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APOLLO ENGINEERING MEMORANDUM AF-M # 4850

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FROM: Mr. P. Grant

SUBJECT: THE FINE SYSTEM OF THE ELECTRONIC COUPLING DATA UNIT (ECDU),
Part I (Paper IV)

This is the fourth of a series of papers describing the electronic CDU. The topic of discussion is the Quadrant Selector Module. An hour long talk in support of this paper will be given on Thursday, November 5, 1964 at 10:00 AM in Conference Room #10.

In reading out angle information the ECDU implements the equation,

$$(1) \pm \sin(\theta - \psi) = \pm \sin \theta \cos \psi \mp \cos \theta \sin \psi$$

and, essentially, matches the resolver angle θ with ECDU angles ψ until a null is accomplished. In obtaining a null it becomes necessary to generate an internal reference which is used to excite the ladder network. This reference is the function $\cos(\theta - \psi)$ and is generated in the ECDU by solving the identity,

$$(2) \cos(\theta - \psi) = \sin \theta \sin \psi + \cos \theta \cos \psi$$

This reference is then applied as excitation for the ladder network and is in phase with respect to the external 800 cps reference (excitation of the resolvers).

In broad terms the operation of the fine system is as follows: Refer to the block diagram. The $\sin \theta$ and $\cos \theta$ signals from the sixteen speed resolver are accepted by the quadrant selector module. Angle information is contained in the RMS value of these voltages and whether they are in phase with the 800 cps reference or not. The quadrant selector phases the $\sin \theta$ and $\cos \theta$ signals so that they are always out of phase with respect to each other. (This is consistent with equation (1)). They are further switched through attenuation resistors and used as inputs to the main summing amplifier, sin amplifier and cos amplifier. The sin and cos amplifiers are utilized in the generation of the reference $\cos(\theta - \psi)$. $\cos(\theta - \psi)$ is applied to the ladder which is controlled by the seven least significant stages of the read counter. Signals from the quadrant selector, sin amplifier, cos amplifier and the ladder are then summed at the input to the main summing amplifier, the main summing junction. The output of the main summing amplifier (fine error) is amplified by the error amplifier to a level

sufficient to trigger the Schmitt triggers when the system is not nulled. If the error is large enough, about twenty bits or greater from null, the two speed Schmitt will trigger and control the logic in the Error Counter and Logic Module (EC and L), to send pulses at high speed (12.8 KC) to the read counter. When the error is reduced to less than approximately twenty bits, the fine Schmitt will take over and allow pulses to be sent at low speed (800 cps) to the read counter. Hence, as long as there is an error signal sufficient to trigger the fine Schmitt, two bits or greater from null, the system will not be nulled and pulses will be sent to the read counter where they will accumulate. While accumulating pulses, the read counter will change the switching configuration of the system (changing values of ψ), until a match is made between θ and ψ to within two bits. When this match occurs the fine error signal will be reduced to below the trigger level of the fine Schmitt and the system will be nulled.

The fine system utilizes the twelve least significant stages of the read counter (2^0 to 2^{11}). 2^{11} corresponds to 180 electrical degrees of the fine system and 11.25 mechanical degrees. Stages 2^9 , 2^{10} , and 2^{11} overlap with the three least significant counter stages of the coarse system. See memo AP-M #4544, Figure 4B. The accumulation of bits in the twelve stages of the fine system control all the switching functions in the fine system.

In the operation of the quadrant selector, $\sin \theta$ is inverted in the I and IV quadrants and $\cos \theta$ inverted in the III and IV quadrants. The inversion of $\sin \theta$ is accomplished by operational amplifiers A1 and A2 and switches S5 and S6 in the following manner: Switch S6 is closed and S5 is opened to provide a feedback path around A2 through R17 and disconnect the output of A2 from the input to A1. $\sin \theta$ becomes inverted by the normal operation of A1 and the desired inverted $\sin \theta$ is available at its' output. When a non-inverted signal is required (quadrants II and III) the switch configuration changes to S5 closed and S6 open. The feedback path around A2 is closed through R16 and the output of A2 is applied to A1 through R9 the resistance of which is half that of the feedback resistor of A1. Hence, at the summing junction of A1 there is the $\sin \theta$ function from R1 and a $\sin \theta$ function of twice the value applied as an inverted signal from R9. This summation results in an inverted $\sin \theta$ at the input to A1 and an in phase $\sin \theta$ at its output.

The logic equations for switches S5 and S6 are given as:

$$S5 = 10 \overline{11} + \overline{10} 11$$

$$S6 = 10 11 + \overline{10} \overline{11}$$

$$\text{where: } 10 = 2^{10} = 90^\circ$$

$$11 = 2^{11} = 180^\circ$$

These equations state that S5 is closed when angle ψ is between 90° and 180° ($10 \overline{11}$) or between 180° and 270° ($\overline{10} 11$) which are the II and III quadrants, respectively, and S6 is closed when ψ is between 270° and 360° ($10 11$) or between 0° and 90° ($\overline{10} \overline{11}$) which are the IV and I quadrants, respectively.

Phasing of the cos θ function is performed in the same manner as the sin θ utilizing A3, A4, S7 and S8. Cos θ is inverted in the III and IV quadrants. The logic equations for S7 and S8 are shown below:

$$S7 = \overline{II}$$

$$S8 = II$$

S8, therefore, will be closed and S7 open when ψ is between 180° and 360° (II) providing for an inverted signal at the output of A3. S7 is closed and S8 open when ψ is between 0° and 180° providing for a non-inverted signal at A2's output.

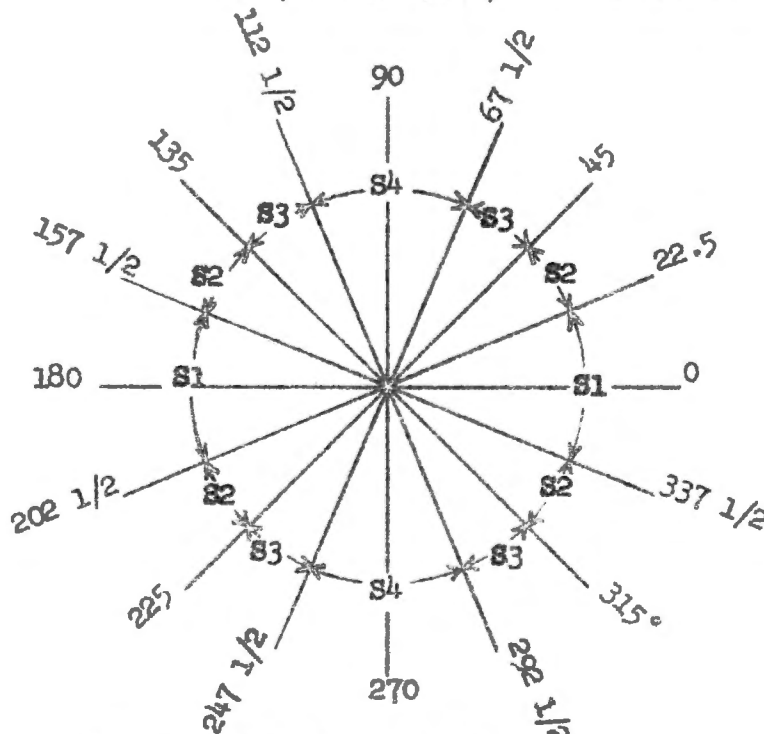
The properly phased sin θ and cos θ signals at the outputs of A1 and A3 respectively, are switched through attenuation resistors by the operation of switches S1 through S4. Their logic equations are shown in the block diagram and are translated into electrical degrees of the fine system by the listing below:

S1 is on between $337 \frac{1}{2}^\circ$ and $22 \frac{1}{2}^\circ$ minus one bit
 $157 \frac{1}{2}^\circ$ and $202 \frac{1}{2}^\circ$ minus one bit

S2 is on between $22 \frac{1}{2}^\circ$ and 45° minus one bit
 135° and $157 \frac{1}{2}^\circ$ minus one bit
 $202 \frac{1}{2}^\circ$ and 225° minus one bit
 315° and $337 \frac{1}{2}^\circ$ minus one bit

S3 is on between 45° and $67 \frac{1}{2}^\circ$ minus one bit
 $112 \frac{1}{2}^\circ$ and 135° minus one bit
 225° and $247 \frac{1}{2}^\circ$ minus one bit
 $292 \frac{1}{2}^\circ$ and 315° minus one bit

S4 is on between $67 \frac{1}{2}^\circ$ and $112 \frac{1}{2}^\circ$ minus one bit
 $247 \frac{1}{2}^\circ$ and $292 \frac{1}{2}^\circ$ minus one bit



S1 THROUGH S4 SWITCHING DIAGRAM

Switches S1 through S4 provide two functions. They select values of attenuation for the properly phased $\sin \theta$ and $\cos \theta$ signals at the inputs to the main summing amplifier and secondly at the inputs to the \sin and \cos amplifiers which are used to generate the reference $\cos (\theta - \psi)$. The implementation of $\cos (\theta - \psi)$ will be explained in the next paper. For the present the concept of solving the system equation will be developed.

The accumulation of bits in the twelve least significant stages of the read counter controls all switches of the fine system. At any position one and only one switch of the four (S1 through S4) is on selecting the appropriate value of attenuation.

- S1 switches in $\sin 11 \frac{1}{4}^\circ$ and $\cos 11 \frac{1}{4}^\circ$
- S2 switches in $\sin 33 \frac{3}{4}^\circ$ and $\cos 33 \frac{3}{4}^\circ$
- S3 switches in $\sin 56 \frac{1}{4}^\circ$ and $\cos 56 \frac{1}{4}^\circ$
- S4 switches in $\sin 78 \frac{3}{4}^\circ$ and $\cos 78 \frac{3}{4}^\circ$


Hence, if θ were equal to any of the exact values given above ($11 \frac{1}{4}^\circ$, $33 \frac{3}{4}^\circ$, $56 \frac{1}{4}^\circ$, $78 \frac{3}{4}^\circ$) or quadrature multiples, a null would be accomplished without the benefit of any other signals at the main summing junction.

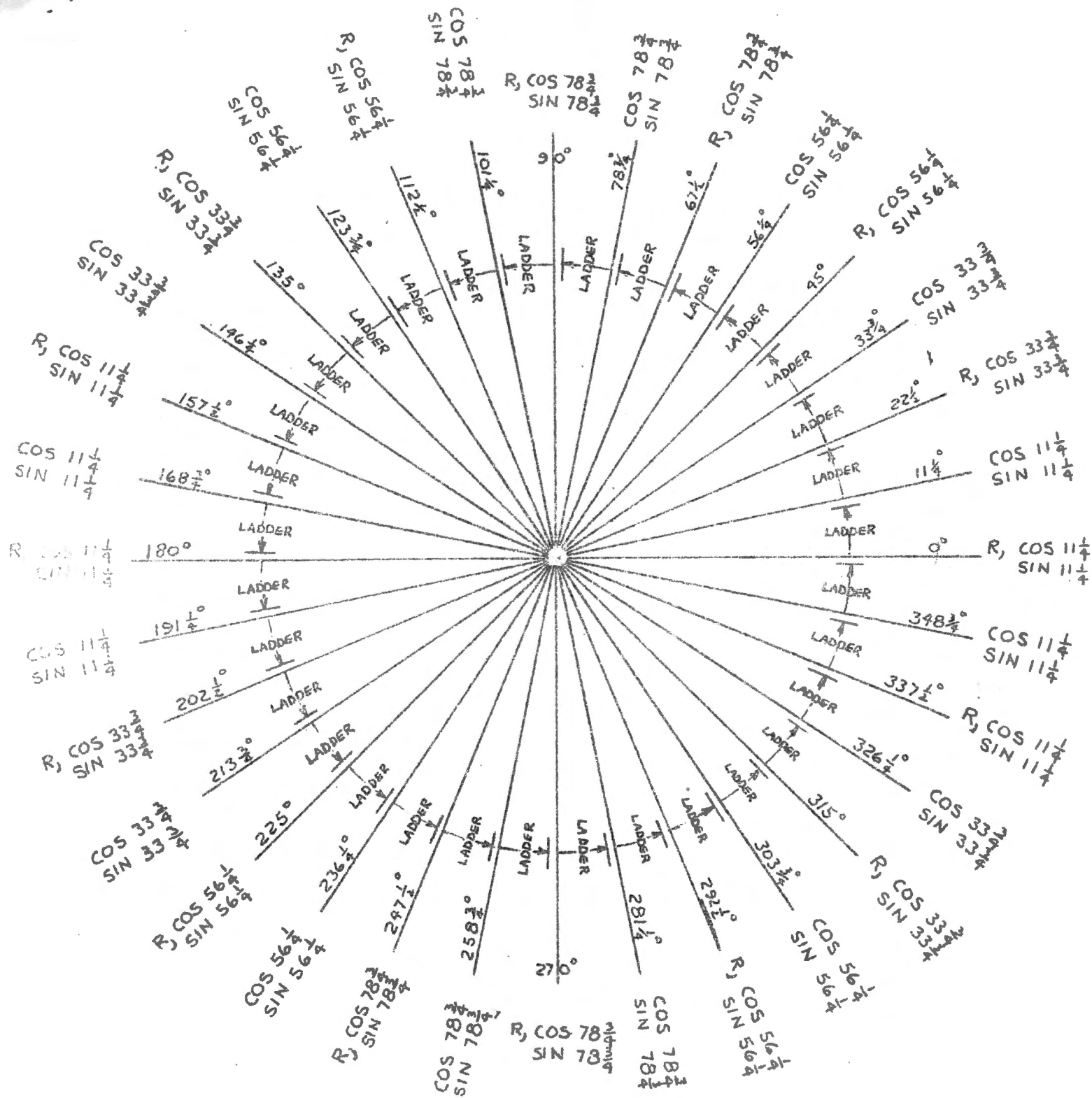
As an example, assume θ is equal to $213 \frac{3}{4}^\circ$. The $\sin 213 \frac{3}{4}$ is a negative quantity (out of phase) as is the $\cos 213 \frac{3}{4}$. Referring to the inversion symbols on the block diagram, the \sin is not inverted in the III quadrant and hence $\sin 213 \frac{3}{4}^\circ$ remains as an out of phase voltage. The \cos is inverted in the III quadrant and the out of phase $\cos 213 \frac{3}{4}^\circ$ signal becomes an in phase voltage. At this value of θ , S2 would be closed and the result at the main summing junction would be:

$$\sin 213 \frac{3}{4}^\circ \cos 33 \frac{3}{4}^\circ - \cos 213 \frac{3}{4}^\circ \sin 33 \frac{3}{4}^\circ = 0$$

and the desired null is obtained.

The next paper will describe the generation of $\cos (\theta - \psi)$, the operation of the ladder network, the quadrature rejection electronics, and the error amplifier.

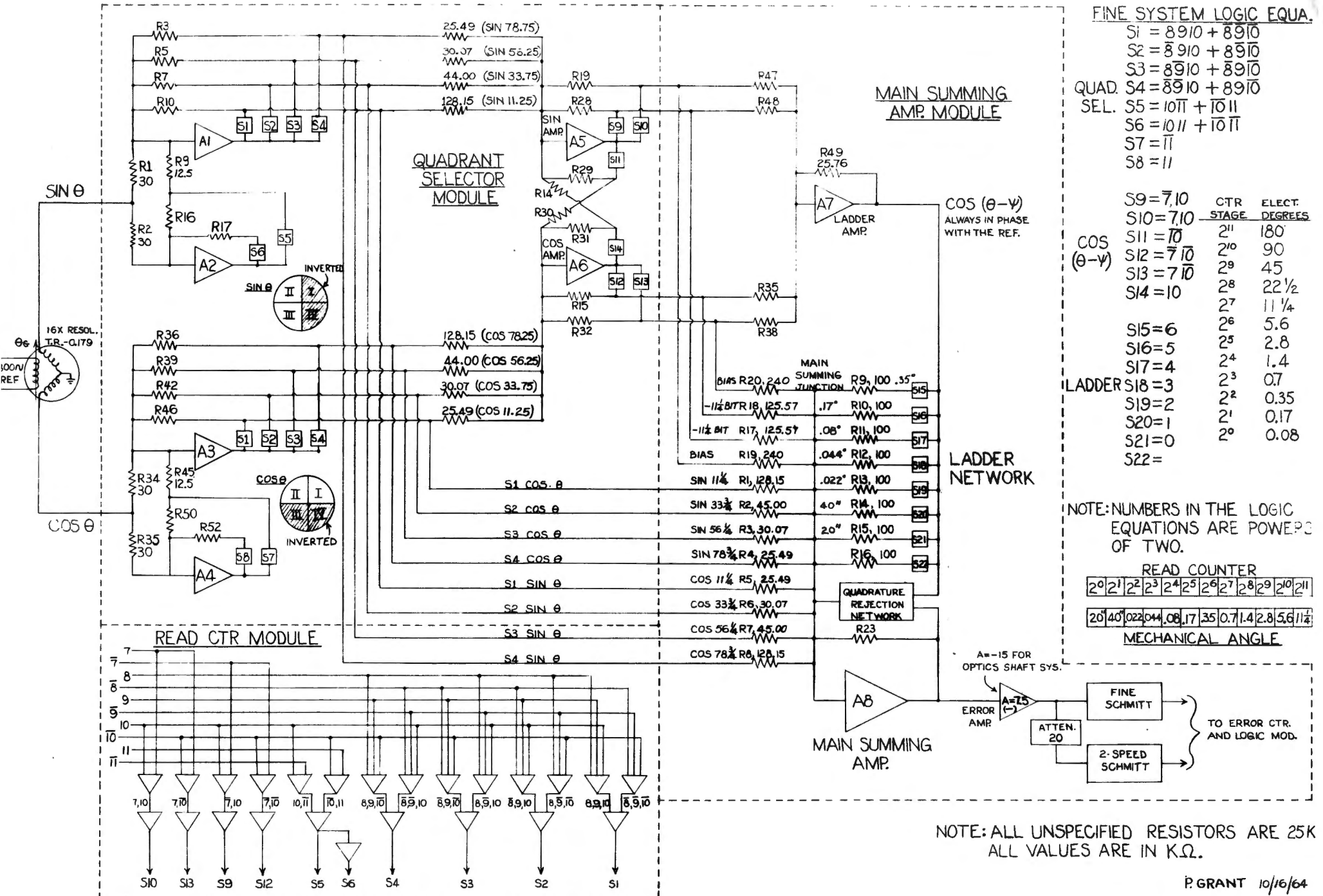

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FINE SWITCHING DIAGRAM

FIG. 2

ECDU FINE SYSTEM BLOCK DIAGRAM



FINE SYSTEM LOGIC EQUA.

$$\begin{aligned}
 S_1 &= 8910 + 8910 \\
 S_2 &= 8910 + 8910 \\
 S_3 &= 8910 + 8910 \\
 \text{QUAD. } S_4 &= 8910 + 8910 \\
 \text{SEL. } S_5 &= 1011 + 1011 \\
 S_6 &= 1011 + 1011 \\
 S_7 &= 11 \\
 S_8 &= 11 \\
 \\
 S_9 &= 710 \\
 S_{10} &= 710 \\
 \text{COS } S_{11} &= 710 \\
 S_{12} &= 710 \\
 S_{13} &= 710 \\
 S_{14} &= 10 \\
 \\
 S_{15} &= 6 \\
 S_{16} &= 5 \\
 S_{17} &= 4 \\
 \text{LADDER } S_{18} &= 3 \\
 S_{19} &= 2 \\
 S_{20} &= 1 \\
 S_{21} &= 0 \\
 S_{22} &=
 \end{aligned}$$

CTR STAGE	ELECT. DEGREES
2 ¹¹	180
2 ¹⁰	90
2 ⁹	45
2 ⁸	22 1/2
2 ⁷	11 1/4
2 ⁶	5.6
2 ⁵	2.8
2 ⁴	1.4
2 ³	0.7
2 ²	0.35
2 ¹	0.17
2 ⁰	0.08

NOTE: NUMBERS IN THE LOGIC EQUATIONS ARE POWERS OF TWO.

READ COUNTER

2 ⁰	2 ¹	2 ²	2 ³	2 ⁴	2 ⁵	2 ⁶	2 ⁷	2 ⁸	2 ⁹	2 ¹⁰	2 ¹¹
20	40	022	044	08	17	35	0.7	1.4	2.8	5.6	11 1/4

MECHANICAL ANGLE

NOTE: ALL UNSPECIFIED RESISTORS ARE 25K
ALL VALUES ARE IN K.Ω.

NOTE: SINGLE VARIABLE SWITCH FUNCTIONS NOT SHOWN.