APOLLO ENGINEERING MEMORANDUM AP-M NO. 5995

4 March 1965

TO: Distribution

FROM: Mr. B. Hobbs

SUBJECT: AMBIGUITY AND THE ELECTRONIC COUPLING DATA UNIT (PAPER IX)

This paper is the ninth of a series describing the electronic CDU. An hour long talk will be given Friday, March 5, at 9:00 A.M. in the SAT Conference Room.

In the operation of the ECDU, there would be a possibility of the gimbals being positioned at 225° and the ECDU indicating 0° if sufficient circuitry were not implemented to prevent the false, or ambiguous, indication from occurring. The discussion that follows will present the reason the ECDU could indicate an ambiguous gimbal position, it will describe the modes under which the possibility of an ambiguity exists, and it will explain how the ECDU prevents an ambiguity from occurring.

The ECDU must follow and indicate to the AGC the gimbal axis to within 40 arc seconds of true position and the optics trunnion axis to within 5 arc seconds of true position (less system error). To accomplish the accuracy requirement, a dual speed resolver system is necessary. A dual speed system reduces the position error of a single speed system by the ratio of the two resolver speeds.

A requirement of the two speed system is a mixing, or synchronizing, network which will permit the coarse, of 1X, resolver to bring the system to zero position. A voltage controlled switch is usually used to switch from coarse resolver to fine resolver control when the coarse voltage decreases to a predetermined level. Figure 1 shows the coarse and fine resolver voltages for an odd speed ratio system.

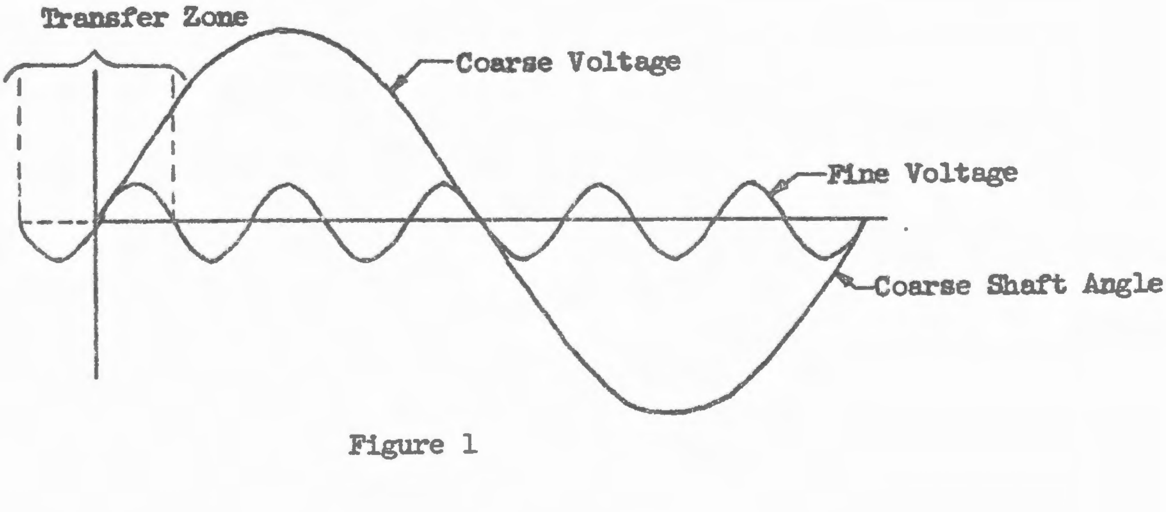

Figure 1

If only the fine voltage from the odd speed ratio system shown in Figure 1 was used for position information, a null would occur each time the fine voltage became 0, or 10 times for each revolution of the coarse shaft. Five of the nulls would be unstable because of the voltage phasing and the system would drive away from the zero point if any disturbance whatsoever occurred. Five of the nulls, however, would be stable and the system would stop every 72° of coarse shaft rotation or 1 cycle of fine voltage. The switch-over from coarse to fine resolver control, therefore, must take place within one half cycle of fine voltage of zero position. If within this transfer zone the fine voltage will be of proper phase to drive the system to a stable null at zero shaft position of both coarse and fine resolvers.

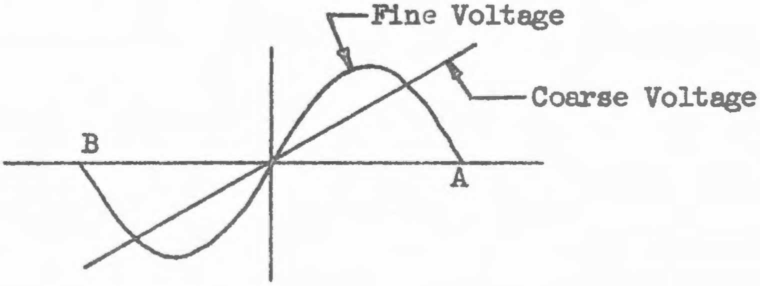

Figure 2

Figure 2 is an expanded view of the coarse and fine resolver voltages at zero position. The transfer can occur anywhere within the zone between A and B. The maximum coarse shaft angle transfer point is given by the equation

$$A = \frac{1}{2} \frac{360}{N}$$

where N is the resolver speed ratio.

To insure stability in case of component drift and tolerance variations, the transfer point is usually selected near the 90° point of fine voltage.

Referring again to Figure 1 and the odd speed ratio system, the coarse and fine voltage are both zero at the 180° point, but this is an unstable null because the voltage phasing is such that the system will drive away from the null and toward the true zero position. In the odd resolver speed ratio system, there is only one point at which the system will come to a stable null and that is the true zero position of coarse and fine shafts. There is no ambiguous, of false null.

If an even speed ratio resolver system is used for position, a problem arises when the coarse shaft is at 180°. Refer to Figure 3.

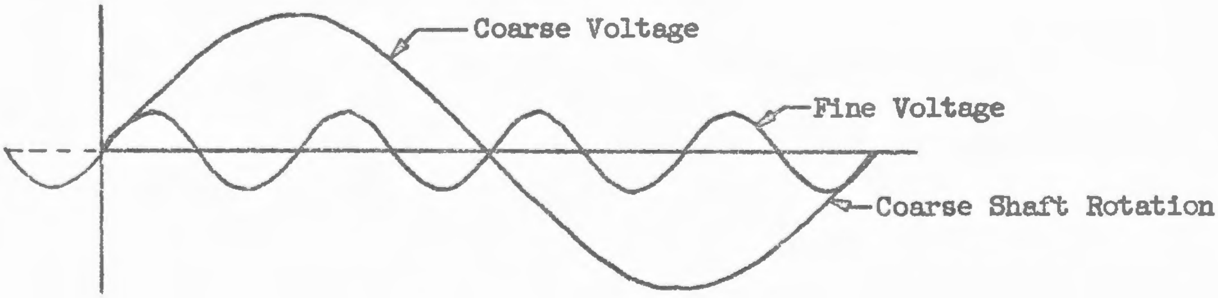

Figure 3

The phasing of the fine voltage on either side of 180° of coarse shaft position is now the same as it is about 0° and the system will drive toward a stable null at 180° when the control is switched to the fine voltage. There is now an ambiguity in the system as there are two indications of zero position 180° of coarse shaft rotation apart. The ambiguity problem is inherent in even speed ratio position systems and provisions must be incorporated into the design to prevent the system from seeking the false null.

The ECDU uses a speed ratio of 16 to 1 between the coarse and fine resolvers, therefore, an ambiguity is present. There is a difference, however, between the system just described and the ECDU. In the ECDU the coarse and fine voltages referred to are not the resolver voltages but are the error voltages from the coarse and fine systems. If the ECDU and gimbals are in correspondence, regardless of angle, the error signals are zero. If the ECDU is held (read counter inhibited) and the gimbal rotated through 360°, one complete cycle of coarse error voltage and 16 cycles of fine error voltage will be generated. The ambiguity in the ECDU is possible when the angle of ECDU-gimbal separation is of such a value to make the coarse and fine error signals simultaneously zero. The important point to consider is the angle of ECDU-gimbal separation rather than resolver angle position.

From the previous discussion of resolver systems, it would seem that the ambiguity in the ECDU would be at 180° of ECDU-gimbal separation but this is not the case. The ECDU in solving the coarse system equation

$$\pm \sin(\theta - \psi) = \pm \sin\theta \cos\psi \mp \cos\theta \sin\psi + K\phi$$

increments ψ and adds a laddered voltage, $K\phi$, to complete the solution. The phase and amplitude of the laddered voltage is dependent upon the ECDU angle. This voltage produces an offset, or stick-off, voltage that shifts the ambiguity point depending on the value of ladder voltage. See Figure 4A. At certain ECDU angles (0, 45, 90, etc.) the ladder voltage, $K\phi$, is at a maximum in phase value and the ambiguity occurs when the ECDU and gimbals are separated by 225°. If the ECDU angle ψ is increased from 0° to 1 bit less than 45°, $K\phi$ changes from maximum in phase to maximum out of phase. This causes the ambiguity point to shift from 225° toward 180°. At this point the angle separation is 135°. An ambiguity zone between 135° and 225° of ECDU-gimbal separation exists as a function of ECDU position. At exactly 45° the ambiguity moves to 270°, or 225° separation, and the process repeats. Figure 4B shows the gimbal ambiguity zones for values of ECDU angles ψ in the first quadrant. For ψ in the second quadrant the gimbal ambiguity zones move to the fourth quadrant but follow the identical pattern as before. The gimbal ambiguity zone is always two quadrants from the ECDU angle. The exact angle at which the ambiguity occurs for any value of ψ can be calculated by solving the following coarse system equation for θ.

$$\sin\theta \cos\psi - \cos\theta \sin\psi + K\phi = 0$$

Two values of θ will be found. One will be the angle that makes θ and ψ equal and the other will be the possible ambiguity angle. If the fine error voltage is also zero, an ambiguity exists. A stable ambiguity can occur every 22.5°, or every one cycle of fine error voltage, within the ambiguity zone (135° - 225°).

Now that system ambiguities have been covered in general its time to see in detail what the ECDU does to overcome the problem. First of all, the ambiguity can occur only if the ECDU and gimbals are separated by a large angle (135° to 225°). In normal operation with the digitizing loop energized, the ECDU angle will always equal the gimbal angle plus or minus some very small error; therefore, a large angular difference can occur only at initial turn-on or during ECDU ZERO mode. At the initiation of these modes the read counter is set to zero but the gimbal can be at any arbitrary angle. From the earlier discussion it was seen that with the ECDU at zero, the gimbal ambiguity was at 225°. The problem angle is now known and it is constant. Both ECDU ZERO mode and INITIAL TURN-ON mode will be discussed.

In ECDU ZERO mode the read counter is set to zero and allowed to count up again to the gimbal angle. Before the read counter is enabled, however, the 1X cos Θ resolver winding is level detected and interrogated with an out-of-phase signal to determine if the gimbal is in the vicinity of 225°. The cos Θ signal is out-of-phase when the gimbal is between 90° and 270°. The level gives information to narrow the band of angles containing the ambiguity.

A schematic diagram of the ambiguity circuitry and logic is shown in Figure 5. The level detection is made by an emitter follower (Q1) driven schmitt trigger (Q2 and Q3) in the coarse system module. The firing level of the schmitt is set at 7.0 V P-P measured at the output of the emitter follower. The schmitt trigger output is buffered by Q4 and transformer coupled to the Digital Mode Module where it is 'anded' with the interrogate pulse and the out-of-phase reference pulse. If an out-of-phase signal is detected, the control flip-flop is set and the ambiguity flip-flop is allowed to be set at the first phase 2 time following an interrogate. An ambiguity override signal, Ao, is generated at the completion of ECDU ZERO and sent to the Error Counter and Logic Module. It forces the rate-select logic into high speed (12.8 K PPS) and the up-down logic into count down. The ECDU counts down at high speed until it reaches 225° at which time the ambiguity flip-flop is reset removing the ambiguity override signal. The normal ECDU operation will complete the ECDU-gimbal readings now that the ECDU is out of the ambiguity zone.

At initial turn-on, it is desired to clear the read counter and to bring the gimbals to zero position and orthogonal as a reference or starting point. Initial turn-on is initiated by commanding ECDU ZERO and COARSE ALIGN ENABLE simultaneously. With the ECDU read counter cleared, the gimbal ambiguity is at 225°. Just as in the ECDU ZERO case, the 1X cos resolver output is level detected and interrogated by an out-of-phase signal to determine if a possibility of an ambiguity exists. The control flip-flop is set enabling the ambiguity flip-flop to be set at the first phase 2 time following an interrogate. A turn-on enable signal (Q) is generated and set to the Read Counter Module. It is used to turn-on the 90° bit. With the ECDU forced to 90°, the gimbal ambiguity point shifts to 315° allowing the gimbals to be driven. The error signal from the summing amplifier in the Coarse Module and Main Summing Amplifier Module (coarse and fine system error) is applied to the mixing amplifier in the Digital to Analog Converter where it is inverted and used as a drive signal to move the gimbal toward 90°. As soon as the gimbal is out of the ambiguity zone the cos Θ signal is insufficient to fire the ambiguity schmitt and the control and ambiguity flip-flops are reset removing the turn-on enable signal (Q). The gimbal will continue to drive until it is in correspondence with the ECDU at 0°.

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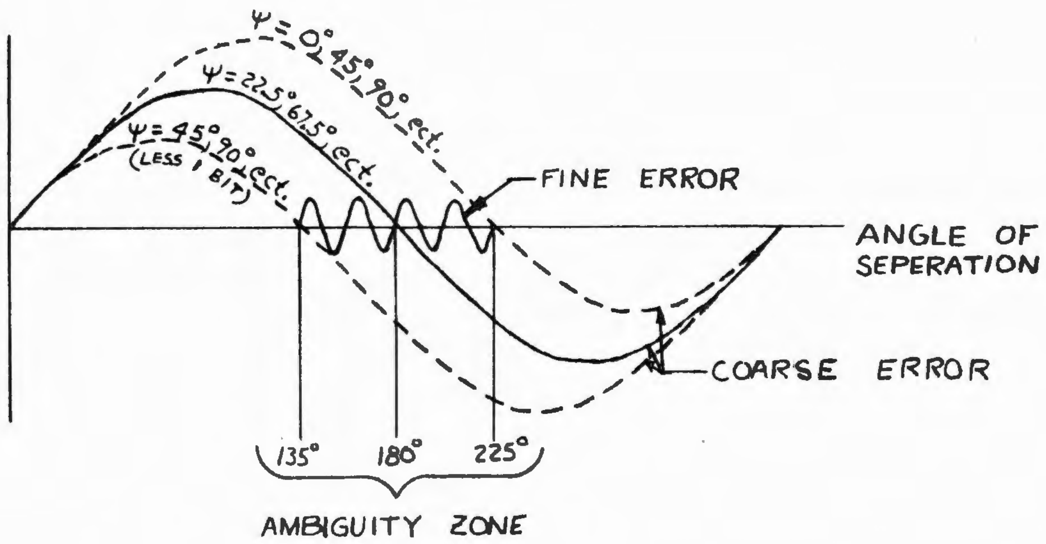


FIGURE 4A

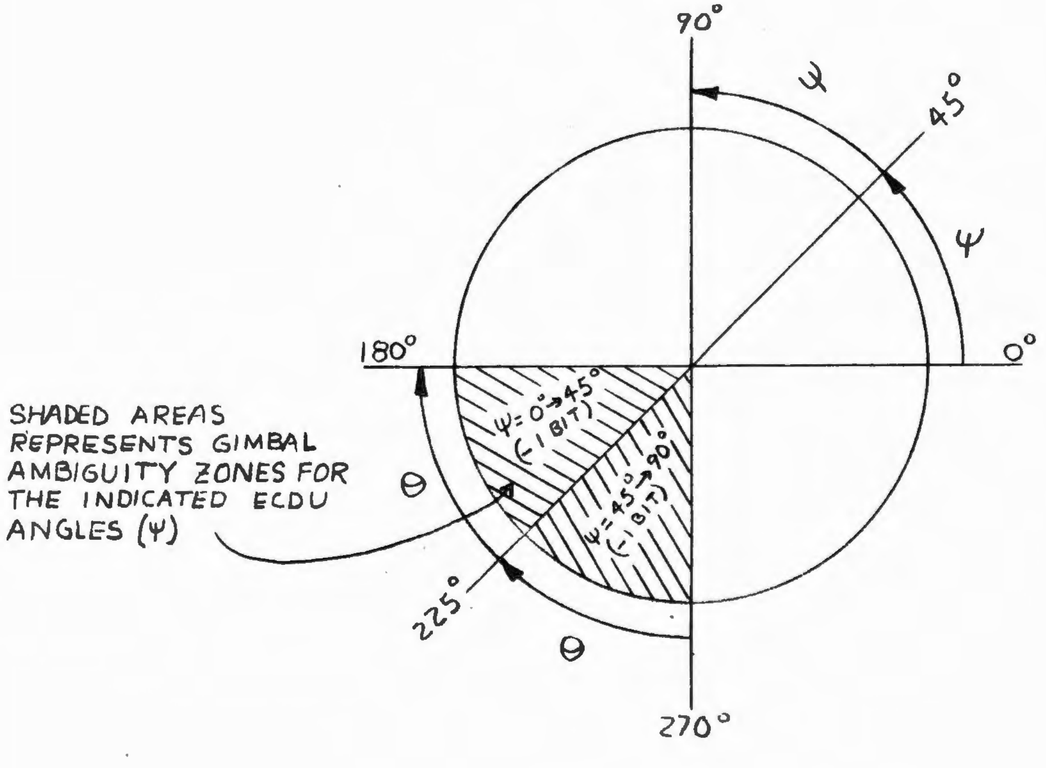
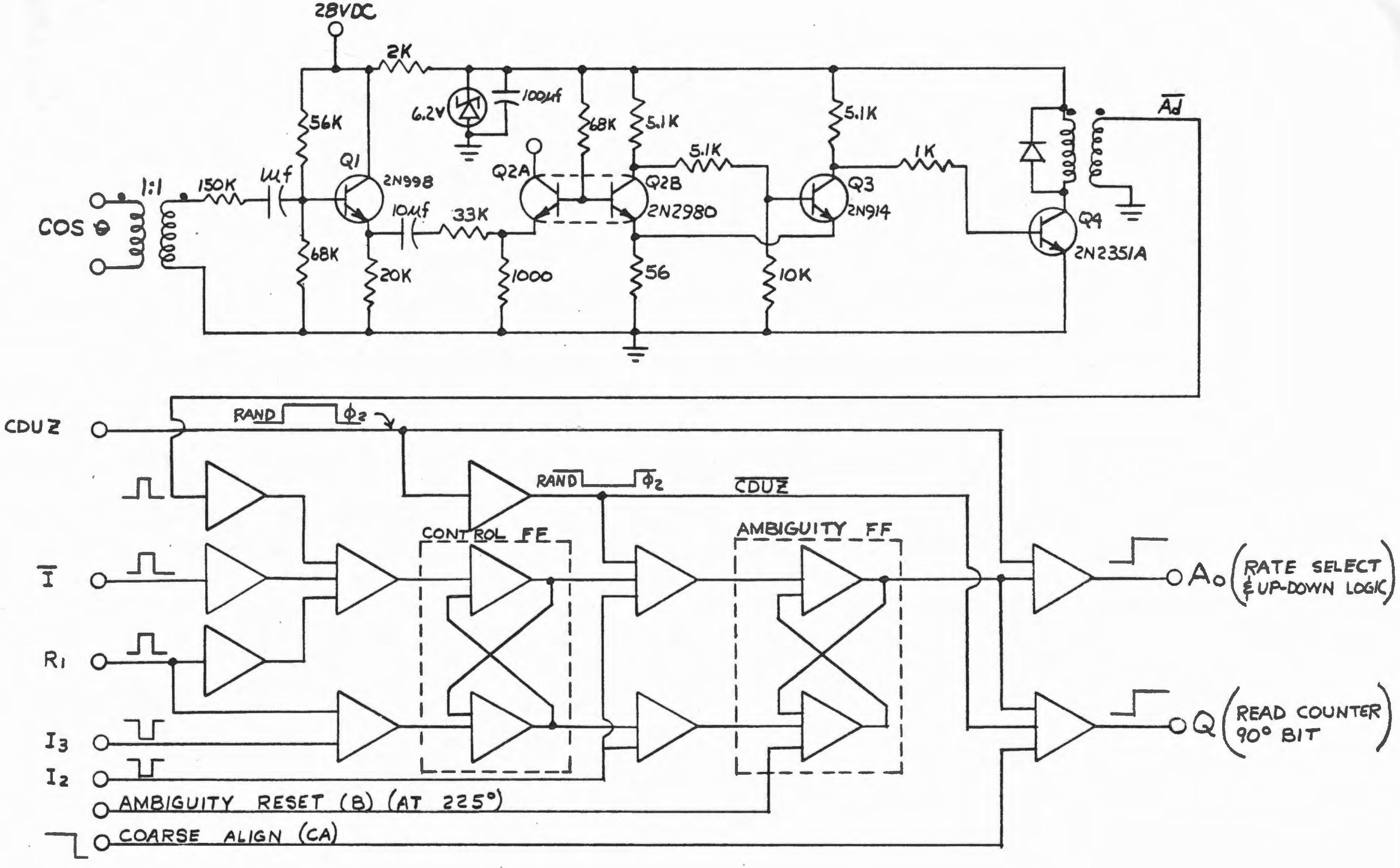


FIGURE 4B



AMBIGUITY LOGIC

FIGURE 5

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