MIT/IL
Apollo Guidance and Navigation
Electronic Design Group Memorandum No. 216

To: Ain Laats

From: John H. Barker

Date: 21 November 1969

Subject: IMU Runaway as Produced by the Setting of Read Counter Bits by Noise

The following design parameters form the basis for the explanation to follow.

1. DAC gain (K_D) through Mixing Amplifier $\approx$ 0.315.
2. Fine Error gain (K_f) through Mixing Amplifier $\approx$ 0.43.
3. Normal operation DAC signal out-of-phase with Fine Error signal.
4. DAC signal is limited by diodes, i.e. Figure 1.
5. Input signal necessary to saturate the TMA $\approx$ 0.105V.
6. Negative (out-of-phase with reference) signals out of DAC produces a positive angular rotation of the gimbals.
7. Negative (out-of-phase with reference) Fine Error signals produces a negative angular rotation of the gimbals.
8. An inphase Fine Error (16X MSA output) forces the Read Counter to count in a positive direction.
9. An out-of-phase Coarse Error (1X) will force the Read Counter to increment in a positive direction.
10. The Block II CDU has a following rate of approximately 70.5 degrees per second in the Inertial mode of operation of the G & N System.
11. The Block II CDU has a following rate of approximately 35 degrees per second in the Coarse Align mode of operation of the G & N system.
12. The torque motors have a capability of driving the gimbals at approximately 13 radians per second (700 degrees per sec.).
13. Rate limiting of the gimbals was required to be below 50 degrees per second to maintain adequate gyro suspension.

14. The CDU provides the lower boundary for rate limiting at a approximately 20 degrees per second due to the saw-tooth form of the Fine Error signal. At rates below 20 degrees per second the saw-tooth frequency drops below 100cps and will produce gimbal vibrations or "jerkiness".

15. Gains exceeding 28v/radian from the resolver shaft to the Torque Motor Amplifier (TMA) produce loop instability.

16. By reducing the PI pulse rate into the Read Counter by one-half during the Coarse Align mode a non-linear high gain condition was produced for gimbal rates exceeding 35 degrees per second. This causes a rapid build up of the Fine Error signal for rates greater than 35 degrees per second.

Figure 1 illustrates the mixing of the Fine Error signal and the DAC output signal.

Figure 2 illustrates the Coarse Align loop of the IMU.

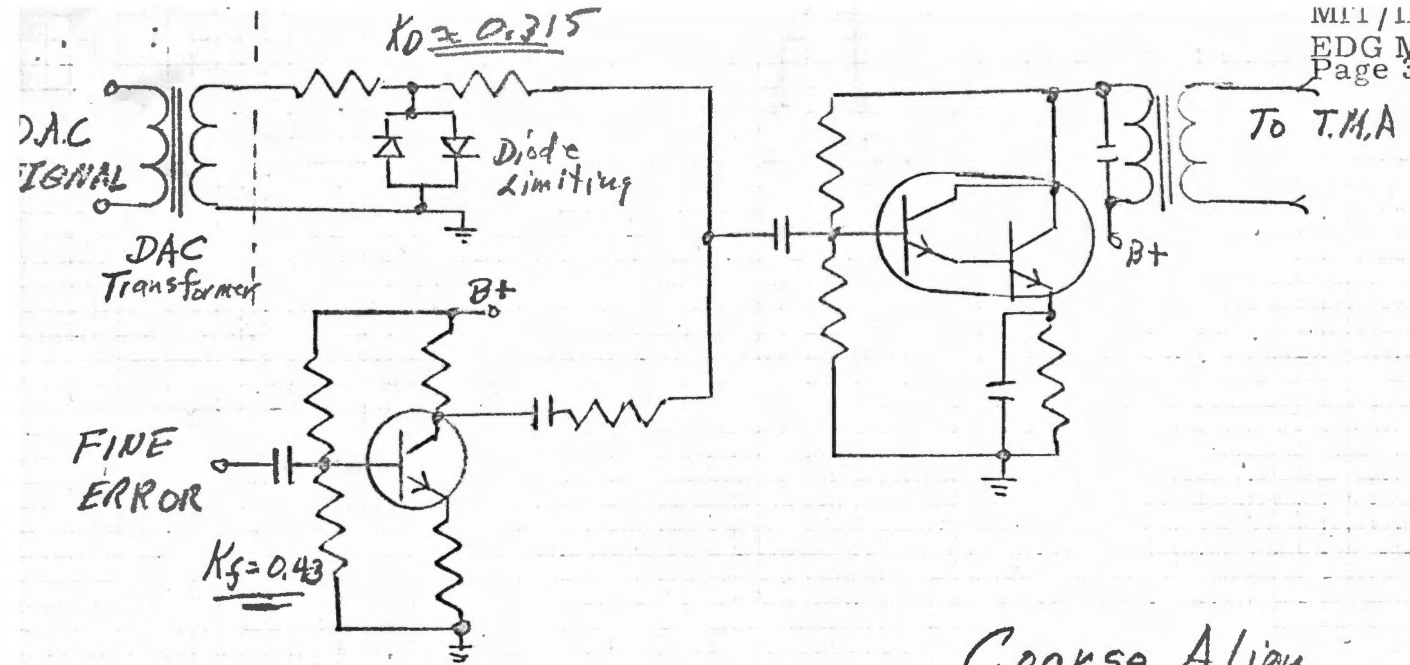

Figure 1 Coarse Align Mixing Amplifier

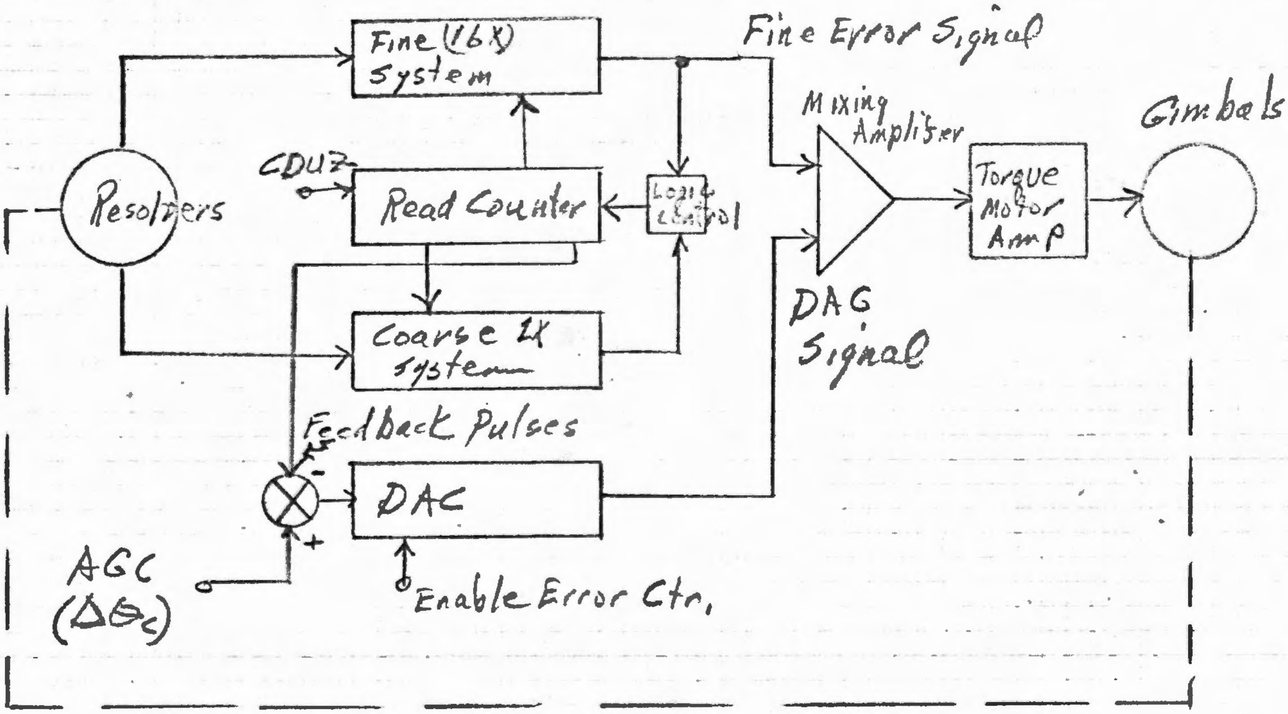

Figure 2 Coarse Align Loop

Problem Description:

The problem description will be related to the Middle Gimbal because of the necessity of down moding to the Coarse Align mode upon receipt of an "apparent" gimbal lock condition by the AGC. Once Coarse Align is moded and Enable Error Counter is present all three gimbals will react to the setting or resetting of bits in their Read Counters in a similar manner.

During the launch phase of Apollo 12 when the power interrupt or glitch was encountered the Middle Gimbal was aligned near zero degrees. Actual data print outs indicate that the gimbal was slightly negative with respect to zero. The G & N system was in the Inertial mode of operation with program P11 being run in the AGC. P11 makes use of the DAC's in the CDU while monitoring the SC attitude. Correction pulses are fed to the DAC's which control the Attitude Error Meters.

If the Middle Gimbal Read Counter received a noise input which would reset the 90 degree or 180 degree bits (2^{14} or 2^{15}) while in the Inertial Mode enough $\Delta\theta$ pulses would be sent to the AGC to indicate that Gimbal Lock had been encountered. This normally occurs at 85 degrees for the Middle Gimbal. Upon receipt of the Gimbal Lock condition the G & N system would be down moded to Coarse Align and the Error Counter enabled. With these conditions present gimbal runaway may be induced in the following manner.

Assuming that the 2^{14} or 2^{15} bit was reset, an out-of-phase Coarse Error would be generated which would start the Read Counter incrementing at a 12.8KC rate in the positive direction. The initial incrementing of the Read Counter in the positive direction will generate an out-of-phase Fine Error signal due to the fact that gimbal positions are negative with respect to the Read Counter angular contents for the 16X system. This incrementing action will be controlled by the Coarse System until the difference between the Read Counter and the gimbal is approximately seven degrees or less. Now with the Read Counter being counted in the positive direction the Up/Down control lines are held in the "Up" position under control of the Coarse System. Due to the normal inversion of counting between the Error Counter and the Read Counter the Error Counter will increment negatively when Coarse Align and Error Counter Enable are moded.

Figure 3 illustrates the relation of the Fine Error signal and the Coarse Error signal during the Inertial Mode of the G & N system after the 2^{14} bit of the Read Counter has been Reset.

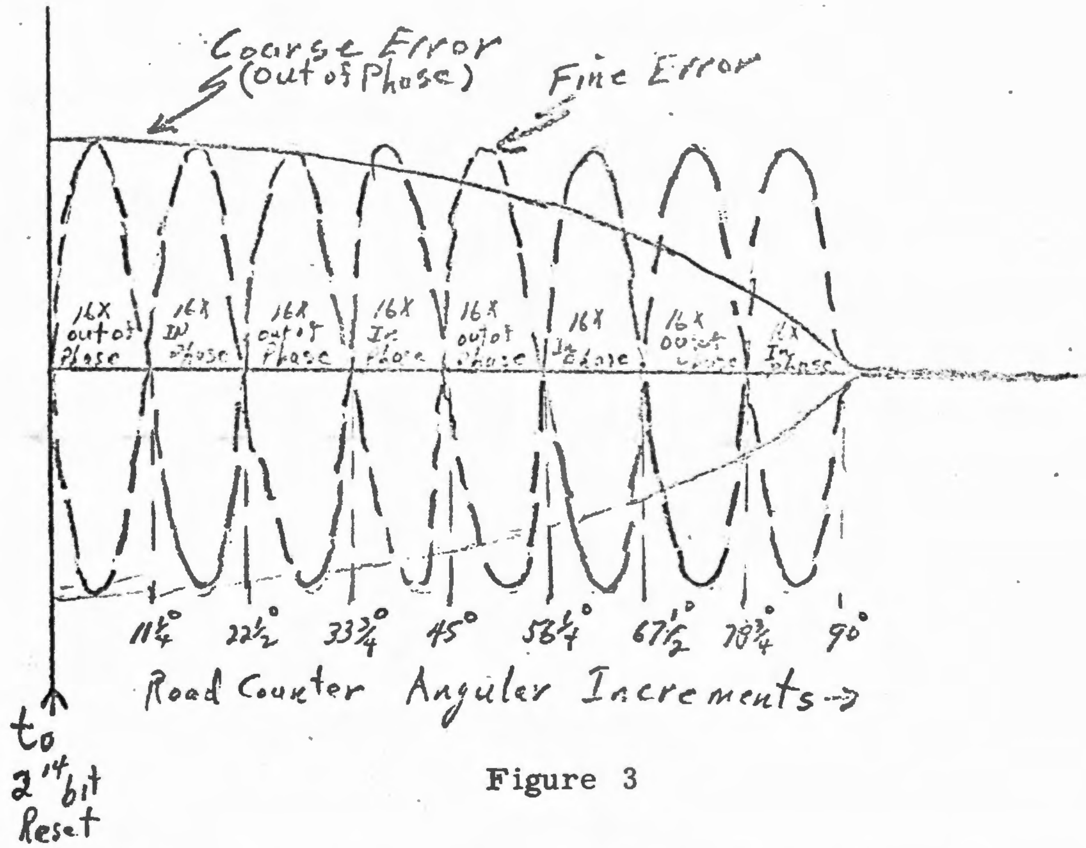

Figure 3

If the system has not been moded to Coarse Align the result of the 2^{14} bit being set by noise would be a 90 degree error stored in the AGC CDU counters. But if the G & N is down moded to Coarse Align during the period of counting out the 90 degree error from the Read Counter the possibility exists that a full 4. 2Vrms signal may be applied to the Coarse Align Mixing Amplifier. With an input gain of 0.43 for this signal an input level of 1.8 Volts will be applied to the Torque Motor Amplifier. Only 0. 105 Volts is necessary to drive this amplifier to its maximum output torquing capability.

Assuming that the Error Counter is enabled with Coarse Align and at a Fine System Null it will build up to oppose the Fine Error signal during the first $11\frac{1}{4}$ degrees of Read Counter incrementing, but due to the diode limiting the maximum input to the Coarse Align mixing amplifier would be ≈(1 Volt X 0.315) or .315 Volts which would not be capable of overriding the Fine Error input of 1.8 Volts. The Read Counter increments with the equivalent of 19.7 $\widehat{sec}$ pulses while the Error Counter with 158 $\widehat{sec}$ increments will not receive an input pulse until eight pulses have been received by the Read Counter therefore the Read Counter applies an error signal to the C.A. Mixing Amplifier before the DAC generates a negative feedback signal. In normal operation of the loop this is not a problem because the DAC signal exits via an AGC command before the Fine Error signal is generated.

Now assume that the system is dropped into the Coarse Align mode during the time that an inphase Fine Error signal is present ($11\frac{1}{4}^{\circ}$ - $22\frac{1}{2}^{\circ}$, $33\frac{3}{4}$ - 45, etc.) i.e. Figure 3. During these periods the Error Counter is still being incremented in the negative direction under control of the Coarse System but the Fine Error signal is now phase additive with the DAC output and will drive the gimbals.

I conclude that by moding a Coarse Align and Enable Error Counter during a noise induced Read Counter transient when the (Fine Error Signal X 0.43) is greater than the (DAC Signal X 0.315) the Gimbals will be driven under control of the Fine Error signal. Rotational rates of the gimbals will vary during a revolution as the Fine Error Signal and the DAC output are inphase or out-of-phase with respect to each other. Average measured gimbal rates are approximately 35 degrees per second. Once the gimbals have reached their "runaway" state monitoring of the error signals will not produce the relationship indicated in Figure 3. Instead the Coarse and Fine Error signals will track each other with the same phase and without alternating of the inphase and out-of-phase condition. Thereby establishing a Fine Error which is always driving the gimbals, but cannot "catch-up" to produce a null.

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