LIGO-T890050-00-R

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List of 5/01/89

Preliminary Report on Shark Sensor/Transducer Development

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4/28/89

Abstract: Development of shark detector sensor/magnetic transducer units similar to those employed with success at Garching and Glasgow is described. The prototype units have attained a shot-noise limited displacement spectral density of approximately 0.7 Angstrom/$Hz^{1/2}$ between 5 Hz and 5 kHz, making them about an order of magnitude more sensitive than previous shadow-sensing designs. This is attained by use of a split photodiode/slit mask sensing geometry which permits cancellation of intensity noise in the light-emitting diode source. Three prototype units have been used to servo the angular orientation of a test optic; measurements of the system performance are underway, as are further electronic refinements to enhance the system's immunity to interference and severe disturbances.

I. Goals of Program

In the upcoming breakup of the beamsplitter mass in the Caltech 40m prototype, it will be necessary to individually control the orientation and relative positions of the various optical components which are currently controlled as an assembly. These include the beamsplitter proper, the circulators or pickoffs which divert the light reflected from the 40m cavities. Also, suspended Pockels cells will be added later to enable beam recombination. The orientation control system currently in use for the 40m prototype test masses was deemed unsuitable for various technical reasons; instead, an enhancement on the approach used by researchers at MPI and U. of Glasgow was favored. In this scheme, compact integrated LED/photodiode shadow sensors and magnetic coil motors are used to servo one linear degree of freedom at each of several points on the suspended component, three to six such units thereby controlling some or all angular and linear degrees of freedom. An important goal is long-term stability sufficient to preclude the need for local optical lever orientation controls, with the added possibility of introducing global optical lever correction signals to control angular motion of the most critical components without disturbance of the remaining controlled degrees of freedom. Sensor noise in the 1 Hz to 100 Hz band is also an important criterion.

Equally important motivation arises from the need to demonstrate a highly reliable and cost-effective control system for application in the LIGO beam-conditioning and test mass optics. Experience with this program is expected to provide data on acceptable performance goals, interface requirements, space requirements, vacuum outgassing properties, reliability criteria, and cost impact of this critical LIGO subsystem.

II. Current Status

Preliminary investigations of noise and drift in various sensor configurations led to acceptance of a basic optomechanical layout on 30 October 1988. On 9 November prototype coil/sensor head and slit vane designs were submitted to the CES machine shop; for reasons of economy only three sets were ordered, enough to control the pitch, yaw and axial position of a test mirror. On 14 December the blank machined prototype heads were received from the shop and copper coils were wound on their coil form sections using a winding machine in the Power Electronics Group lab in Steele building. Sensing electronics were then installed in one of the prototype heads and the operation and noise specs were checked.

In January 1988 small rare earth/cobalt magnets (to be fastened to the suspended objects), split photodiodes and LED's were ordered in sufficient quantity to cover an anticipated initial production run of 50 head units. Also, tasks related to the electronics needed for full testing were submitted to Jeff Harman, who has since been designing and supervising construction of prototypes for all major functional units. The principal electronic projects are as follows;

1. D.C. Coupled Head Transceivers. These drive the LED and read out the photodiode signal, as well as servoing the LED intensity to maintain immunity from intensity noise and diode imbalance. The D.C. coupled design may prove to have insufficient immunity from stray light for critical applications, so an A.C. design is being pursued as well. The output of the transceiver is a voltage proportional to the linear position of the sensor from the controlled object. Status; completed, tested and operational (for three prototype heads).

2. Servo Filters and Coil Drivers. These provide servo tailoring and provide suitable correction currents to the integral coils in response to position error signals from the transceiver. The prototype unit is adapted from a coil driver PC board provided by MIT. Status; completed, tested and operational.

3. Pitch/Yaw/Mean Position <=> 3 Point Position Matrix Decoder. This unit will allow introduction of independently derived angle feedback from a global optical lever system, taking over the operation of the shark coil motors for differential modes (angles) while retaining shadow sensor control for common mode (linear) degrees of freedom. The unit has been designed using multiplying DAC's in place of potentiometers, for reliability, versatility and rapid upgrade to computer control. Status; completed and tested electronically; awaiting installation and closed-loop tests.

4. A.C. Modulated/Demodulated Head Transceivers. This upgrade should make the shark sensors immune to stray light and electrical interference by modulating the LED current at high frequency and demodulating the photodiode signals synchronously. Status; a preliminary design has been accepted and a prototype is under construction.

5. Quadrant Photodiode Receiver/Decoder. This unit will be used for the global control system for the beamsplitter. Status; prototype constructed, tested and operational.

6. Laser Diode Driver. LD's are being investigated as possible alternative to HeNe lasers for the beamsplitter global. Status; prototype constructed and tested.

Martin Regehr and Stephen Winters have been involved in both the electronic projects and in building and testing optomechanical prototypes and test rigs. Some of these are;

1. Dummy Mirror Test Suspension. An aluminum disk was outfitted with magnets and shadow vanes and suspended in air by thin wires. The three prototype shark heads were assembled and tested and then employed to successfully servo the test object. Improvements were made to the servo electronics, and measurements of the servo loop gain and tolerance to external disturbances were initiated. Status; operational.

2. Angle Noise Test Rig and Global System Prototype. An optical system intended to cancel out drift and jitter in the initial pointing of a global laser beam has been constructed and shown to work well. Measurements using this system on the angular stability of the dummy mirror have begun. In addition, a corner cube reflector required for the beamsplitter global has been ordered and obtained. Finally, design and construction work on a collimator/telescope for the diode laser has begun. Status; ongoing.

3. Improved Shark Head Mechanical Design. Refinements in the electronics and proof of satisfactory performance allow a considerable reduction in the size of the shark heads over the prototype design. Improved packaging and handleability, as well as reduced fabrication costs, are expected. When completed the improved design will be submitted for initial production (approximately 50 units). Status; ongoing.

4. Component Cage/Shark Head Support Design. The needs for earthquake protection and adjustable support of the shark heads around each suspended component will be met with a simple mechanical structure. Designs will be submitted for construction before or during the initial head production run. Status; on hold pending finalization of head design.

III. Manpower Allocation

At present personnel resources are allocated to the program approximately as follows (note that some people work part-time only; their maximum possible contributions are listed in parentheses).

Person	Role	FTE's (available FTE's)	
M. Zucker	Scientist	.1	
J. Harman	Engineer	.25	
B. Tinker	Sr. Tech	.9	
M. Regehr	Grad	.5	(.5)
S. Winters	Grad	.5	(.5)
D. Brettle	UG Tech	.25	(.25)

IV. Summary of Results to Date

The shark head sensors have achieved AC noise levels significantly better than needed to satisfy the constraints imposed by current noise models. Coil force and current have been shown to be within acceptable bounds during operation. Loop gain tests indicate that target values are readily achievable, as predicted, without interference from cross-coupling of the various normal modes of the test body. Preliminary drift tests indicate that the drift of the suspended components will probably not be dominated by electronic or optical drift in the sensor heads, but rather by thermal drift of the supporting structure; therefore the ability of these systems to universally replace local optical levers may hinge on the as yet unknown stability of the seismically isolated in-vacuum platforms upon which they will be mounted. Experience with similar platforms in the 40m prototype is encouraging in this respect. Electronic simulation testing of the matrix decoder has demonstrated the capability for controlling the angular degrees of freedom of the test body independently of mean "center of mass" position with less than 1% crosstalk. In addition, an optical system which suppresses spurious global laser drift by a factor of at least 1,000 has been demonstrated on a 10m baseline in the Bridge laboratory.

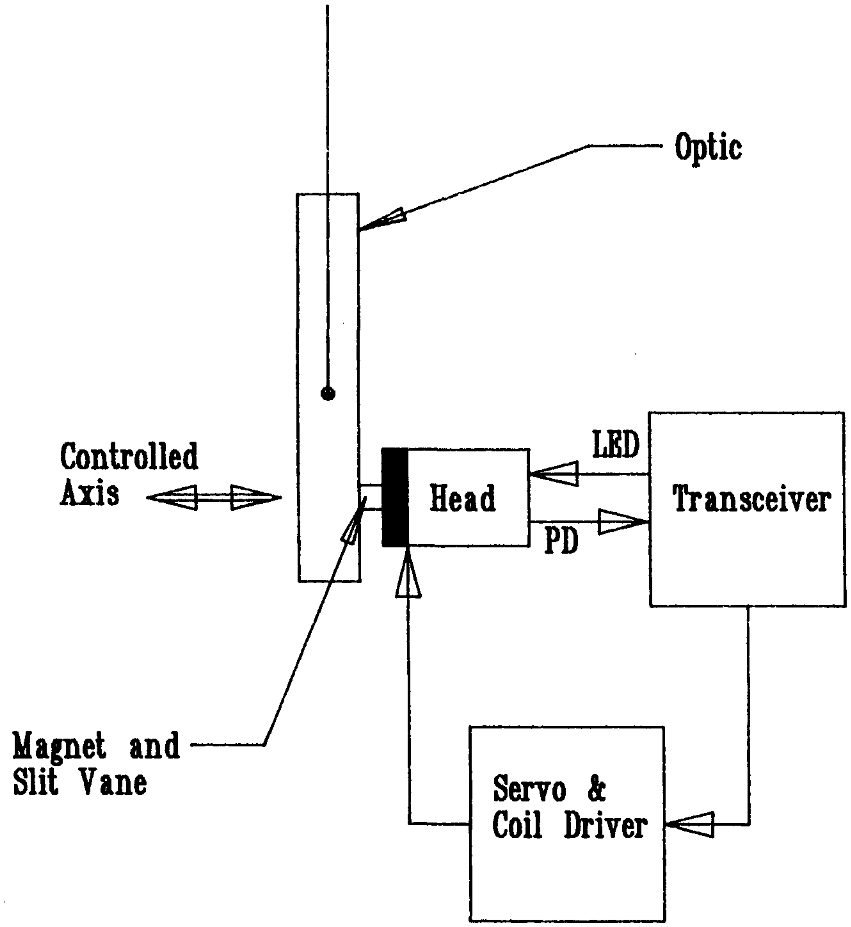
The principal remaining experiments involve testing the new AC transceivers, employing the matrix decoder and prototype global control system in a combined global angle/local position feedback mode test, and investigating questions of drift, robustness, immunity from light and electrical interference, etc. Tests of vacuum outgassing properties and wiring and connection strategies are also needed. Finally, in-vacuum tests of a real suspended system, using parts prepared for the beamsplitter breakup project and production-run heads and electronics, will be initiated to characterize the system, fine tune its performance, and minimize the down-time incurred by the actual 40m installation.

An exploration of the tolerance of the servo system to extreme overloads and their ability to recover control of the component after such conditions is also required. Several improvements to the head electronics are contemplated to help achieve the goal of extended operation without operator intervention, even after disturbance by earthquakes or intervention by experimenters. At present the test mirror requires some twenty seconds to reacquire lock after a severe shock (involving displacement of the mirror by about a centimeter); the suggested improvements should reduce this time to less than one second. We can probably make the system capable of permanent unattended operation, including automatic self-recovery from power failures and earthquakes.

V. Diagrams and Spectra

Functional block diagrams, mechanical drawings, and circuits, as well as noise spectra and sensitivity curves, are included. Please remember that all data and designs are preliminary; finalized designs will of course be circulated for discussion before initial production begins.

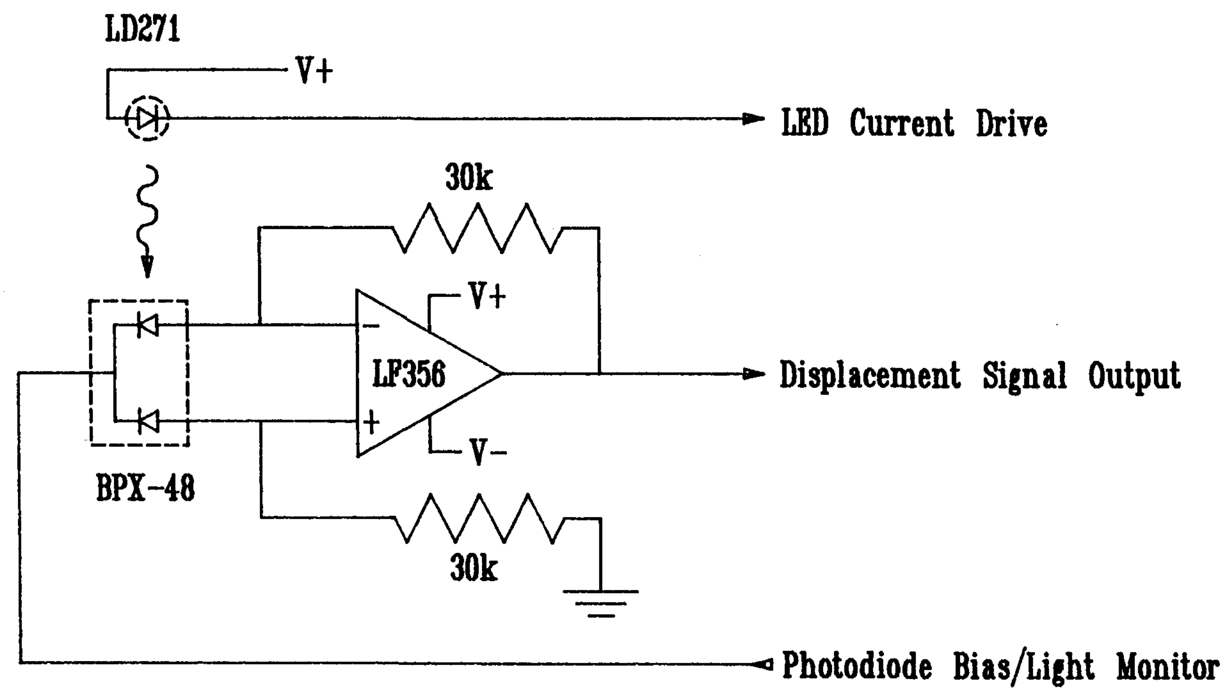
REVISION	BY	DATE



"Local" Control Mode
(One of 6 Possible
Heads Shown)

TITLE: Local Shark Detector System Block Diagram		PAGE: 1
DWG.# 89P-0011	DATE: 4/28/89	SCALE: 1:1
BY: M. E. Zucker (x4017, x3979)		
MATERIAL: N/A		NO. REQ'D: N/A
Caltech/MIT LIGO Project Account No. N/A		

REVISION	BY	DATE

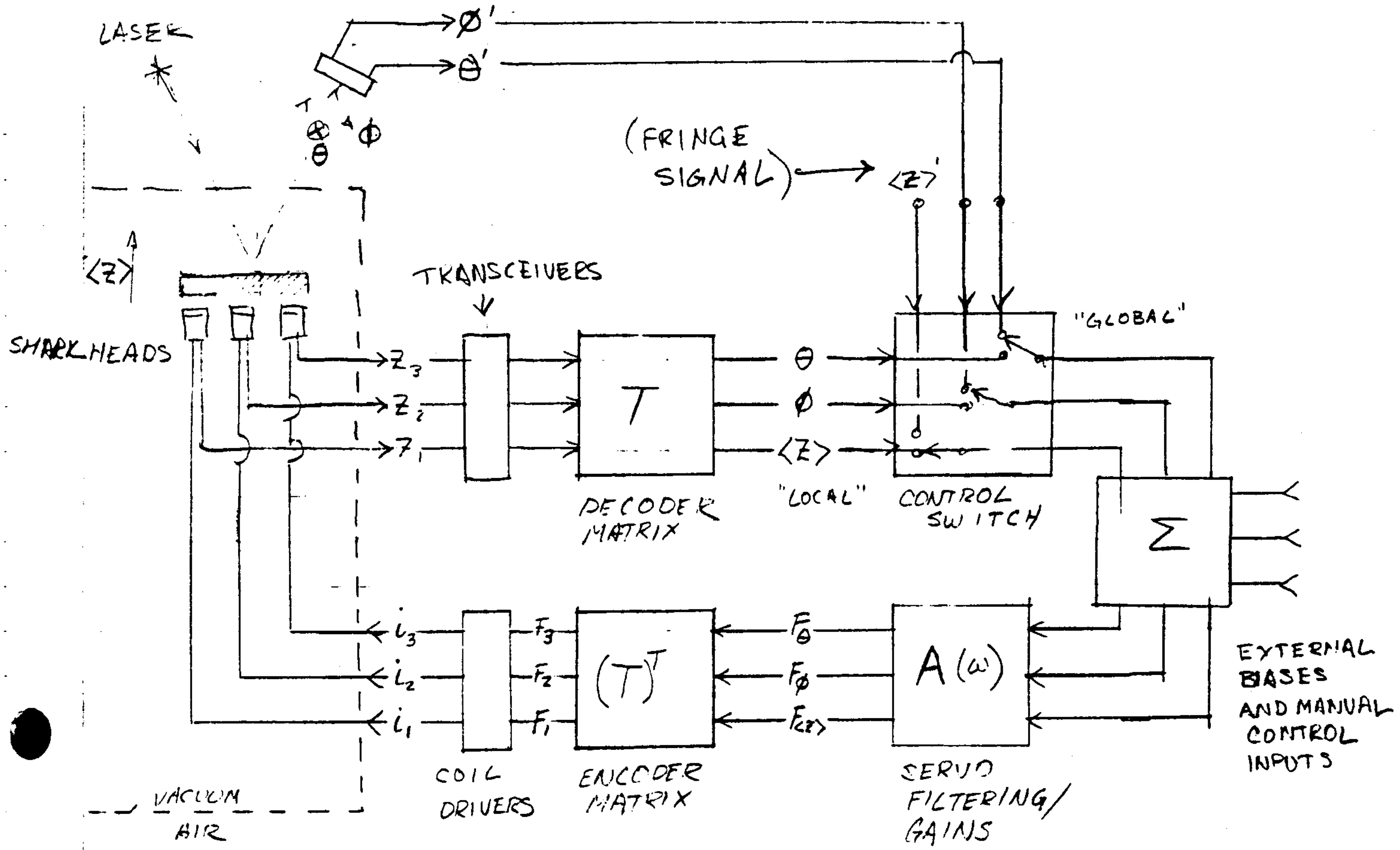


TITLE: DC Shark Detector Head Electronics		PAGE: 2
DWG.# 89P-0012	DATE: 4/28/89	SCALE: 1:1
BY: M. E. Zucker (x4017, x3979)		
MATERIAL: N/A		NO. REQ'D: N/A
Caltech/MIT LIGO Project	Account No. N/A	

GLOBAL-OPTIONAL

0019

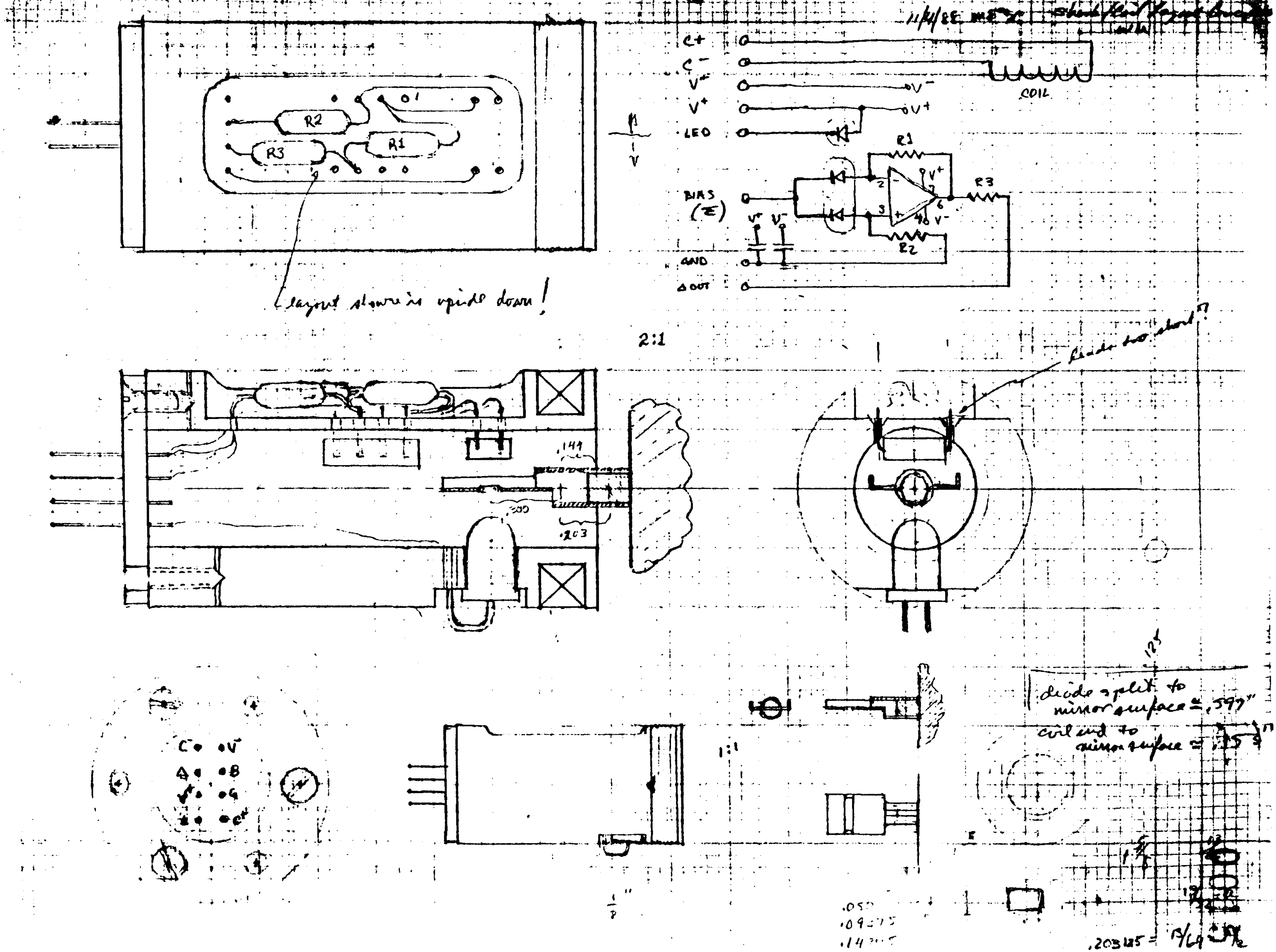
1/6/89 Functional Block Diagram of Shark/Coil Control Loops

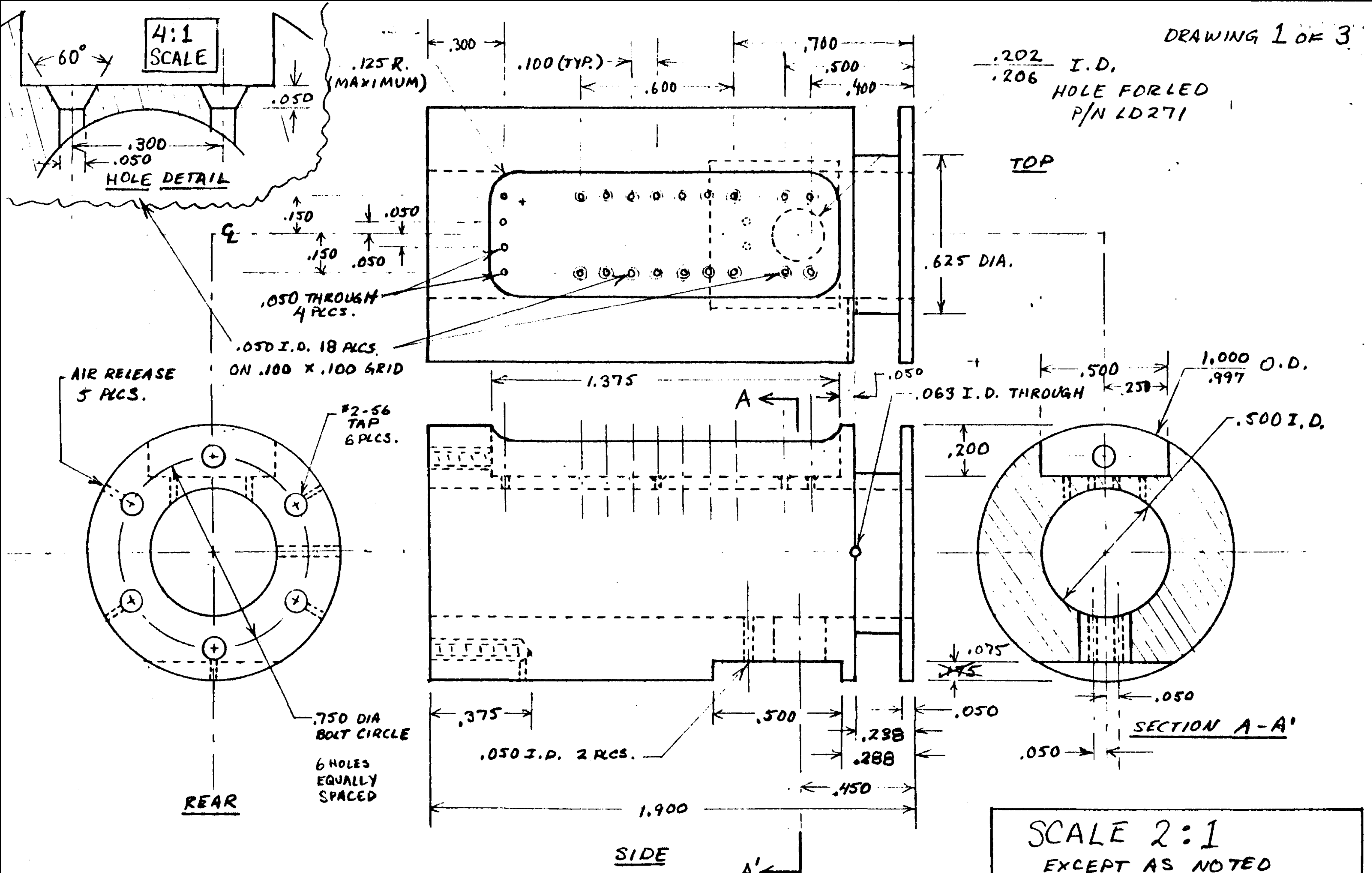


MATRIX T IS DEFINED SO THAT

$$\begin{pmatrix} T_{11} & T_{12} & T_{13} \\ T_{21} & T_{22} & T_{23} \\ T_{31} & T_{32} & T_{33} \end{pmatrix} \begin{pmatrix} Z_1 \\ Z_2 \\ Z_3 \end{pmatrix} = \left(\theta \quad \phi \quad \langle Z \rangle \right)$$

715


11/4/88
C+
C−
V−
V+
LED
COIL
R1
R2
R3
BIAS
GND
OUT
layout shown is upside down!
2:1
.149
.300
.203
1:1
diode split to mirror surface ≈ .597"
coil end to mirror surface ≈ .125"
.203125 =



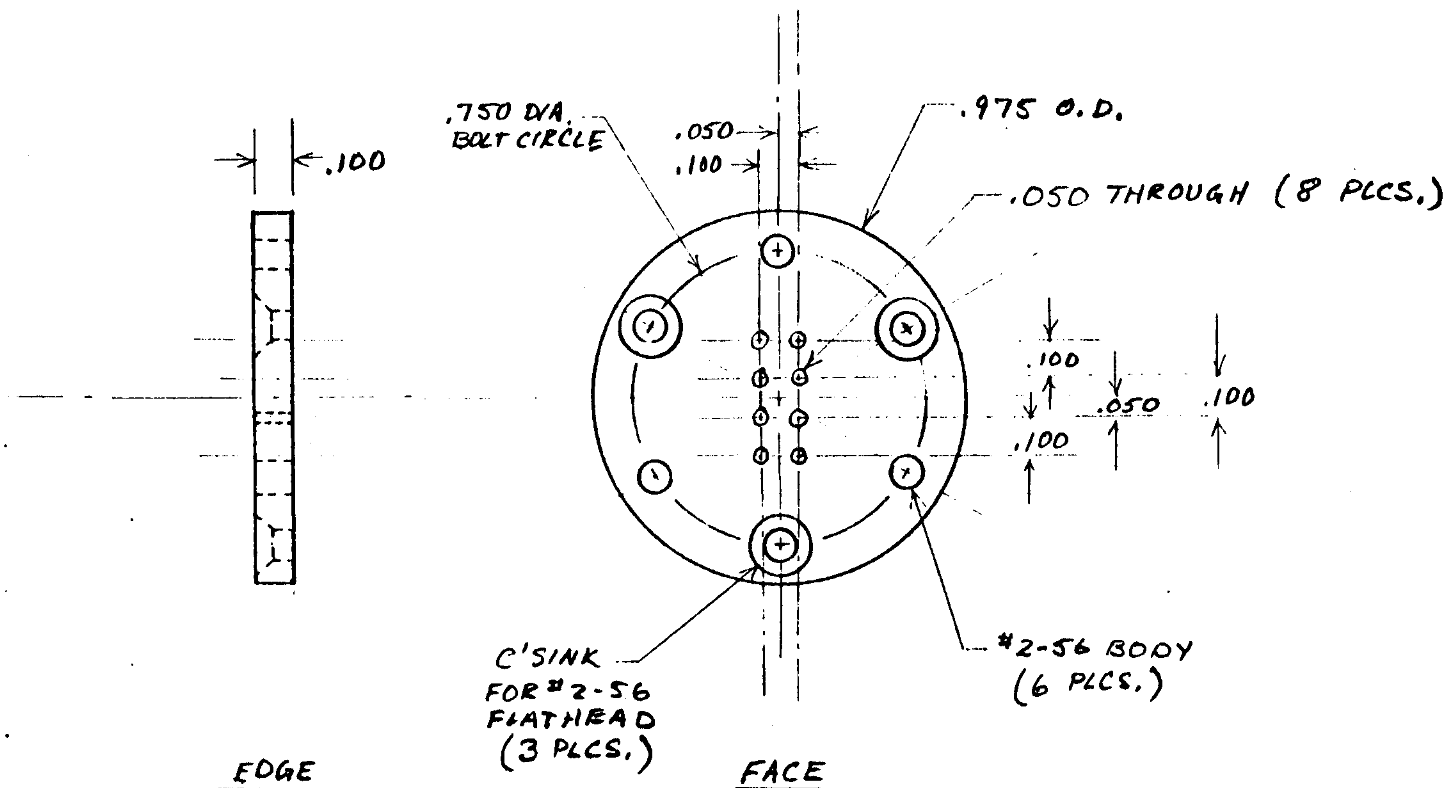
SPLIT-CELL SHARK SENSOR BODY / COIL FORM

M.E. ZUCKER GRAVITY PHYSICS x4017, x3979
11/9/88 (LAST REV. ______)
WORK ORDER #97842

SCALE 2:1
EXCEPT AS NOTED

MATERIAL; BLACK DELRIN OR FIBER-REINFORCED TEFLON

MAKE 3 (PROTOTYPE RUN)

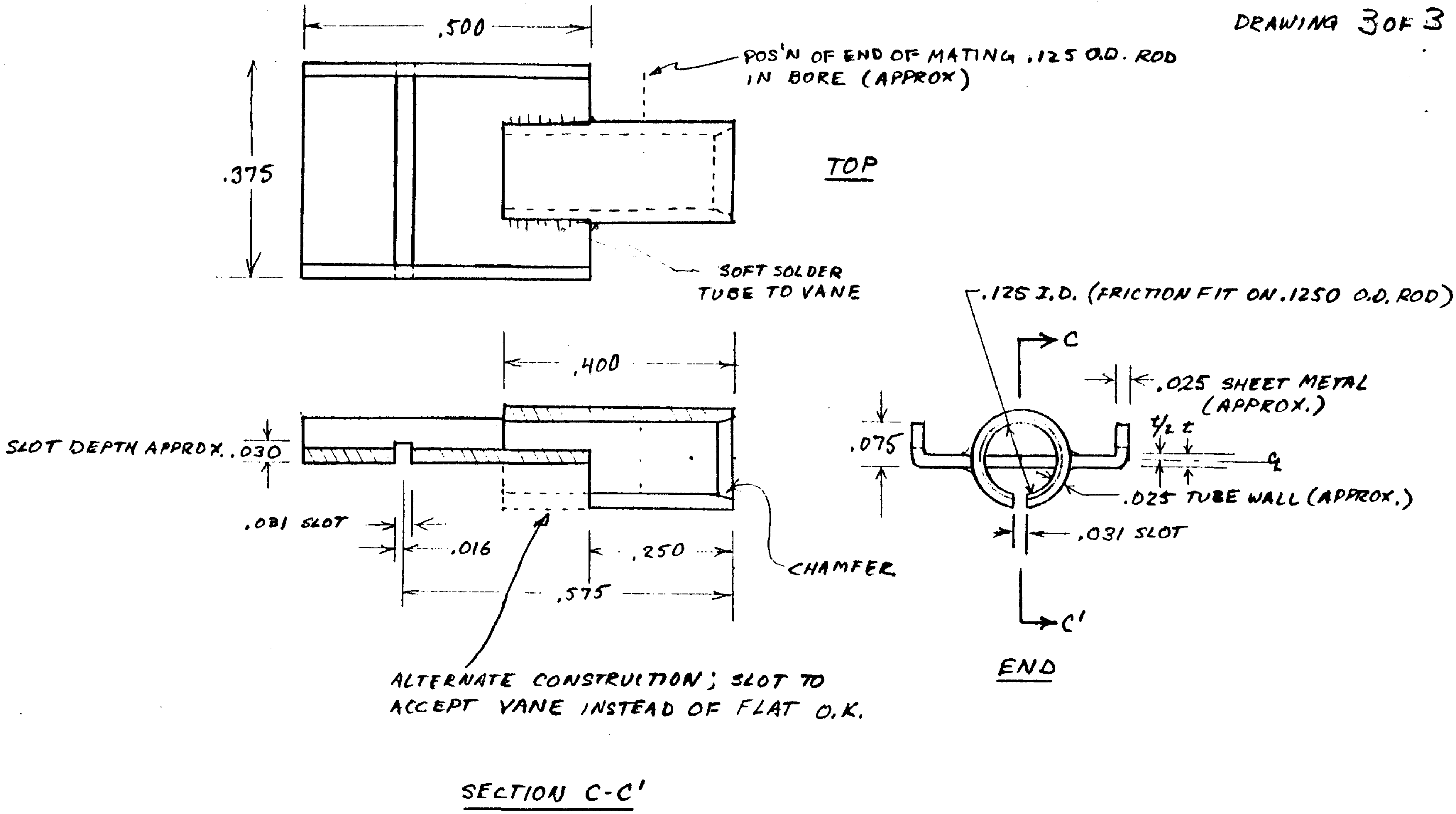


SHARK BODY END PLATE
M.E. ZUCKER GRAVITY PHYSICS x4017, x3979 11/9/88 (LAST REV. ______) WORK ORDER #97842

SCALE 2:1

MATERIAL; SAME AS BODY

MAKE 3



SHARK "FIN" SHADOW MASK
M.E. ZUCKER GRAVITY PHYSICS x4017, x3979 11/9/88 (LAST REV. ______) WORK ORDER # 97842

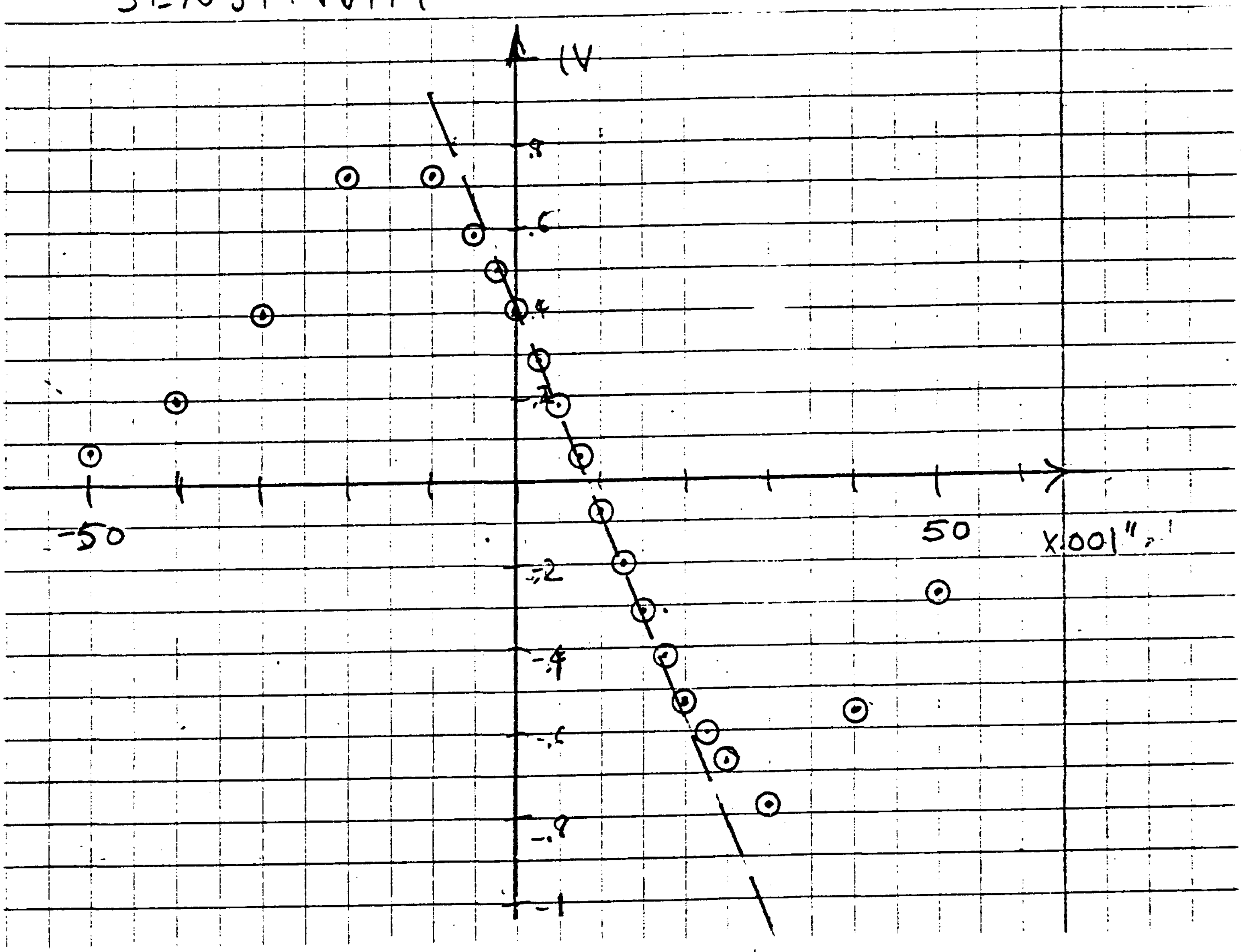
SCALE 4:1

MATERIAL; BRASS SHIM AND TUBING JOINED W/ SOLDER

MAKE 3

D. C. SHARK DETECTOR

SENSITIVITY

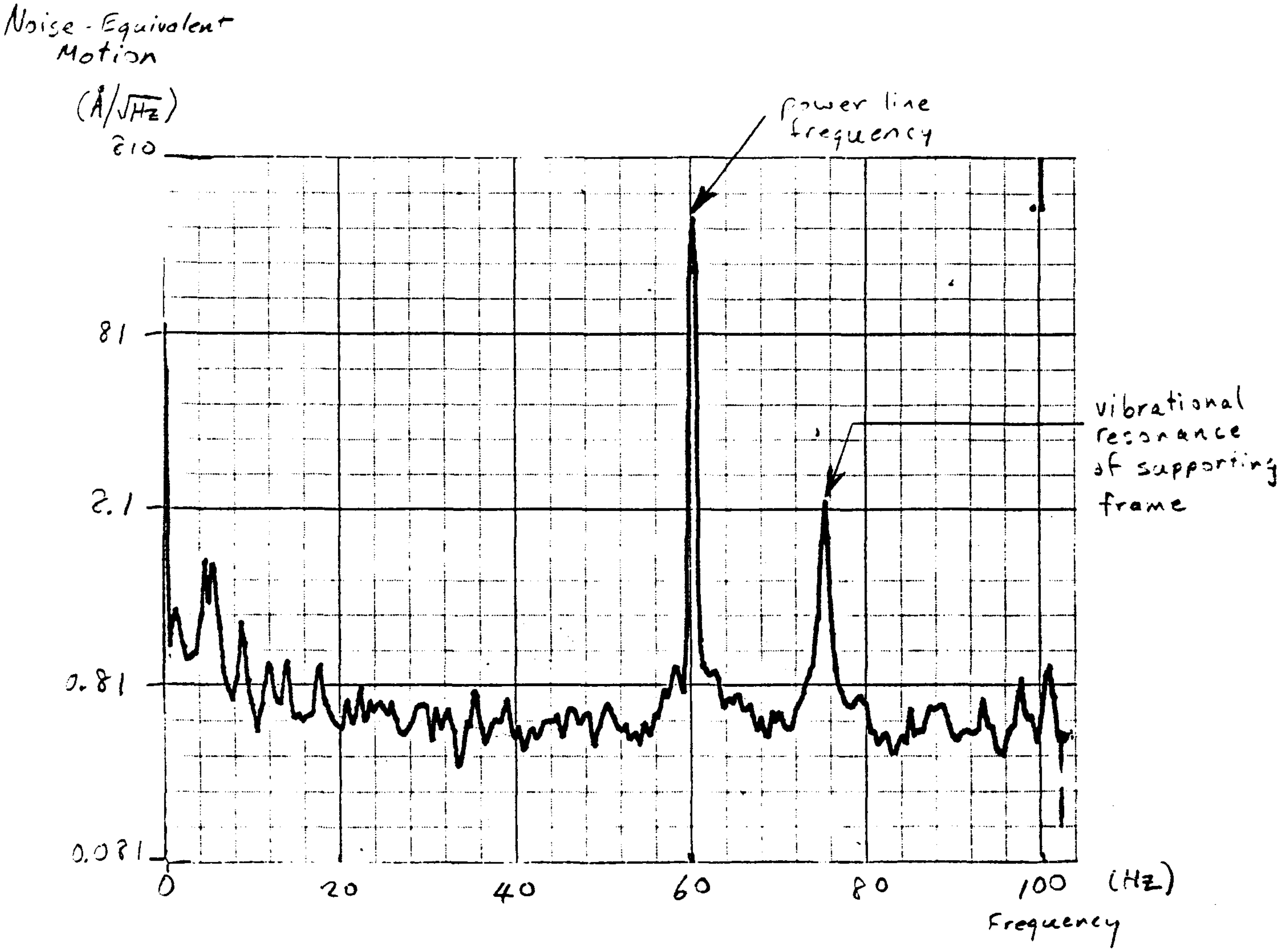


50 V / inch or 510 μ/V

DISPLACEMENT SIGNAL OUTPUT
VS.
DISPLACEMENT

MWR

Shark Detector Noise



MWR