TWO-SPEED SYNCHRO CONVERSION SYSTEMS

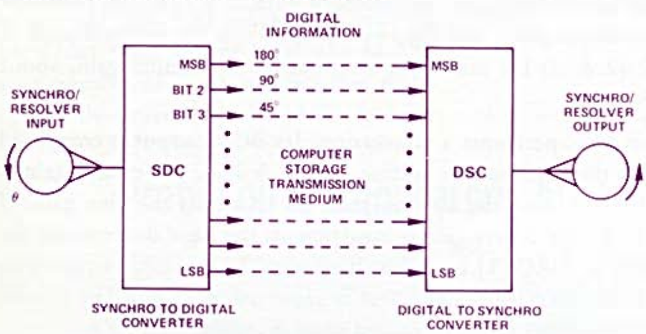
Use Moderate-Resolution Converters for High Angular Resolution, Limited Only by Gear Quality

by D. McDonnell

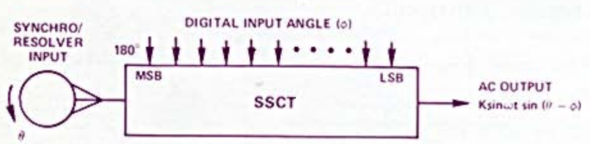
Synchro-Control Generator – A rotary component for transforming the shaft angle to a corresponding set of electrical signals for ultimate retransformation to the shaft position in a remote location.[1]

The transmission of angular shaft position by the use of ac synchro transmitters and receivers is a well-established field of engineering. Recent developments have widened the application of these electromechanical devices enormously.

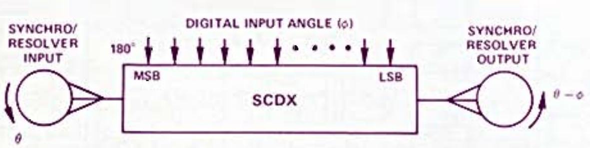
The original synchro transmission systems were purely electromechanical; electronics was used only in phase-sensitive rectification and power amplification. When the digital computer arrived, angular data in digital form had to be translated into synchro-type signals (and *vice versa*). This interface requirement was satisfied by the development of the synchro-to-digital converter (SDC) and the digital-to-synchro converter (DSC). These were soon followed by solid-state versions of the electromechanical control transformer (solid-state control transformer, SSCT), and control differential transformer (solid-state control differential transformer, SCDX).* Functional block diagrams of these units are shown in Figure 1.



a) Synchro/digital and digital/synchro converters



b) Solid-state control transformer



c) Solid-state control differential transformer

Figure 1. Synchro-digital conversion components

[1]*Modern Dictionary of Electronics*, R. F. Graf, Howard W. Sams, Inc., 1972

*For information and prices on ADI synchro conversion products, request **P4**.

Accuracy of transmission of angular data with simple systems is limited by the precision with which the output amplitudes of the synchro can be made to vary sinusoidally with the angle of rotation. With a good synchro, this limits the practical angular resolution to about 2 arc-minutes (93ppm of one revolution). Since it is possible to couple shafts with less than 2' gearing error, so-called *two-speed* (or *coarse-fine*) systems of angular-positional transmission are used. Even if greater errors are tolerable, it may simply be better economy to use two inaccurate synchros with accurate gears instead of a single high-accuracy synchro system.†

In a two-speed system, the shafts representing the angular position at both the transmitting and receiving ends are geared to additional shafts with step-up gearing. Synchro transmitters are coupled to both pairs of shafts at the transmitting end; receivers are coupled to both pairs of shafts at the receiving end. Typical gearing ratios might be 9:1 to 36:1, or (in the digital era) the binary ratios 8:1 to 32:1. This means that for each degree of arc traversed by the slow (coarse) shaft, the fast (fine) shaft turns through 9°, 36°, 8°, 32°, or whatever (60:1, or 60° in the clock-face analogy).

With two-speed systems, it is possible to transmit angular data representing the angle of the slow shaft (the hour-hand) with an accuracy limited only by the backlash plus nonuniformity of gearing referred to the slow shaft, without the use of very precise synchro receivers and transmitters. To transmit the angular position accurately, the coarse synchro should be capable of determining the angle to within one revolution of the fine synchro, and the precision of the fine-synchro data should be much better than the gearing backlash-angle, referred to the fine shaft.

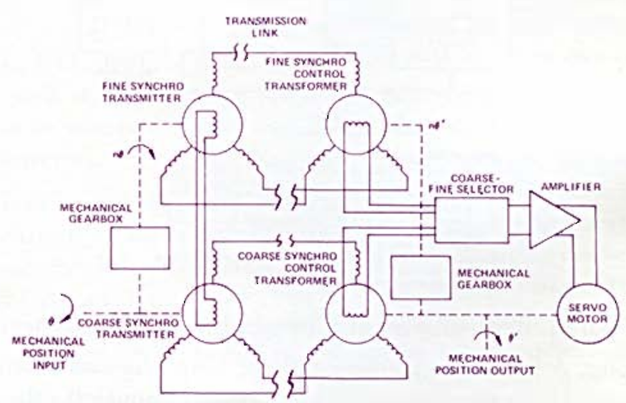


Figure 2. Electromechanical two speed synchro system

†Perhaps the most-familiar example of a visual-readout coarse-fine system is the familiar clock face. A three-speed system, its second-hand offers a 3600:1 improvement in resolution over the hour hand; the resolution of the entire system, even in the cheapest such watches, is of the order of 23ppm of 12 hours.

Figure 2 portrays an electromechanical two-speed system. The dotted lines represent mechanical coupling. The block marked "coarse-fine selector" in the remote-receiver portion determines whether *coarse* or *fine* signals are fed to the amplifier. Once the *coarse* error signal has determined the output angle to within one cycle of the fine synchro, the coarse-fine selector can switch to the *fine* converter to correct the remaining error.

Electromechanical two-speed systems have been in use for many years. Their special considerations are well-documented: e.g., the best point to switch over from *coarse* to *fine*, dealing with the change in loop gain, the possibility of stable false nulls with even gear-ratios, combatting them with "stick-off", etc.

TWO-SPEED DIGITAL TECHNIQUES

Besides the need to interface the *simple* synchro-format signals to digital computers, a need also arises to interface *two-speed* synchro signals to and from computers. This brief note considers mainly the acquisition problem: to develop a digital word representing the coarse shaft angle accurately from the coarse and fine synchro-format signals.*

Given the S/D transmitter system of Figure 3, with two sets of signals from the two synchros on the coarse and fine shafts, the problem is to produce an *unambiguous* digital word representing the angle of the coarse shaft with error less than the gearing imperfections and backlash referred to the coarse shaft angle.

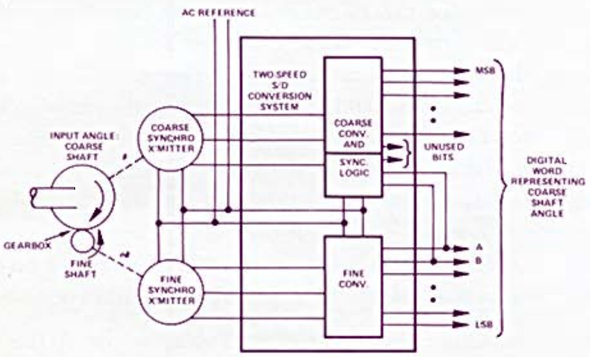


Figure 3. Two-speed synchro-to-digital conversion

For simplicity, let us assume a coarse shaft angle of 15° and a binary ratio (say 32:1). Using the angle-to-bit conversion scheme of Table 1, 10 bit S/D converters on the coarse and fine shafts would provide digital words corresponding to 15° and 32 x 15° = 120° (modulo 360°), or 0000101010 and 0101010101. Since the fine shaft's reading represents 1/32 of its actual position (in terms of the coarse shaft rotation), it must be divided by 32. This is easily done in binary fashion simply by shifting it 5 places to the right, viz., 000000101010101. We may now compare the two readings by listing them columnwise:

	CD
Coarse shaft reading	00001|01|010
Fine shaft reading/32	00000|01|01010101
	AB

In this case, there does not appear to be a conflict between the two shaft readings, and the output digital word will be 000010101010101 → 14.9963°. However, in a practical system, the overlapping digits will not change together at major transition points and the two digital readings will conflict. An unambiguous digital output is obtained by adding extra logic circuits, referred to as *synchronizing logic*.

The key to synchronizing is the fact that, considering errors in the coarse-shaft digitizing (bit 10), backlash on the coarse shaft (e.g., bit 11), and the fine synchro (bit 15), the fine synchro is certainly the most accurate. Therefore, the entire fine-shaft reading, starting with digit A, determines the last 10 digits and can answer the question as to whether or not the first 5 bits of the coarse shaft reading are correct (perhaps there is an erroneous carry or borrow at a major transition.

The synchronizing logic performs the operation indicated in the truth table, adding either +1, -1, or 0 to digit D, depending

A	B	Addition To D
0	0	+1
1	1	-1
0	1	0
1	0	0

on the state of A and B, and allowing borrows or carries to ripple back as far as they will go. The output word is then the resulting first 5 coarse digits, plus the fine digits.

For example, if the coarse word is 10000|00|000 and the fine word begins: |11| . . . , 1 must be subtracted from digit D, the resulting modified coarse bits are 01111|11|, and the correct word is 0111111 . . . (Note that in the first example given, the first five bits are unchanged by the application of this procedure.)

NON-BINARY RATIOS, HARDWARE

For non-binary ratios, the principle is similar, except that the digital multiplication and division by, say, 36, is not a mere matter of shifting the digits left or right. Since the logic circuitry is more extensive, it is usually embodied in a purely-digital *2-speed processor* (TSL1612), employed with two standard S/D converters (e.g., SDC1602, SDC1603). In the simpler case of binary ratios, however, the synchronizing logic is contained in a special *coarse* S/D converter (TSDC1610), and the fine converter is an ordinary type, such as the SDC1602.

DIGITAL-TO-SYNCHRO COARSE/FINE SYSTEMS

In digital-to-synchro systems, the input data, representing the desired coarse shaft angle, is used to generate digital inputs for the coarse and fine digital-to-synchro converters. Again, binary scaling (e.g., 32:1) requires merely shifting the fine data, while arbitrary scaling calls for shift-and-add multiplication. Control-system design requirements determine the nature of coarse-fine selection, which can now benefit by the flexibility inherent in digital processing. The conversion systems for D/A coarse-fine are straightforward; there is no complexity comparable to the synchronizing logic of two-speed S/D's.

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Table I. Angular bit weights

BIT NUMBER	WEIGHT (DEGREES)
1 (MSB)	180.0000
2	90.0000
3	45.0000
4	22.5000
5	11.2500
6	5.6250
7	2.8125
8	1.4063
9	0.7031
10 (LSB for SDC 10)	0.3516
11	0.1758
12	0.0879
13	0.0439
14 (LSB for SDC 14)	0.0220

*For a more-detailed application note on 2-speed conversion and appropriate converter- and processor data sheets, request **P5**.