PROJECT ECHO

Antenna Steering System

By R. KLAHN, J. A. NORTON, and J. A. GITHENS

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The Project Echo experiment employed large steerable communication antennas at the ground terminals. These are highly directional transmitting and receiving antennas which must be continuously and accurately pointed at the passing satellite. While the dynamic control of antennas has not been required in prior Bell System communications, it will play an important role in future systems utilizing many orbiting repeaters.

I. INTRODUCTION

Although communications antennas could be slaved to optical or radar trackers at each antenna site, the use of basic orbital information to generate antenna steering instructions is expected to be more economical when many antennas and sites are served. The latter method was used in Project Echo and employed the following steps:

1. determine satellite positions by accurate radio observations and, from these, calculate the basic satellite orbital elements;
2. use these elements to calculate future satellite positions;
3. from these positions, compute pointing angles for the antennas.

In the Echo experiment, these functions were performed by the Minitrack satellite tracking network and the Goddard Space Flight Computation Center, which are facilities of the National Aeronautics and Space Administration. The predicted angles were transmitted by teletypewriter from the computer at Washington to the Bell Telephone Laboratories antennas on Crawford Hill at Holmdel, New Jersey. The first portion of this paper discusses system design problems concerning the transmission of pointing information from computer to antenna site, and conversion of these data into servo-actuating signals that move the antennas to the predicted angles at the desired time. The second portion describes how these problems were approached in the antenna pointing system provided for Project Echo.*

1.1 *System Considerations*

Several factors affect the design of a data processing system for antenna steering. Functions performed by the system include:

1. transmission of predicted pointing data from a computer location to the communication antenna site and temporary storage there prior to each satellite pass;
2. assembly of the data from storage and synchronization to real time;
3. error checking and rejection of erroneous quantities;
4. conversion of the digital orders into analog command signals to control the antenna drive mechanisms.

The most important factor affecting the transmission facility, storage medium, and data reconstruction equipment is the sampling interval of the discrete pointing information delivered by the computer.

We will use the term *data point* to denote one sample of this information, and the term *data-point interval* to denote the interval between successive points. A wide range of intervals is possible, and interesting trade-offs can be made between data transmission rate, storage requirements, complexity of the conversion equipment, and reliability of performance.

There is, at one extreme, the possibility of transmitting large numbers of data points with short data-point intervals. Advantages of this approach come from two considerations. First, the digital-to-analog conversion process involves straightforward conversion of each point into an equivalent analog command. This simplifies the conversion equipment and offers advantages in reliability. Second, the data interval is short; therefore errors that occur in transmission, storage, or assembly from storage cause only momentary effects. Disadvantages result from the large quantity of data required to describe each satellite pass. This places an excessive load on the computer, the transmission, and the storage facilities.

At the other end lies the possibility of transmitting fewer sets of pointing angles with their derivatives at data-point intervals of many seconds. Interpolation between data points using these derivatives provides reconstruction of continuous pointing information. Reduction of data for

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* Although this equipment was designed by the Bell System as part of its research and development program, it was operated in connection with Project Echo under Contract NASW-110 for the National Aeronautics and Space Administration.

each pass is obtained at the expense of more extensive calculations by the computer and more complex conversion equipment at the antennas. There is a trade between the data rate of the transmission and capacity of terminal storage facilities on one hand, and the complexity of the data-conversion equipment at the antenna on the other.

When long data intervals are used, reliability considerations become more complicated. Discrete samples of position and higher derivatives become initial conditions in an integration process which extends over each data interval. Errors in transmitted data which are not detected and removed affect the system for the duration of the data interval. However, in this case redundancy for automatic error checking can be applied to the encoded quantities without requiring prohibitively large amounts of data.

To summarize, the optimum data interval is a function of several factors. These include the load imposed on the Goddard computer in the generation of error-correcting codes and higher-order derivatives, the cost and availability of transmission links, and the complexity of the data conversion equipment needed at each antenna.

Other design considerations include the method used for conversion of the transmitted digital data into antenna steering commands. There are two methods. The first employs electronic decoding of digital pointing commands to equivalent analog signals. These may then be used to direct a number of antennas at one site. A second method involves encoding of the antenna shaft positions in digital form and a subtraction between the encoded positions and the digital command signals. Here digital error signals are derived, which are more easily converted to analog signals to actuate the antenna servos. The latter method, preferred for precise antenna control, requires separate encoding mechanisms and digital subtractors with each antenna mount.

II. ANTENNA STEERING FOR ECHO I

This section describes the system which was designed to transmit pointing instructions from the Goddard computer to Holmdel and there convert them into antenna steering orders.

2.1 *System Philosophy*

In the design, many of the factors discussed in Section I were considered. Uncertainties regarding expected orbital perturbations of the balloon satellite placed emphasis on an approach that would provide updated pointing instructions after each satellite pass. The experimental nature of the project dictated the use of inexpensive transmission and storage media, and a reasonably simple digital-to-analog converter.

Of primary importance are the dynamic range of the steering signals, the conversion precision needed, and the form of analog signals required by the antenna control systems.

The Echo satellites were to be placed in near-circular orbits at altitudes of 800 to 1000 miles. Maximum angular tracking velocities would be under 1.5° per second, and average velocities would be much lower than this.

To insure that data conversion errors would not affect radio transmission characteristics, design error tolerances were set at ±0.05°.

Continuous three-wire ac synchro voltages were required as outputs of the converter, to command each antenna and optical mount control system. While direct conversion from digital form to ac signals is possible, an approach using small intermediate servos to position synchro transmitter units was more attractive.

Pulse-time-modulation techniques were used to position these servos. Digital input commands were converted into pulse-position-modulated (PPM) signals. At the same time, the servo output shaft positions were monitored by precision resolver angle transducers. Resolver outputs produce PPM signals of the same form. The two PPM signals were compared on a time basis to create error signals that position the servo units.

2.2 *Input Data Transmission*

A four-second data-point interval was chosen. This allows the description of a single satellite pass to be transmitted over a 60-word-per-minute teletypewriter channel in approximately the same amount of time taken by the pass. The choice of standard-speed teletypewriter was influenced by two factors. Conversion equipment was available at the Goddard computer center to produce punched-paper teletypewriter tape from the computer output. This tape could be transmitted and reproduced at the antenna site to provide economical data storage.

The pointing data furnished are the azimuth and elevation antenna angles computed for the geographic location at Holmdel. These are supplemented by the average rates of azimuth and elevation over the succeeding data interval to permit a linear interpolation between data points.

2.3 *Digital-to-Analog Converter Organization*

The data format, scale factors, and coding were chosen to minimize the digital-to-analog converter equipment. Teletypewriter code combinations were used to denote decimal data in an 8-4-2-1 binary code, with the fifth level of the tape being used as a single redundant parity-check bit. This was possible because a total of only 14 characters was needed. Sequences of tape characters called *words* represent the data-point time, azimuth angle, elevation angle, azimuth rate, and elevation rate. Each word is identified on the tape with an identifying "tag" code which follows the word. In addition to identifying the words, these tags control the switching of the words to the proper destination within the conversion unit. The use of tags makes the operation less dependent on the sequence of words and makes the system more tolerant of errors introduced by transmission links.

The conversion unit assembles the data from tape, synchronizes it with real time, and switches it to counting decoders, which produce pulse-position-modulated signals proportional to the digital data. The following paragraphs describe logical features of the conversion unit. The operation of the counting decoders and conversion of the PPM signals to analog commands are described in later sections.

A block diagram of the digital-to-analog conversion unit is shown in Fig. 1. A photoelectric tape reader reads the tape characters in sequence

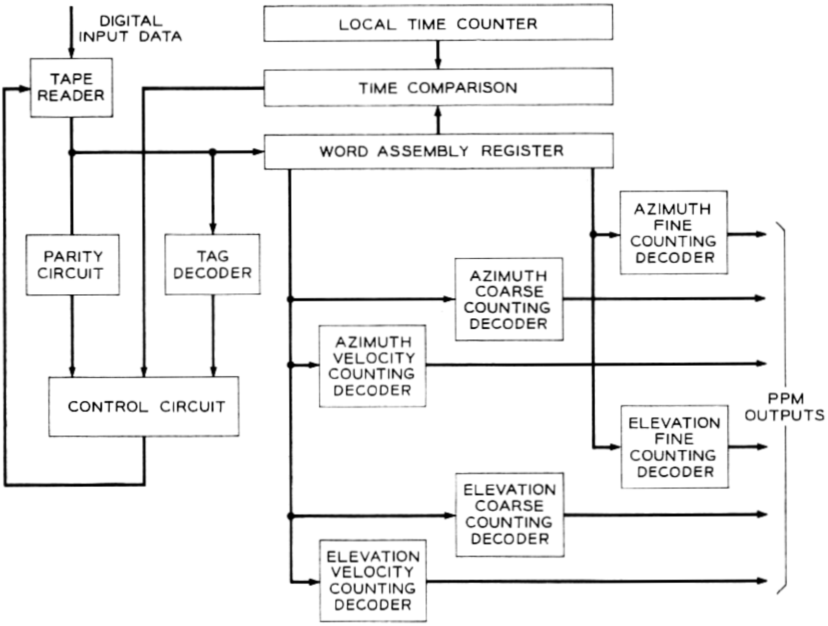


Fig. 1 — Block diagram of data conversion unit for Crawford Hill.

and converts the information to electrical signals. These are introduced to a shift register used to assemble the serial information from the tape into parallel words. The word-assembly register output feeds the counting decoders and the time-comparison circuit. The other input to the time-comparison circuit is the output of a local time counter. This circuit provides the conversion unit with real-time synchronization. Reader outputs are also applied to the tag decoder and the parity-check circuit. These actuate the control unit and determine the action taken by the conversion unit.

Consideration of events that occur while a block of information is read from the tape illustrates the operation of the conversion unit. Assume that the tape is stopped after the reader has read a time tag. This tag identifies the word in position in the word-assembly register as the time word corresponding to the time for the next data point. This time word is compared in the time-comparison circuit with the contents of the local-time counter. An affirmative indication from the time-comparison circuit causes a clock pulse to indicate that the next data point should be decoded. Tape reader action is initiated. As the tape moves, each character is examined by the tag decoder. If the tape character being read is not a tag, the contents of the word-assembly register are shifted one digit to the right and the new character is entered on the left.

This process continues until a tag is encountered — in this instance, the azimuth quantity. Detection of the azimuth tag indicates that the azimuth angle is in position in the word-assembly register and is ready for transmission to the azimuth-counting decoders. When a signal from the azimuth decoder indicates that it is ready to receive new data, it is cleared and the new azimuth word is gated from the word-assembly register. Reading of the tape continues, with examination of each character being introduced to the word-assembly register until the elevation tag is encountered. This causes the elevation word to be placed in the elevation decoder. The rate information is handled similarly. After the rate information has been transferred to the rate registers, reading of the tape continues until the next time tag is detected. This indicates that the time word for the next block of information is in the word-assembly register and is being compared with local time, to complete the cycle.

The logic of the time-comparison circuit is designed so that, for data blocks in the proper sequence, the comparison circuit will indicate comparison as soon as a time tag is detected in the reader. This comparison holds for the four-second interval. If, when a time tag is read, the contents of the word-assembly register and the local-time counter do not compare, the control circuit causes the tape to advance to the next time tag and make another comparison. If these times compare, it then proceeds as normal; if not, it stops and gives an alarm. If the comparison should become good, it turns off the alarm and proceeds as usual. Thus, in the event of a time-comparison failure, the system makes a quick check to see that it has not somehow got behind, as may happen if an error makes a data character look like a time tag. If the comparison check still fails, the alarm alerts operating personnel. However, if, because of transmission drop-outs or errors, the system has got a few seconds ahead, it will automatically correct itself, probably before any manual maintenance routines can be initiated.

The redundant check bit with each character is checked as the character is read. If a parity error is detected, the control circuit causes the tape to advance to the next time tag. Thus, when an error is detected, the data block is discarded. As described in a later section, the counting decoders continuously decode azimuth and elevation angles, which are up-dated with the last-received rate information. This gives the system a coasting feature, so that erroneous blocks of information may be discarded without seriously affecting the system accuracy.

2.4 *Counter Decoding*

The conversion of digital pointing commands involves an intermediate conversion to PPM signals. This is performed in high-speed sequential counting circuits. The concept is very simple: the number to be converted is placed in a counter which is designed to count toward zero. At the occurrence of a start pulse, this number is reduced by one unit for each elapsed cycle of a stabilized clock pulse source. Zero-detection circuitry arranged on the counter output produces an output pulse when the counter reaches zero. The time interval t_{1d} between the start pulse and the output is related to the clock frequency f_c and the number being decoded θ, by

$$t_{1d} = \frac{\theta}{f_c}. \tag{1}$$

This time interval is clearly proportional to θ. Essential portions of the logical connections for a single counting decoder are seen in Fig. 2.

By arranging the counter to recycle after it reaches its zero content, successive zero-crossing output pulses are produced at time intervals equal to the product of the clock frequency and the total number of states in the counting sequence. Moreover, by arranging the repetition times of the start pulses t_s at

$$t_{ks} = \frac{kC}{f_c} \qquad k = 0,1,2 \cdots, \tag{2}$$

where C = total number of states in the counter, successive zero crossings times t_{kd} are always delayed from the start pulses by the same amount. That is,

$$t_{kd} = \frac{1}{f_c}(\theta + kC). \tag{3}$$

By subtracting (2) from (3), a repeated measure of θ is generated as

$$t_{kd} - t_{ks} = \frac{\theta}{f_c}. \tag{4}$$

Each pulse position is modulated by the digital quantity placed in the counter. The relationships between counter contents, start pulses, and outputs are usually shown as in Fig. 3.

Although a number placed in the counter is regularly being counted around, storage of that number is provided within the counter as the conversion process proceeds. This is a result of the unique relationship between counter contents and time that exists for each input.

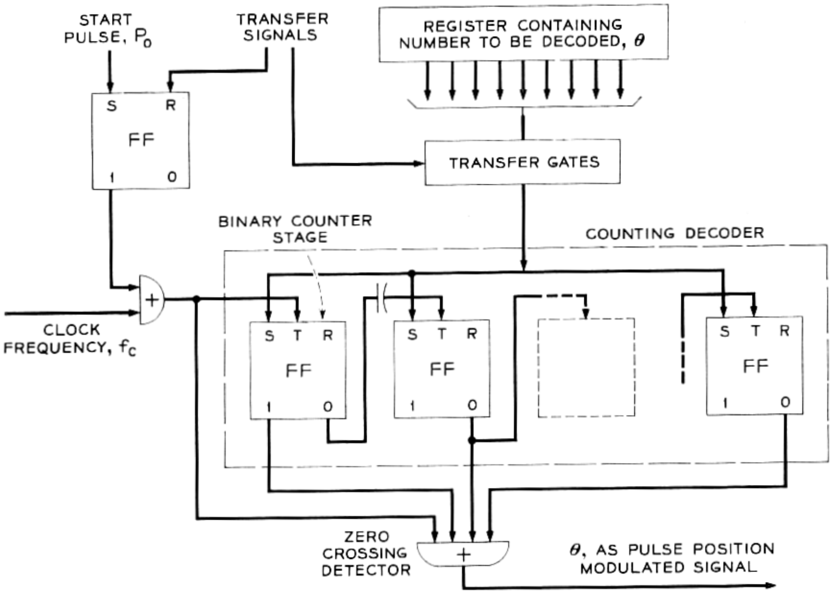


Fig. 2 — Counting decoder logic.

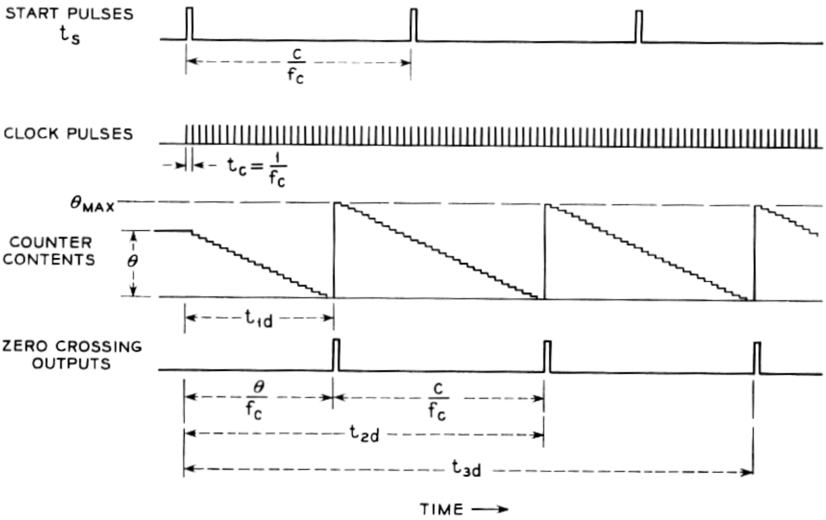


Fig. 3 — Counting decoder contents and waveforms.

In real-time control system applications, the repetition rate of the decoding process is important. This rate determines the bandwidth of signals that can be decoded. The decoding resolution is, of course, determined by the number of states in the counter. Counter stages operating at 5 mc allow sufficient range in resolution and repetition rate.

2.5 *Interpolation*

So far, counter decoding processes have been considered in which the counting rate remains constant and uninterrupted. The generated time interval is unchanged. However, by momentarily altering the counting rate, the arithmetic operations of addition and subtraction can be performed on the contents of the counter while the decoding process continues. For example, consider a down-counting sequential counter in which a number of clock input pulses are inhibited. The usual counting process is momentarily halted. The zero crossing occurs later than it ordinarily would have and a quantity equal to the number of inhibited clock pulses is effectively added to the counter. Similarly, if the clock input is shifted to the next most significant counting stage, the counting sequence is accelerated to twice its usual rate. A quantity equal to the number of shifted pulses is effectively subtracted from the counter contents.

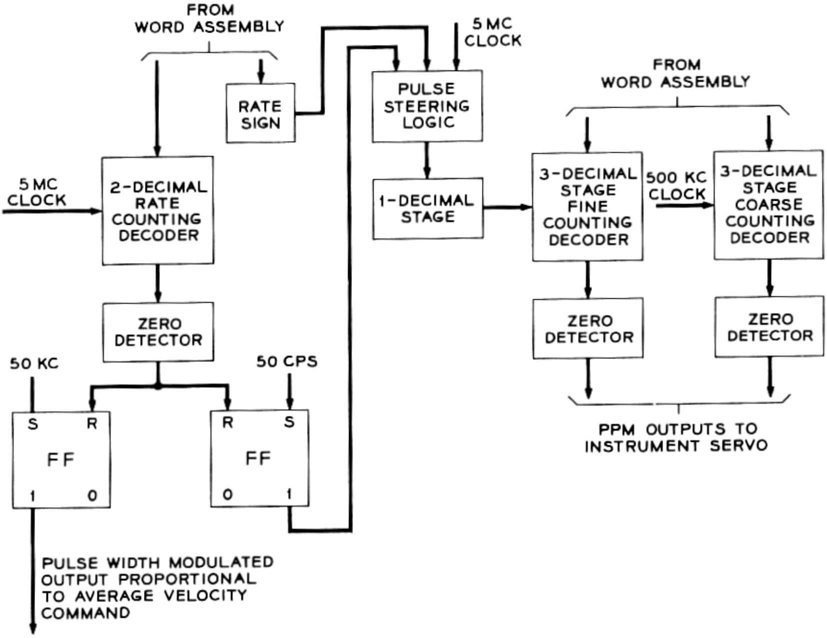


Fig. 4 — Interpolation logic.

The ability to modify the contents of the counter is used for interpolation of input data over each data interval. Angular position commands are placed in the counters at the beginning of each data-point interval. At the same time, angular velocity commands are placed in similar counters. Time intervals determined by the velocity counter decoders are extracted and used as gating signals to alter the number of clock pulses fed to the position counter decoders. Depending on the polarity of the velocity information, the inputs to the position counters are either inhibited or shifted one stage for the duration of this interval. In this manner increments of position proportional to average velocity are added to the position command several times over the data interval.

In the digital-to-analog converter, angle position commands are decoded to PPM signals to provide a modulo 360-degree, or coarse, command and a modulo 3.6-degree, or fine, command. Decoding is performed in a three-stage decimal counter, giving a decoding resolution of 0.0036°. A counter clock frequency of 500 kc provides outputs at a 500-cps rate.

Rate information is decoded with a clock frequency of 5 mc to PPM signals having a 50-kc repetition rate. One of these outputs is extracted 50 times per second, and controls the counting of a decimal stage preceding the fine position decoder. The logical connections for this control are shown in Fig. 4. This yields a quasi-linear interpolation in steps of $\frac{1}{50}$-second duration, as shown in Fig. 5. The maximum deviation of this output from true linear interpolation is a sawtooth function with a 50-cps repetition rate and a maximum amplitude of 0.036°.

III. THE INSTRUMENT SERVO SYSTEM

The instrument servos convert the PPM signals produced by the counting decoders into analog command signals for the communications antennas. The control systems of these antennas use two-speed synchro control transformers as error detectors. The instrument servos position the two-speed synchro transmitters, which in turn command the antennas. Two instrument servos are required, one to command the azimuth and the other the elevation axes of the antennas. The two units are identical in design and construction and, in the following θ represents either the azimuth or elevation angle.

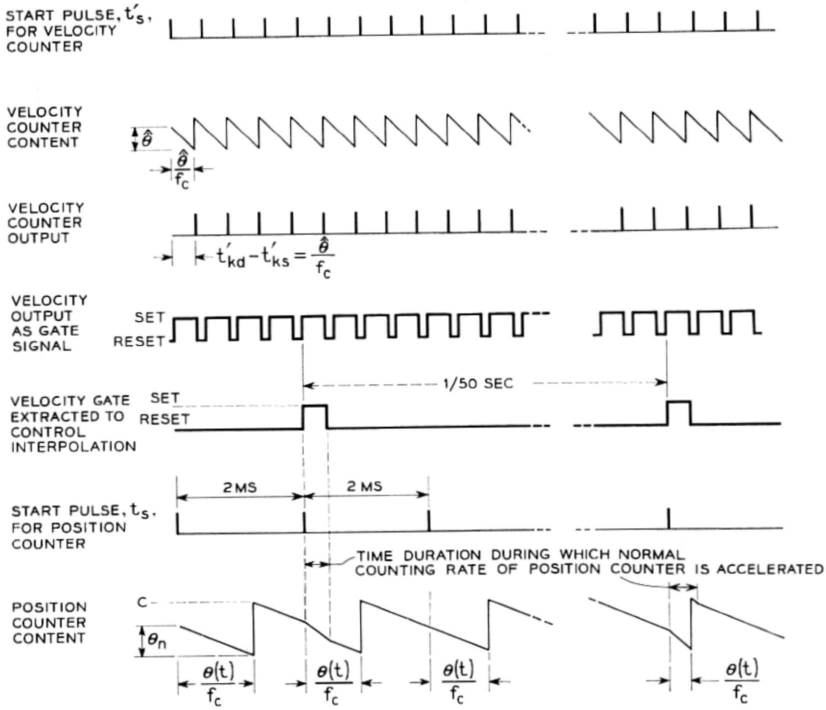


Fig. 5 — Quasi-linear interpolation.

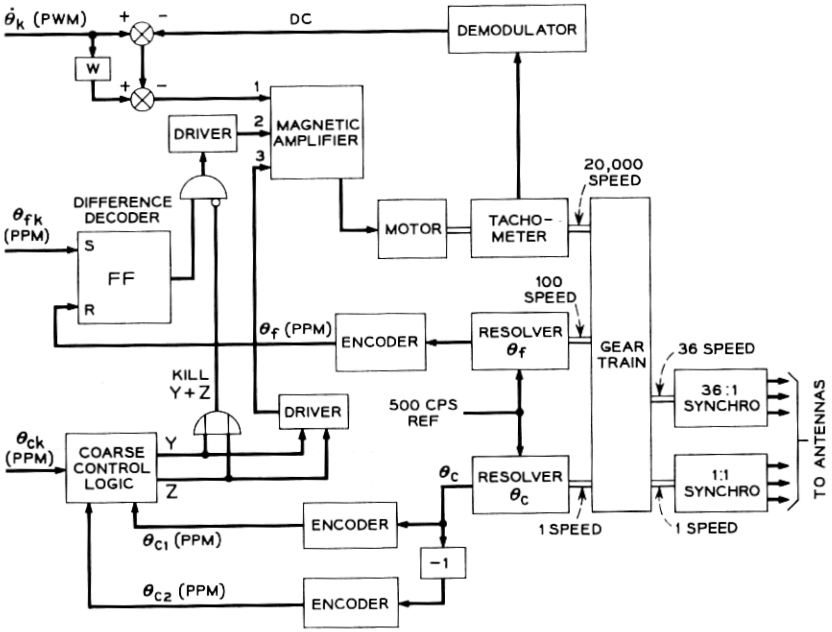


Fig. 6 — Block diagram of instrument servo.

3.1 *System Mechanization*

Inputs to the instrument servos are the PPM pulse trains derived from the counting decoders. Corresponding PPM follow-up signals are obtained from two angle-encoding resolvers connected to the 1:1 and 100:1 speed shaft on the servo gear trains. A description of the method of encoding shaft positions with these resolvers is given in Section 3.4. A block diagram of the instrument servo system, shown in Fig. 6, shows the derivation of the position and velocity follow-up signals, as well as the two-speed synchro transmitters which command the antenna control system. A high-speed two-phase servo motor is used to position the instrument servos. A magnetic amplifier provides the power for the controlled phase of the motor.

3.2 *Tracking Control System*

If the error between the angle θ called for by the counting decoders and the angle encoded from the resolvers is less than 1.8°, a system using θ_{fk} as a command and θ_f as a follow-up signal controls the servo. For errors larger than 1.8° a slewing mode of operation is employed, which is

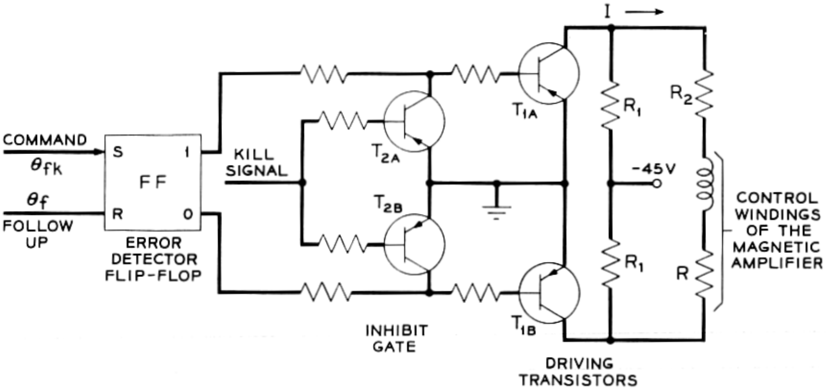


Fig. 7 — Simplified θ_f circuit.

described in Section 3.3. The circuitry used in the tracking mode consists of the position feedback loop controlled by the fine position command θ_{fk} , the velocity loop controlled by the velocity command $\dot{\theta}_k$, and the feed-forward compensation represented by the block w in Fig. 6.

3.2.1 *The Fine Position Loop*

In this loop the follow-up pulse train θ_f is phased with respect to the decoded command pulse train θ_{fk} so that for zero error the pulses of one train occur half-way between the pulses of the other. The difference decoder is a flip-flop, with the θ_{fk} pulse train applied to the "set" input and θ_f to the "reset" input. For zero error the flip-flop spends equal time in the two states. For a nonzero error the duration of one of the states exceeds the other by an increment linearly proportional to the error. A current proportional to the difference of the dwell times of the two states is used to drive one of the control windings of the magnetic amplifier, which in turn controls the motor. Fig. 7 shows the simplified circuit between the output of the difference decoder and the magnetic amplifier. In absence of a "kill" signal, that is, with transistors T_{2A} and T_{2B} nonconducting, the flip-flop drives the magnetic amplifier through alternate switching of transistors T_{1A} and T_{1B} . The gain of this loop is set by the voltage applied to R_1 and R_2 and the resistance R of the control winding circuit. In order to provide the required tracking accuracy, the gain is adjusted so that an error of 0.01° gives ample drive to overcome sticking friction of the motor and gear train.

Due to the high gain of this loop it is necessary to disable it when the error is greater than 1.8° to prevent it from interfering with the slewing mode of operation. The "kill" signal actuates the inhibiting gate composed of T_{2A} and T_{2B}, which disables the fine position loop. The generation of the "kill" signal is indicated in Fig. 6 and is described in Section 3.3.

3.2.2 *The Velocity Loop*

The velocity feedback loop is necessary to stabilize the system and improve its dynamic response. To prevent tachometric feedback from causing tracking errors proportional to motor velocity, a signal proportional to the difference between the actual and commanded motor speeds is used to drive the magnetic amplifier. The command signal is obtained from the rate-counting decoder. It is a pulse-width-modulated signal whose average value is proportional to $\dot{\theta}_k$. The follow-up consists of an ac tachometer followed by a demodulator producing a dc voltage proportional to motor speed.

3.2.3 *The Feed-Forward Compensator*

Ideally the feed-forward compensator (w) should provide a signal which is equal to that required by the motor to follow the commanded input. Tracking a satellite requires operation of the servo at almost constant speeds over periods of time which are long with respect to the characteristic time constants of the servo. Hence the feed-forward path provides the magnetic amplifier with a signal necessary to obtain the commanded velocity under steady-state operation. Since the relationship between the steady-state motor speed and the magnetic amplifier control winding current is almost linear over the range of speeds used in tracking, the required block w of Fig. 6 is a fixed attenuator. This is mechanized by increasing the voltage gain of the $\dot{\theta}_k$ decoder in the velocity loop, and therefore no additional circuitry is needed.

The instrument servo-tracking control system provides a static accuracy of ±0.01° and maximum errors in the tracking mode of ±0.025°.

3.3 *Slewing Control System*

If the magnitude of the position error is greater than 1.8° the θ_f loop cannot bring the error to zero. This is because the θ_f loop operates on the error modulo 3.6°. If the position error, ϵ_c, as determined by the comparison of θ_{ck} and θ_c, exceeds an angle of δ degrees (where $\delta \leqq 1.8°$) the fine loop is disabled by the "kill" signal. A saturation torque is commanded to decrease the error to a value less than δ degrees in minimum time. The actuating signal produced by the slewing control system assumes one of three values: zero, clockwise saturation torque, and counter-clockwise saturation torque. Fig. 8 illustrates the slewing strategy. The follow-up pulse trains θ_{c1} and θ_{c2} (see below) shown in Fig. 6 are used to obtain gate signals corresponding to the regions A, B, C, and D of Fig. 8. Since A, B, C, and D form a mutually exclusive complete set of time intervals over the $\frac{1}{500}$-second command repetition time, the command pulse θ_{ck} will then occur during one of these gate pulses and determine the error region. Let the commands of the clockwise and counter-clockwise torque be represented by binary functions Y and Z respectively; for example, the counter-clockwise torque is commanded if and only if $Y = 1$.

From Fig. 8,

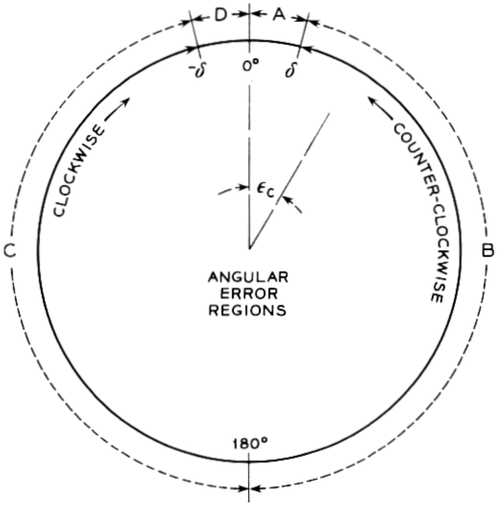
$$\text{counter-clockwise:} \quad Y = \theta_{ck} \otimes B,$$

$$\text{clockwise:} \quad Z = \theta_{ck} \otimes C,$$

$$\text{also the “kill” signal:} \quad K = Y \oplus Z,$$

where $\oplus$ = logical OR, $\otimes$ = logical AND.

The timing pulses for the generation of the gate signals are obtained from θ_{c1} and θ_{c2}. The phase of the follow-up pulse train θ_{c1} is adjusted so that for zero error it coincides with θ_{ck}, the course command pulse train.



SLEWING CONTROL LOGIC	
ERROR REGION	TORQUE COMMAND
A OR D	NONE
B	COUNTER-CLOCKWISE
C	CLOCKWISE

$\epsilon_C = \theta_{CK} - \theta_{C1}$

Fig. 8 — Slewing strategy in θ_c control logic.

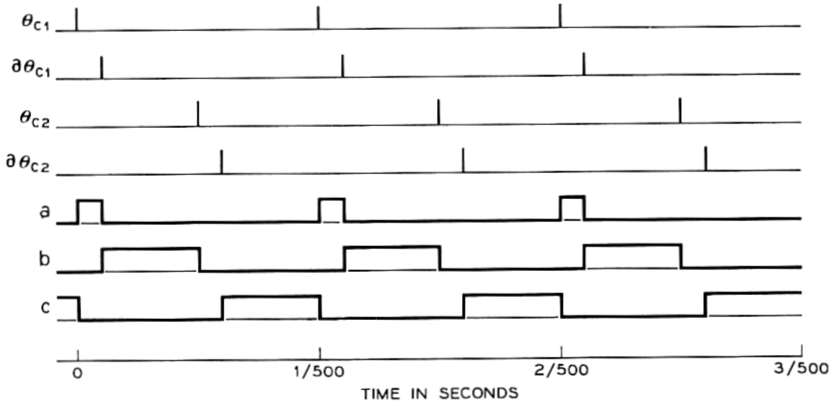


Fig. 9 — Generation of gates a, b, and c in θ_c control logic.

The θ_{c2} follow-up signal is 180 electrical degrees behind θ_{c2}. Circuits providing a time delay corresponding to δ degrees are used in the generation of the gate signals. Fig. 9 shows the generation of the gates a, b and c by a set of flip-flops operated by the follow-up signals. By comparing Fig. 8 and Fig. 9 it is evident that:

$$\begin{aligned} a &= A = \partial D, \\ b &= B, \\ c &= \partial C, \end{aligned}$$

where ∂ is a delay operator of δ degrees.

The determination of the error regions is done 500 times per second. Flip-flops Y and Z are set by the detection of error region B and C respectively; both are reset by the detection of region A or D. The required output to drive the motor is obtained from one of the two flip-flops. Therefore:

$$\begin{aligned} Y_s &= \theta_{ck} \otimes B = \theta_{ck} \otimes b, \\ Z_s &= \theta_{ck} \otimes C = \partial\theta_{ck} \otimes \partial C = \partial\theta_{ck} \otimes c, \\ Y_r &= Z_r = (\theta_{ck} \otimes A) \oplus (\theta_{ck} \otimes D) = (\theta_{ck} \otimes A) \oplus (\partial\theta_{ck} \otimes \partial D) \\ &\qquad = (\theta_{ck} \otimes a) \oplus (\partial\theta_{ck} \otimes a) = (\theta_{ck} \oplus \partial\theta_{ck}) \otimes a, \\ K &= Y \oplus Z, \end{aligned}$$

where Y_s and Y_r are the set and reset inputs to the Y flip-flop respectively. Similarly for the Z flip-flop. A circuit diagram for the above logic is shown in Fig. 10.

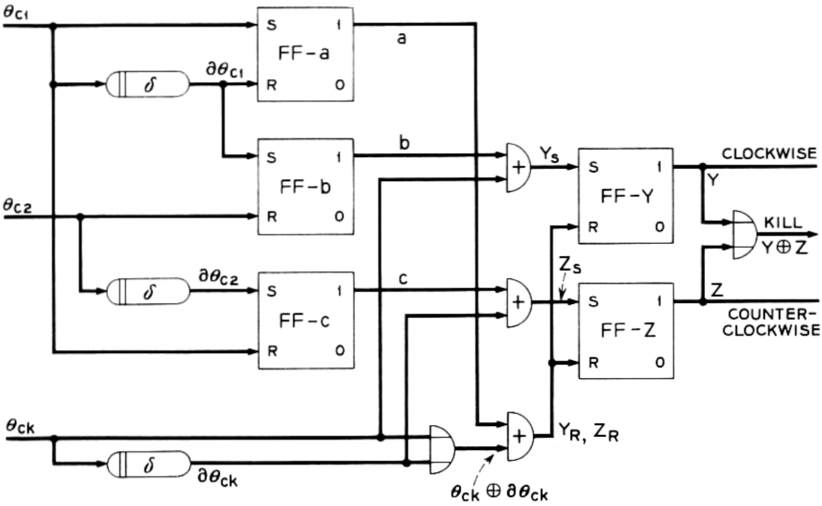


Fig. 10 — Circuit diagram for θ_c control logic.

The signals Y and Z are applied to a pair of transistors driving the magnetic amplifier control winding No. 3 as shown in Fig. 11.

3.4 *Resolver Encoding*

Shaft positions of the instrument servos are encoded to PPM signals using resolver encoding techniques. Two precision resolvers are used with each instrument servo. The first of these rotates 1:1 with the servo output and gives a modulo 360-degree indication of the shaft angle. The second rotates 100:1 with respect to the output, to give the modulo 3.6-degree indication of the shaft angle. These ratios were chosen to match the coarse and fine outputs of the decimal counting decoders.

The method used to convert these resolver outputs to PPM signals

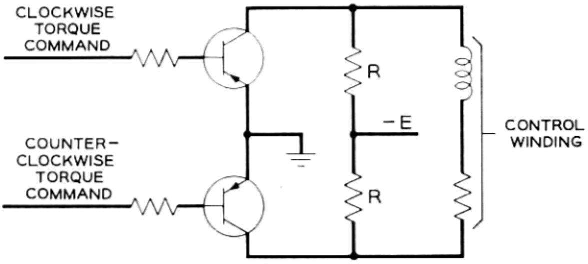


Fig. 11 — Coarse control circuit.

has been described in an earlier paper,[1] but will be reviewed here for completeness. Electrically, each resolver is a mechanically variable transformer with couplings between primary and secondary windings that are functions of the rotor angle θ_R. When excited by the ac signal

$$E_{\text{in}} = E_{\max} \sin \omega t,$$

output voltages are the input voltage modulated by the sine and cosine of the rotor shaft angle θ_R. The resolver outputs are combined in phase-shifting networks which advance the phase of the sine voltage by $\pi/2$ degrees and add it to the cosine voltage. Thus a phase-modulated signal results according to:

$$E_{\max} \sin\left(\omega t + \frac{\pi}{2}\right) \sin \theta_R + E_{\max} \sin \omega t \cos \theta_R = E_m \sin\,(\omega t + \theta_R).$$

The positive-going zero crossing of this signal is the desired PPM signal representing the shaft position. Since the excitation voltage is 500 cps, a 0.18° movement in the output of the instrument servo causes a change of 1 microsecond in the PPM output of the coarse encoder. Similarly, a movement of 0.0018° causes a 1 microsecond change in the PPM output of the fine encoder.

Resolver excitation is derived from the digital-to-analog converter central timing by filtering and amplification of a 500-cps square wave. A zero-crossing detector, similar to the one used for encoding the phase-shifted resolver output, is connected to the resolver excitation. This output is the start pulse and is so phase-locked to the resolver excitation. It is used in the digital portion of the conversion equipment to time the start of the counter decoder sequence.

IV. SUMMARY

The above is a description of a new type of special purpose data converter for the direction of narrow beam communication antennas from predicted information. It is capable of converting digital input data into real-time analog voltage commands with a dynamic accuracy ±0.05°, which is sufficiently accurate for the present antennas. It employs a moderate quantity of input data, and a reasonably simple digital-to-analog converter.

The single-parity-bit error detection provides moderate resistance to transmission errors. During the Echo I experiments the number of errors in transmissions from Goddard Space Flight Center were logged for 30 passes. Out of a total of 250 errors, the single-parity detection was effective in rejecting over 90 per cent of the erroneous data. During these periods the coasting features designed into the converter provided adequate antenna commands.

The use of instrument servos as an intermediate step in the conversion process provides convenient generation of two-speed voltages for commanding more than one antenna or optical mount simultaneously. Separate synchro units can be placed on the gear trains for each antenna, and each synchro can be excited by the particular frequency required by that mount. Furthermore, choice of the ratios in the gear train provides outputs in the "two-speed" combination required by each mount.

The use of counter decoders is quite attractive. They provide the storage necessary to give continuous outputs to command the servos. Data interpolation makes possible an input data interval sufficiently long so that ordinary teletypewriter transmission can be used. The interpolation method outlined here makes additional use of the counter decoders, without the need for a conventional arithmetic unit. The interconnections between counters needed to perform interpolation require simple control logic. Since the decoders and many of the low-speed operations in the converter operate synchronously, the additional pulse rates needed for interpolation are already available from the timing section.

The resolver encoding technique converts instrument servo shaft positions into pulse-position-modulated signals of the same general form as the counter output. These signals are easily combined to form error signals to control the servos. In the same manner that gear ratios can be chosen to provide outputs at a desired "two-speed" ratio, the gearing between resolver encoders can be chosen to yield PPM signals in any desired speed ratio. This allows freedom of the number base in which the decoding process is performed.

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