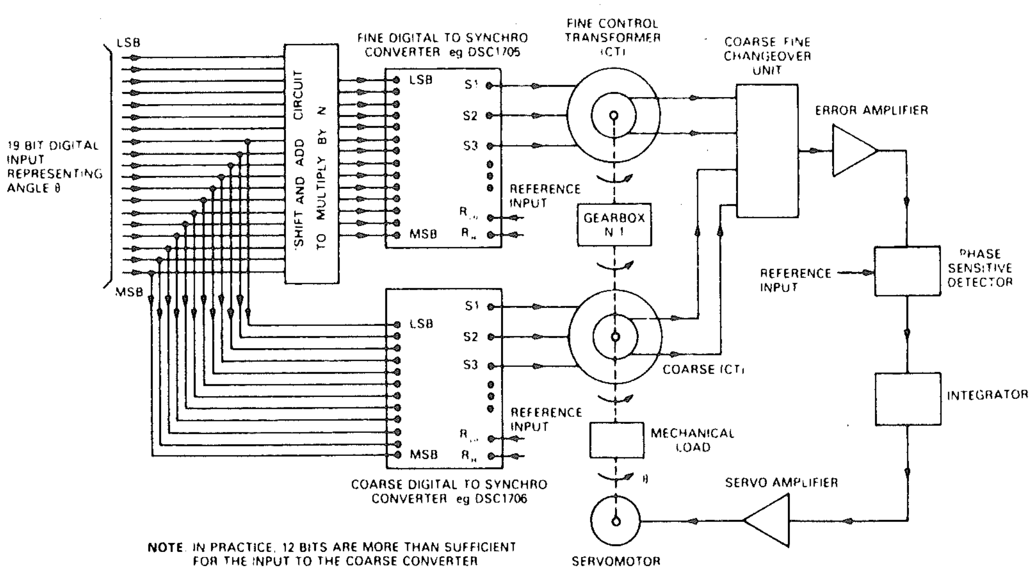


Fig. 4-41 Non-binary ratio coarse/fine digital to synchro conversion system driving a coarse/fine servo control loop.

In Fig. 4-41 the multiplication is carried out by the shift and add multiplier.

A 9:1 shift and add multiplier circuit is shown in Fig. 4-42. In the case of an 18:1 system, the most significant bit of the input word is not connected, i.e. a shift of 1 place or a multiplication of 2 is made. In the case of a 36:1 system the two most significant bits of the input word are not connected.

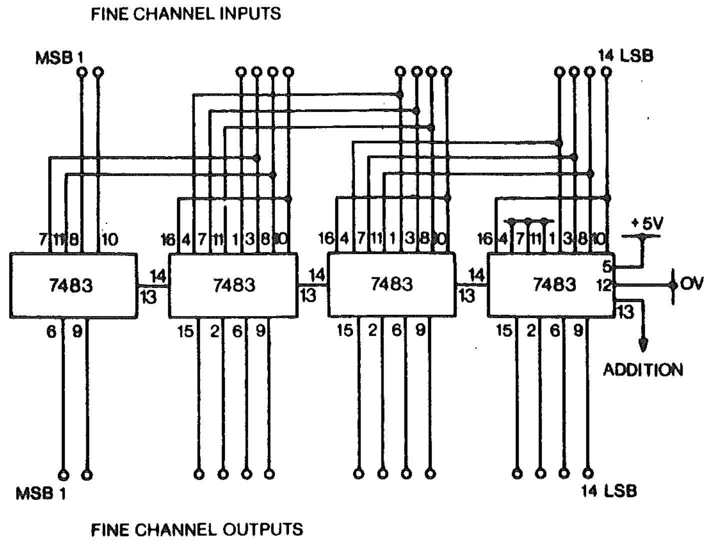


Fig. 4-42 A Shift and Add Multiplier circuit.

DRIVING LOADS GREATER THAN 1.3 VA

Most of the standard modular digital to Synchro and Resolver converters available contain internal amplifiers which are capable of driving a 1.3 VA load. This is sufficient to drive most Synchro and Resolver control transformer loads. If a load greater than this has to be driven then two alternatives exist.

(a) Load tuning can be used. This has already been described.

(b) External amplifiers can be used.

In the case of (b), a suitable system can be formed to drive a load of up to 5 VA, which is the load presented by 4 size 11 Synchro control transformers, by using a combination of one of the digital vector generators type DTM1717 or 1716 and the SPA1695 amplifier. A digital to resolver converter could be used in place of the Digital Vector Generator but it would mean a duplication of amplifiers. The DTM1716 and 1717 also have the added advantage of being low profile (0.4 inches) and therefore can be used with 0.5 inch printed circuit rack spacing assuming that the SPA1695 can be mounted externally. The illustration in Fig. 4-31 shows a suitable configuration for such a system.