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PROJECT TUBEFLIGHT

DENNIS I. POWELL

ROBERT E. DUFFY

AN INFLIGHT DATA RECORDING SYSTEMS FOR TUBEFLIGHT VEHICLES

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by

Dennis I. Powell
Robert E. Duffy

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SUMMARY

This report is concerned with the technique of measuring the attitude of a tubeflight vehicle while it is traversing through a guideway. In addition, a method was designed for measuring the fluid velocity ahead of the vehicle. Specifically, this study was directed toward developing measurement techniques for application to flight vehicles tested in Rensselaer Polytechnic Institute's T-2 facility.

It is determined that the most efficient way in which to record inflight data is to use an FM telemetry system. Such a system has been designed, fabricated and tested.

The output of a telemetry system is fed into a digital computer program which furnishes the time history of the vehicle motion as well as the fluid velocity immediately upstream. The reliability of the program to give an accurate profile of the transit is found to be directly dependent on the unit of time between telemetry readings chosen.

The total telemetry system is analyzed and areas requiring improvement is discussed.

INTRODUCTION

The testing of a small-scale model tubeflight vehicle has been conducted in the T-2 facility constructed by Rensselaer Polytechnic Institute. This facility is a 2000 foot long welded-up steel pipe with an inner diameter of 12.40 inches. In order to determine the vehicle's stability derivatives and to analyze the vehicle's performance, it is required to know the motion of the tubeflight vehicle relative to the fixed guideway as a function of time. The vehicle motion cannot be observed directly nor can instrumentation be connected to it externally as is the practice for wind-tunnel testing. In order to gain some useful data about the vehicular motion, the T-2 facility was instrumented with photoelectric cell transducers at 10 foot intervals along the longitudinal axis of the tube. As the vehicle passed each of these transducers, lights carried by the vehicle triggered the cells and the transit-time interval data between all of the stations was recorded for later analysis. The only indications of the vehicular motion that could be obtained were its velocity and acceleration averages over the 10 foot intervals between transducers as a function of time and tube location. This was not sufficient for a performance and stability analysis.

DATA RECORDING SYSTEM

Some possible solutions to the problem of obtaining data from which vehicular motion can be interpreted would be to 1) carry on-board flight instruments recorded by camera, 2) carry on-board recording devices, or 3) utilize electronic transmitting equipment and record the vehicular motion external to the vehicle. Solution 1) suffers from the drawback that flight instruments are quite sluggish in operation and consequently such a system would be adaptable only to low frequency studies. Solution 2) is limited in that on-board recording devices, such as tape recorders, are not only acceleration sensitive but also bulky and heavy.

After a careful analysis of the problem, the staff of Project Tubeflight, in conjunction with Malech Engineering and Eltech Laboratories, Inc. proposed an electronic telemetry system employing on-board transmitting and receiving equipment (Solution 3). A system of transducers attached to the vehicle is continually monitoring the vehicle's attitude and motion, which are electronically transmitted to a recording device.

Figure 1 is a drawing of a typical tubeflight vehicle equipped with sensing devices. A system of seven transducers is shown, two of which are used for powerplant studies.

The proximity transducers (Bently Nevada, Model 4106) measure the position of each support pad from the inner diameter of the guideway as a function of time. The longitudinal acceleration transducer (Bourns, Model 602A, $\pm$ 2.5G's) is sensitive to changes in the axial velocity of the vehicle and thus records the acceleration of the vehicle along its longitudinal axis as a function of time. A pair of acceleration sensors

(G. M. Giannini & Co. Linear Accelerometers, Model 3858, $\pm$ 2.5G's) comprise the roll system. They are mounted equidistant from the model centerline and aligned in opposite directions. The average output of the two transducers is electrically accomplished and indicates the net roll acceleration of the vehicle, also as a function of time. Both the longitudinal accelerometer and the roll acceleration systems are shock mounted (see Figure 2). The natural frequency of the mounting system is small enough so that the accelerometer outputs are not effected. The pressure transducer (G.M. Giannini & Co., Model 302, 0-.5 psi) measures the difference between the total pressure and the static pressure of the air upstream of the vehicle. One of the powerplant transducers measures the engine RPM as a function of time. This is accomplished by means of a highly sensitive magnetic proximity transducer placed near an eccentricity on the engine crankshaft. The other engine transducer (Kistler, special design) monitors the combustion chamber pressure.

The information from each of the sensing devices is continually supplied to a voltage controlled oscillator (VCO), multiplexed and transmitted to a receiver at the end of the tube (see Figure 3). There are eight channels of transmission; seven are for vehicle information and one is for monitoring the transmitter performance. The signal is then demultiplexed and introduced to a visicorder (Honeywell, Model 1508) which makes a permanent and continuous record of the time history of the vehicular motion. The visicorder record can be analyzed by use of the digital computer scheme introduced later in this report.

A reliable system for braking the vehicle at the end of the tube was also needed. Thus, a "failsafe" deceleration system was incorporated

in the telemetry system. Mounted on the vehicle is a sheet of soft rubber wrapped around the fuselage and firmly attached and sealed along its edges (see Figure 4). If air is forced into the space between the rubber and the fuselage under pressure of approximately 5.0 psig, the rubber sheet will expand to almost fill the tube but not touch it. This expansion system works similarly to the old style aircraft wing leading edge de-icer system. The decrease in cross-sectional area will act as an aerodynamic brake. The braking system is actuated electronically as the vehicle passes a predetermined location in the tube and triggers a photoelectric cell transducer. This then signals the failsafe transmitter which in turn sends a signal into the vehicle.

Appendix A is a report by Eltech Laboratories, Inc. describing the electronics of the telemetry system. This report also explains the procedure to be followed when operating the telemetry system.

SYSTEM CALIBRATION

Since the total system is composed of many separate components (transducers, transmitter, receiver, visicorder, etc.) each information channel must be calibrated in stages. An example of the necessary procedure is shown here for one of the proximity transducers:

1) Transducer output voltage vs Transducer location

2) Voltage out of demultiplexer vs Voltage into voltage controlled oscillators

3) Voltage into visicorder vs Visicorder deflection.

This procedure must be completed for each transducer. Step 1) should be performed while the transducers are mounted on the vehicle to account for all interaction effects. Step 2) must be executed for all seven information channels. Appendix A includes some initial linearity

system tests (called for in Step 2). The system test, outlined in Appendix A, should also be tested at a few locations along the tube to assure this portion of the calibration does not vary with the vehicle's location. Step 3) of the calibration procedure has previously been completed. The calibration charts for the proposed visicorder channels are presented in Figures 5 through 12. No special channel on the visicorder need be used with a specific transducer since all visicorder channels meet the maximum output frequency specifications of the FM telemetry system. After completing the three individual steps listed above, the steps can be consolidated into one calibration chart for each channel of information presuming Step 2 is found to be independent of vehicle location. These charts should be validated at regular intervals to assure that the system components have not changed their characteristics (temperature variation, time delay, recorder limitations, etc.).

COMPUTER ANALYSIS METHOD

The purpose of the telemetry system is to make available a time history of the data related to the motion of a tubeflight vehicle and the absolute velocity of the air upstream of the vehicle. The engine horsepower will be handled by means of direct calibration charts and is therefore not considered in this section.

Table I is a breakdown of the information that is required to determine the vehicular motion. Table II is a listing of the data available from the visicorder readings. With the present system, five channels of data can be recorded which are directly related to the motion of the vehicle. As these sensors are presently installed, only motions of the

vehicle which lie in a diametrical plane are discernible. Motions associated with yaw and/or transverse displacement cannot be determined. Since two of the vehicular data transducers measure acceleration (longitudinal and roll) and two sensors measure displacement (proximity transducers on pads) both integration and differentiation of the data is necessary. The best way to make the transfer of available (input) data to required (output) information is by the use of a digital computer method of analysis. The following is a discussion of the data reduction program and the procedure for its usage.

Figure 13 is a flow diagram presenting the calculations necessary to achieve the required output. The computer process is mainly unidirectional and therefore each part of the program can be handled separately. It is completely written in Fortran language as used by the IBM 360 System. The basic program terminology is listed in Table III.

INPUT

The input phase has been designed to provide an ease of specifying input data that will help avoid input errors. To provide insight into data requirements and the processing used, the logical structure of the input is described below.

The first five entries Table II are continuously recorded by the visicorder. At regular time intervals, starting with the launch condition and progressing completely to the vehicle's final resting state (or some convenient other time), these five variables should be tabulated. This data, in addition to the times to arrive at each photoelectric cell transducer from the starting point, constitute the prime computer input.

All input cards use one format statement, that allows the use of standard Fortran computer cards. The input cards described will be

illustrated using Figure 14, which is a representation of one card. The basic card consists of 80 columns; therefore, the numbers on the figure represent columns on the card. Since all of the data follows the same format statement, all data should be prepared in the same manner. The format is an E13.6 type specification which is analogous to a power of ten representation of a number:

$$+428.013 = +0.428013 \times 10^{+3}$$

in computer notation:

+428.013 = +0.428013E+03

+0.0007273 = +0.727300E-03

-5790.0212 = -0.579002E+04

When preparing such numbers for data input, they should be punched on cards in the form shown in Figure 15. In general, the form is:

Column # 1	Blank
Column # 2	The Number Sign
Column # 3	Zero
Column # 4	Decimal Point
Column # 5 - #10	The Digits
Column #11	E
Column #12	Sign of the Power of Ten
Column #13 - #14	The Power of Ten Digits

The order of data input is as follows (refer to Table III):

TIME	1 Card
TOTIME	1 Card
ROLLAC (J)	NUM Cards in Chronological Order
FOWPRK (J)	NUM Cards in Chronological Order
RERPRX (J)	NUM Cards in Chronological Order
TUBEAC (J)	NUM Cards in Chronological Order
PRESSR (J)	NUM Cards in Chronological Order

TIM	1 Card
TIMLON (J)	TIM Cards in Chronological Order
TUBPOS (J)	TIM Cards in Chronological Order
FOWINT	1 Card
RERINT	1 Card
PRSINT	1 Card
START	1 Card
TEMP	1 Card
TOTPRS	1 Card
PRXDIS	1 Card
GGFORW	1 Card
GGREAR	1 Card
GGPROX	1 Card

The complete data deck should be placed immediately behind the main program deck following the /DATA card. The actual computer program is presented in Appendix B.

The methods for calculating the required results follow. Note that in each section the respective accelerations have been assumed constant in a time unit interval. Thus the smaller the time unit, the more accurate will be the results.

PITCH VARIABLES

Pitch Angle	-	Calculation Exact
Pitch Velocity	-	Averaged between indexed time and previous time
Pitch Acceleration	-	Averaged between indexed time and previous time

(see Figure 16)

$$PICHAN(L) = SIN^{-1}\left[\frac{FOWPRX(L) - RERPRX(L)}{PRXDIS}\right]$$

$$PICHVE(L) = \frac{PICHAN(L) - PICHAN(L - 1)}{TIME}$$

$$PICHAC(L) = \frac{PICHVE(L) - PICHVE(L - 1)}{TIME}$$

HEAVE VARIABLES

Heave Position	-	Calculation Exact
Heave Velocity	-	Averaged between indexed time and previous time
Heave Acceleration	-	Averaged between indexed time and previous time

(see Figure 17)

Nose Up

$$HEVPOS(I) = RERPRX(I) + \left[COS\left[PICHAN(I)\right]\right]\left[CGPROX\right] + \left[SIN\left[PICHAN(I)\right]\right]\left[CGREAR\right]$$

Nose Down

$$HEVPOS(I) = FOWPRX(I) + \left[COS\left[PICHAN(I)\right]\right]\left[CGPROX\right] + \left[SIN\left[PICHAN(I)\right]\right]\left[CGFORW\right]$$

$$HEVVEL(I) = \frac{HEVPOS(I) - HEVPOS(I - 1)}{TIME}$$

$$HEVACC(I) = \frac{HEVVEL(I) - HEVVEL(I - 1)}{TIME}$$

ROLL VARIABLES

Roll Angle - Integration based on average acceleration between indexed time and previous time

Roll Velocity - Integration based on average acceleration between indexed time and previous time

Roll Acceleration - Exact Measurement

$$ROLLAC(N) = \text{Measured}$$

$$ROLLVE(N) = ROLLVE(N-1) + [TIME]\left[\frac{ROLLAC(N) + ROLLAC(N-1)}{2}\right]$$

$$ROLLAN(N) = [TIME][ROLLVE(N-1)] + ROLLAN(N-1) + [TIME]^2\left[\frac{ROLLAC(N) + ROLLAC(N-1)}{4}\right]$$

LONGITUDINAL VARIABLES (from Telemetry Input)

Longitudinal Position - Integration based on average corrected acceleration between indexed time and previous time

Longitudinal Velocity - Integration based on average corrected acceleration between indexed time and previous time

Longitudinal Acceleration - Exact Measurement corrected for pitch angle

$$TUBEAA(IJ) = \frac{TUBEAC(IJ)}{COS[PICHAN(IJ)]}$$

$$TUBEVE(IJ) = TUBEVE(IJ-1) + [TIME]\left[\frac{TUBEAA(IJ) + TUBEAA(IJ-1)}{2}\right]$$

$$TUBEPO(IJ) = [TIME][TUBEVE(IJ - 1)] + TUBEPO(IJ - 1) + [TIME]^2 \left[\frac{TUBEAA(IJ) + TUBEAA(IJ - 1)}{4}\right]$$

LONGITUDINAL VARIABLES (from Photocell Readings)

Longitudinal Position - Known

Longitudinal Velocity - Averaged between indexed photocell station and the previous station

Longitudinal Acceleration - Averaged between indexed photocell station and the previous station

TUBPOS(MM) = Inputed Data.

$$TUBVEL(MM) = \frac{TUBPOS(MM) - TUBPOS(MM - 1)}{TIMLON(MM) - TIMLON(MM - 1)}$$

$$TUBACC(MM) = \frac{TUBVEL(MM) - TUBVEL(MM - 1)}{TIMLON(MM) - TIMLON(MM - 1)}$$

UPSTREAM AIR VELOCITY and VEHICLE MACH NUMBER

Vehicle Mach number - Based on the averaged velocity TUBEVE(KK)

$$VEMACH(KK) = \frac{TUBEVE(KK)}{49.02\sqrt{TEMP}}$$

Upstream Air Velocity - Based on the average velocity TUBEVE (KK)

$$\text{AIRVEL(KK)} = \frac{\text{TUBEVE(KK)}}{49.02\sqrt{\text{TEMP}}\sqrt{5.0\left[\left(1.0 - \frac{\text{PRESSR(KK)}}{\text{TOTPRS}}\right)^{-2/7} - 1.0\right]}}$$

OUTPUT

The printed output from the program has been divided into three sections. The first is a printed listing of the input data organized in variable name groups (all FOWPRX(I) together, etc.). The second is a time history of the vehicle motion and the velocity of the air upstream of the vehicle. The form of this output is shown in Table IV. All of the data in this section has been computed with the aid of the telemetry system. The third and last section of the output is a listing of the data obtained from the photoelectric cell transducers mounted on the tube at 10 foot intervals. This data is organized as shown in Table V.

ANALYSIS

The capacity of the program to give very accurate results is a function of the amount of data fed into it. In other words, the time unit parameter is the only direct control of the error imposed on the results. If however the time unit chosen is overly small, the amount of data requiring key punching will become unbearable. A compromise must be made which will allow convenience, yet will yield reliable indications of the motion of the vehicle.

The program has only one limitation in its present form. The maximum number of data inputs for the subscripted parameters is 400. If, for any reason, more input data is necessary, the "dimension" statement within the program body must be corrected by changing the number 400 to the necessary figure.

The program was tested for reliability with a rather rigorous specified flight profile. Table VI is a listing of the equations describing each phase of the vehicle's proposed motion. A time unit of 0.05 seconds was chosen and the variables required as computer input (see INPUT) were calculated and keypunched for processing. This block of data constitutes the computer input. After running the input through the program, comparative graphs were made relating the computer output to the completely known motion of the vehicle. The resulting curves are presented in Appendix C. In each case, the solid curves are the plots of the proposed known motion and the circles are discrete points from the computer output.

It is readily seen that the digital computer representation of the vehicular motion and the proposed motion are just about one and the same. Thus, the computer program presented here can be used as part of the total telemetry system and thus yield very reliable results.

SYSTEM ANALYSIS

As it is designed, the telemetry system is an extremely versatile method of determining the vehicular motion. The system can be used with any tubeflight vehicle. However, as the system is presently constituted a number of characteristics are still lacking. The proximity transducers have an output voltage versus displacement curve that levels off at about 0.6 inches. If the support pads were to heave more than 0.6 inches, the output readings would indicate only 0.6 inches.

Also, the vehicular yaw and transverse displacement as yet has not been examined. The present system includes a sensor arrangement which assumes that the vehicle is always aligned along one of the tube's cross-sectional diameter lines. If the vehicle were to yaw without

heaving, the output with the system in its present state would indicate a pure heave (see Figure 18).

From stability theory, it is known that the degrees of freedom for moderate disturbances are coupled. Thus, a yaw analysis is required for a complete vehicle stability and control analysis. This is particularly true if it is desired to examine the motion of tube-flight vehicles in curved guideways.

A total solution to this problem could be accomplished with the maximum addition of four extra channels of transmission and four proximity transducers (see Figure 19). A minimum of two additional channels would be required if acceleration transducers are used. At the present time it is felt that the use of proximity transducers would be the most reliable method of recording yaw and transverse motion. When the system is equipped with these newly proposed transducers, the required six degree of freedom analysis can be made.

TABLE I

Longitudinal Location	
Longitudinal Velocity	(from telemetry system)
Longitudinal Acceleration	
Longitudinal Location	
Longitudinal Velocity	(from photoelectric cells)
Longitudinal Acceleration	
Roll Angle	
Roll Velocity	
Roll Acceleration	
Pitch Angle	
Pitch Velocity	
Pitch Acceleration	
Heave Position	
Heave Velocity	
Heave Acceleration	
Vehicle Longitudinal Mach Number	
Velocity of Air Upstream of the Vehicle	

TABLE II

Longitudinal Acceleration (uncorrected for pitch)

Roll Acceleration

Heave of Forward Support Pad

Heave of Rear Support Pad

Pressure Differential Upstream of the Vehicle

The Times to Arrive at Each of the Photoelectric Cells from the Starting Position

TABLE III

TERMINOLOGY

AIRVEL( )	absolute velocity of the air forward of the vehicle at time interval ( ), FT/SEC
AVLGAC( )	average longitudinal acceleration in time interval ( ), FT/SEC^2
AVRLAC( )	average roll acceleration in a time interval RAD/SEC^2
CGINIT	initial vehicular heave, FT
CGFORW	longitudinal distance from forward proximity transducer to the center of gravity, FT
CGPROX	vertical distance from the center of gravity to proximity transducers, FT
CGREAR	longitudinal distance from rear proximity transducer to the center of gravity
FOMACH( )	Mach number of vehicle relative to air forward of the vehicle at time interval ( )
FOVELO( )	velocity of vehicle relative to air forward of the vehicle at time interval ( ), FT/SEC
FOWINT	initial heave position of forward proximity transducer, FT
FOWPRX( )	height of forward proximity transducer at time interval ( ), FT, position up
HEVACC( )	heave acceleration of center of gravity at time interval ( ), FT/SEC^2, positive up
HEVPOS( )	heave position of center of gravity at time interval ( ), FT, positive up
HEVVEL( )	heave velocity of center of gravity at time interval ( ), FT/SEC, positive up
NUM	number of data time points
PAINIT	initial pitch angle, RAD

TABLE III
(con't.)

PICHAC( )	pitch acceleration at time interval ( ), RAD/SEC^2, positive nose up
PICHAN( )	pitch angle at time interval ( ), RAD, positive nose up
PICHVE	pitch velocity at time interval ( ), RAD/SEC, positive nose up
PRESSR( )	pressure differential at time interval.( ) LB/IN^2
PRSINT	initial pressure differential LB/IN^2
PRSRAT( )	pressure ratio, P/PTOT, at time interval ( )
PRXDIX	distance between proximity transducers, FT
RERINT	initial heave position of rear proximity transducer, FT
RERPRX( )	height of rear proximity transducer at time interval ( ), FT, positive up
ROLINT	initial roll angle, RAD
ROLLAC( )	roll acceleration at time interval ( ), RAD/SEC^2, positive clockwise
ROLLAN( )	roll angle at time interval ( ), RAD, positive clockwise
ROLLVE( )	roll velocity at time interval ( ), RAD/SEC positive clockwise
SOUND	speed of sound in tube, FT/SEC
START	initial longitudinal position, FT
TEMP	total temperature of "at rest" air in tube, degrees R
TIM	number of longitudinal photocell photocell pickups

TABLE III
(con't.)

TIME	time unit for dividing into intervals, SEC
TIMLON( )	time to longitudinal positions of photocells, from starting position, SEC
TOTIME	total time of test, SEC
TOTPRS	total pressure in tube, LB/IN^2
TUBACC( )	longitudinal acceleration at photocell pickup averaged in range, FT/SEC^2, positive forward
TUBEAC( )	longitudinal acceleration at time interval ( ) uncorrected for pitch, FT/SEC^2, positive forward
TUBEAA( )	longitudinal acceleration at time interval ( ) corrected for pitch, FT/SEC^2, positive forward
TUBEPO( )	longitudinal position at time interval ( ) corrected for pitch, FT, positive forward
TUBEVE( )	longitudinal velocity at time interval ( ) corrected for pitch, FT/SEC, positive forward
TUBPOS( )	longitudinal distance to photocell pickup from starting position, FT, positive forward
TUBVEL( )	longitudinal velocity at photocell pickup averaged in the range, FT/SEC, positive forward
VEMACH( )	actual Mach number of vehicle relative to the tube at time interval ( )

TABLE IV

ACTUAL TIME	TUBEPO	ROLLAN	HEVPOS	PICHAN	VEMACH
	TUBEVE	ROLLVE	HEVVEL	PICHVE	AIRVEL
	TUBEAA	ROLLAC	HEVACC	PICHAC	

TABLE V

TUBPOS	TUBVEL	TUBACC

TABLE VI

Longitudinal Position

0 - 3.5 sec.	$6t^2$
3.5 - 4.6 sec.	$5(t - 3.5)^2 + 42(t - 3.5) + 73.5$
4.6 - 5.6 sec.	$3(t - 4.6)^2 + 53(t - 4.6) + 125.75$
5.6 - 6.5 sec.	$1.5(t - 5.6)^2 + 59(t - 5.6) + 181.75$
6.5 - 7.3 sec.	$0.5(t - 6.5)^2 + 61.7(t - 6.5) + 236.065$
7.3 - 16 sec.	$62.5(t - 7.3) + 285.745$
16 - t_f sec.	$\frac{-31.25}{t_f - 16}(t - 16)^2 + 62.5(t - 16) + 829.495$

Longitudinal Velocity

0 - 3.5 sec.	$12t$
3.5 - 4.6 sec.	$10(t - 3.5) + 42$
4.6 - 5.6 sec.	$6(t - 4.6) + 53$
5.6 - 6.5 sec.	$3(t - 5.6) + 59$
6.5 - 7.3 sec.	$1(t - 6.5) + 61.7$
7.3 - 16 sec.	62.5
16 - t_f sec.	$\frac{-62.5}{t_f - 16}(t - 16) + 62.5$

TABLE VI
(con't.)

Longitudinal Acceleration

0 - 3.5 sec.	12
3.5 - 4.6 sec.	10
4.6 - 5.6 sec.	6
5.6 - 6.5 sec.	3
6.5 - 7.3 sec.	1
7.3 - 16 sec.	0
16 - 6π sec.	$\frac{-62.5}{6\pi - 16}$

Roll Angle

0 - 10 sec.	$\frac{\pi}{400} t^2$
10 - 11 sec.	$\frac{\pi}{1000}(t - 10)^2 + \frac{\pi}{20}(t - 10) + \frac{\pi}{4}$
11 - 12 sec.	$\frac{26\pi}{500}(t - 11) + \frac{301\pi}{1000}$
12 - 16 sec.	$-\frac{\pi}{600}(t - 12)^2 + \frac{26\pi}{500}(t - 12) + \frac{353\pi}{1000}$
16 - 6π sec.	$\frac{1603\pi}{3000} - \frac{1603\pi}{6000} \sin\left(\left(\frac{\pi}{6\pi - 16}\right)(t - 8 - 3\pi)\right)$

TABLE VI
(con't.)

Roll Velocity

0 - 10 sec.	$\frac{\text{ना}}{200}\,t$
10 - 11 sec.	$\frac{\text{ना}}{500}(t - 10) + \frac{\text{ना}}{20}$
11 - 12 sec.	$\frac{26\text{ना}}{500}$
12 - 16 sec.	$-\frac{\text{ना}}{300}(t - 12) + \frac{26\text{ना}}{500}$
16 - 6ना sec.	$\frac{58\text{ना}}{1500} - \frac{1603\text{ना}}{6000}\,\frac{\text{ना}}{6\text{ना} - 16}\cos\left(\left(\frac{\text{ना}}{(6\text{ना} - 16)}\right)(t - 8 - 3\text{ना})\right)$

Roll Acceleration

0 - 10 sec.	$\frac{\text{ना}}{200}$
10 - 11 sec.	$\frac{\text{ना}}{500}$
11 - 12 sec.	0
12 - 16 sec.	$-\frac{\text{ना}}{300}$
16 - 6ना sec.	$\frac{1603\text{ना}}{6000}\left(\frac{\text{ना}}{(6\text{ना} - 16)}\right)^2 \sin\left(\left(\frac{\text{ना}}{(6\text{ना} - 16)}\right)(t - 8 - 3\text{ना})\right)$

TABLE VI
(con't.)

Pitch Angle (θ)

$0 - \pi/2$	sec.	$0.0043635 + 0.0043635 \sin(2t - \pi/2)$
$\pi/2 - \pi$	sec.	0.008727
$\pi - 3\pi/2$	sec.	$0.0043635 + 0.0043635 \cos(2t - 2\pi)$
$3\pi/2 - 19\pi/8$	sec.	$0.00218175 \sin(4t - 6\pi)$
$19\pi/8 - 22\pi/8$	sec.	$-0.001090875 + 0.001090875 \sin(8t/3 - 41\pi/6)$
$22\pi/8 - 7\pi/2$	sec.	$0.0043635 + 0.0043635 \sin(8t/3 - 47\pi/6)$
$7\pi/2 - 5\pi$	sec.	0.00000
$5\pi - 6\pi$	sec.	$0.00218175 + 0.00218175 \sin(2t - 21\pi/2)$

Pitch Velocity ($\dot{\theta}$)

$0 - \pi/2$	sec.	$0.008727 \cos(2t - \pi/2)$
$\pi/2 - \pi$	sec.	0.00000
$\pi - 3\pi/2$	sec.	$-0.008727 \sin(2t - 2\pi)$
$3\pi/2 - 19\pi/8$	sec.	$0.008727 \cos(4t - 6\pi)$
$19\pi/8 - 22\ /8$	sec.	$0.002909 \cos(8t/3 - 41\pi/6)$
$22\pi/8 - 7\pi/2$	sec.	$0.011636 \cos(8t/3 - 47\pi/6)$
$7\pi/2 - 5\pi$	sec.	0.00000
$5\pi - 6\pi$	sec.	$0.0043635 \cos(2t - 21\pi/2)$

TABLE VI
(con't.)

Pitch Acceleration ($\ddot{\theta}$)

$0 - \pi/2$	sec.	$-0.017454 \sin(2t - \pi/2)$
$\pi/2 - \pi$	sec.	0.00000
$\pi - 3\pi/2$	sec.	$-0.017454 \cos(2t - 2\pi)$
$3\pi/2 - 19\pi/8$	sec.	$-0.034908 \sin(4t - 6\pi)$
$19\pi/8 - 22\pi/8$	sec.	$-0.007757 \sin(8t/3 - 41\pi/6)$
$22\pi/8 - 7\pi/2$	sec.	$-0.031029 \sin(8t/3 - 47\pi/6)$
$7\pi/2 - 5\pi$	sec.	0.00000
$5\pi - 6\pi$	sec.	$-0.008727 \sin(2t - 21\pi/2)$

Heave Position

$0 - \pi/2$	sec.	$0.1115 + 0.0035 \cos(2t) + (6.5/12) \cos(\theta)$
$\pi/2 - 3\pi/2$	sec.	$0.1165 + 0.0085 \sin(t - \pi) + (6.5/12) \cos(\theta)$
$3\pi/2 - 5\pi/2$	sec.	$0.1250 + 0.0020 \cos(60t/7 - 195\pi/14) + (6.5/12) \cos(\theta)$
$5\pi/2 - 7\pi/2$	sec.	$0.1250 + 0.0150 \sin(2t - 5\pi) + (6.5/12) \cos(\theta)$
$7\pi/2 - 9\pi/2$	sec.	$0.1250 + 0.0020 \sin(8t - 28\pi) + (6.5/12) \cos(\theta)$
$9\pi/2 - 5\pi$	sec.	$0.1250 + (6.5/12) \cos(\theta)$
$5\pi - 6\pi$	sec.	$0.1125 + 0.0125 \sin(t - 9\pi/2) + (6.5/12) \cos(\theta)$

TABLE VI
(con't.)

Heave Velocity

$0 - \pi/2$	sec.	$-0.0070 \sin(2t) + (6.5/12)(\sin\theta)\frac{d\theta}{dt}$
$\pi/2 - 3\pi/2$	sec.	$0.0085 \cos(t - \pi) + (6.5/12)(\sin\theta)\frac{d\theta}{dt}$
$3\pi/2 - 5\pi/2$	sec.	$0.0171 \cos(60t/7 - 195\pi/14) + (6.5/12)(\sin\theta)\frac{d\theta}{dt}$
$5\pi/2 - 7\pi/2$	sec.	$0.0300 \cos(2t - 5\pi) + (6.5/12)(\sin\theta)\frac{d\theta}{dt}$
$7\pi/2 - 9\pi/2$	sec.	$0.0160 \cos(8t - 28\pi) + (6.5/12)(\sin\theta)\frac{d\theta}{dt}$
$9\pi/2 - 5\pi$	sec.	$0.0000 + (6.5/12)(\sin\theta)\frac{d\theta}{dt}$
$5\pi - 6\pi$	sec.	$0.0125 \cos(t - 9\pi/2) + (6.5/12)(\sin\theta)\frac{d\theta}{dt}$

Heave Acceleration

$0 - \pi/2$	sec.	$-0.0140 \cos(2t) - 6.5/12\left(\cos\theta\left(\frac{d\theta}{dt}\right)^2 + \sin\theta\left(\frac{d^2\theta}{dt^2}\right)\right)$
$\pi/2 - 3\pi/2$	sec.	$-0.0085 \sin(t - \pi) - 6.5/12\left(\cos\theta\left(\frac{d\theta}{dt}\right)^2 + \sin\theta\left(\frac{d^2\theta}{dt^2}\right)\right)$
$3\pi/2 - 5\pi/2$	sec.	$-0.1469 \sin(60t/7 - 195\pi/14) - 6.5/12\left(\cos\theta\left(\frac{d\theta}{dt}\right)^2 + \sin\left(\frac{d^2}{dt^2}\right)\right)$
$5\pi/2 - 7\pi/2$	sec.	$-0.0600 \sin(2t - 5\pi) - 6.5/12\left(\cos\theta\left(\frac{d\theta}{dt}\right)^2 + \sin\theta\left(\frac{d^2\theta}{dt^2}\right)\right)$
$7\pi/2 - 9\pi/2$	sec.	$-0.1280 \sin(8t - 28\pi) - 6.5/12\left(\cos\theta\left(\frac{d\theta}{dt}\right)^2 + \sin\theta\left(\frac{d^2\theta}{dt^2}\right)\right)$
$9\pi/2 - 5\pi$	sec.	$0.0000 - 6.5/12\left(\cos\theta\left(\frac{d\theta}{dt}\right)^2 + \sin\theta\left(\frac{d^2\theta}{dt^2}\right)\right)$
$5\pi - 6\pi$	sec.	$-0.0125 \sin(t - 9\pi/2) - 6.5/12\left(\cos\theta\left(\frac{d\theta}{dt}\right)^2 + \sin\theta\left(\frac{d^2\theta}{dt^2}\right)\right)$

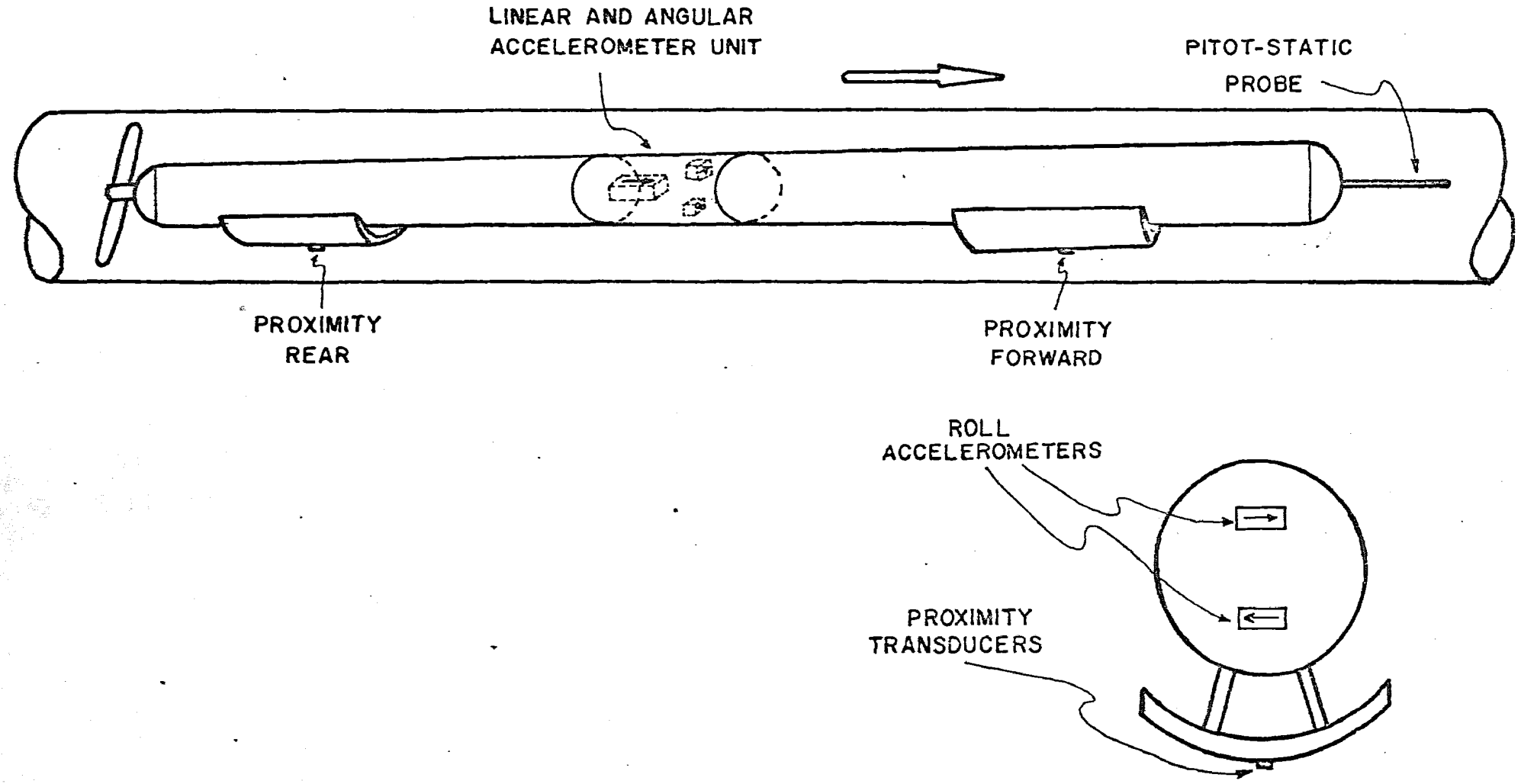

LINEAR AND ANGULAR
ACCELEROMETER UNIT
PITOT-STATIC
PROBE
PROXIMITY
REAR
PROXIMITY
FORWARD
ROLL
ACCELEROMETERS
PROXIMITY
TRANSDUCERS

FIG. 1

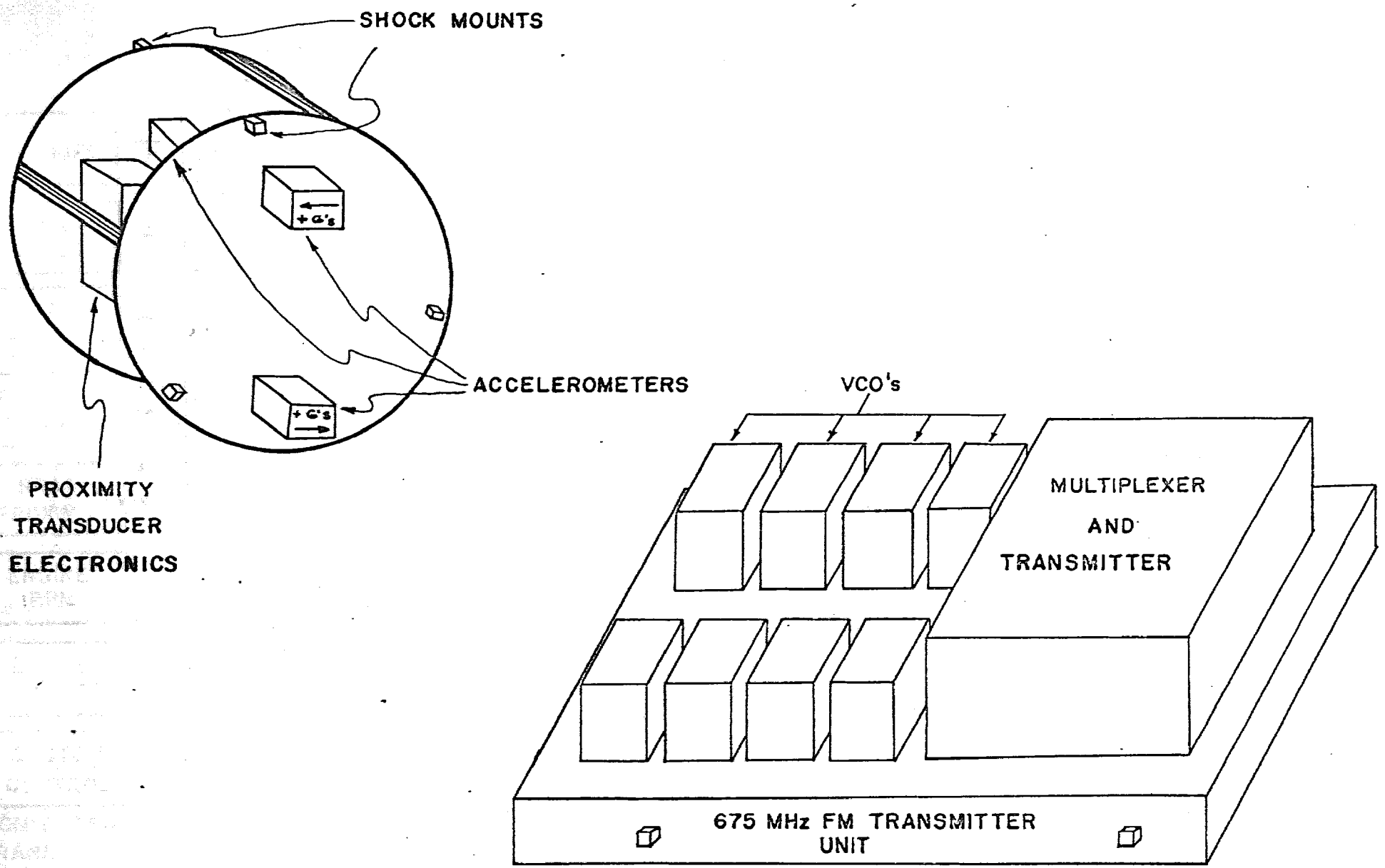

SHOCK MOUNTS
+G's
+G's
ACCELEROMETERS
PROXIMITY
TRANSDUCER
ELECTRONICS
VCO's
MULTIPLEXER
AND
TRANSMITTER
675 MHz FM TRANSMITTER
UNIT

FIG. 2

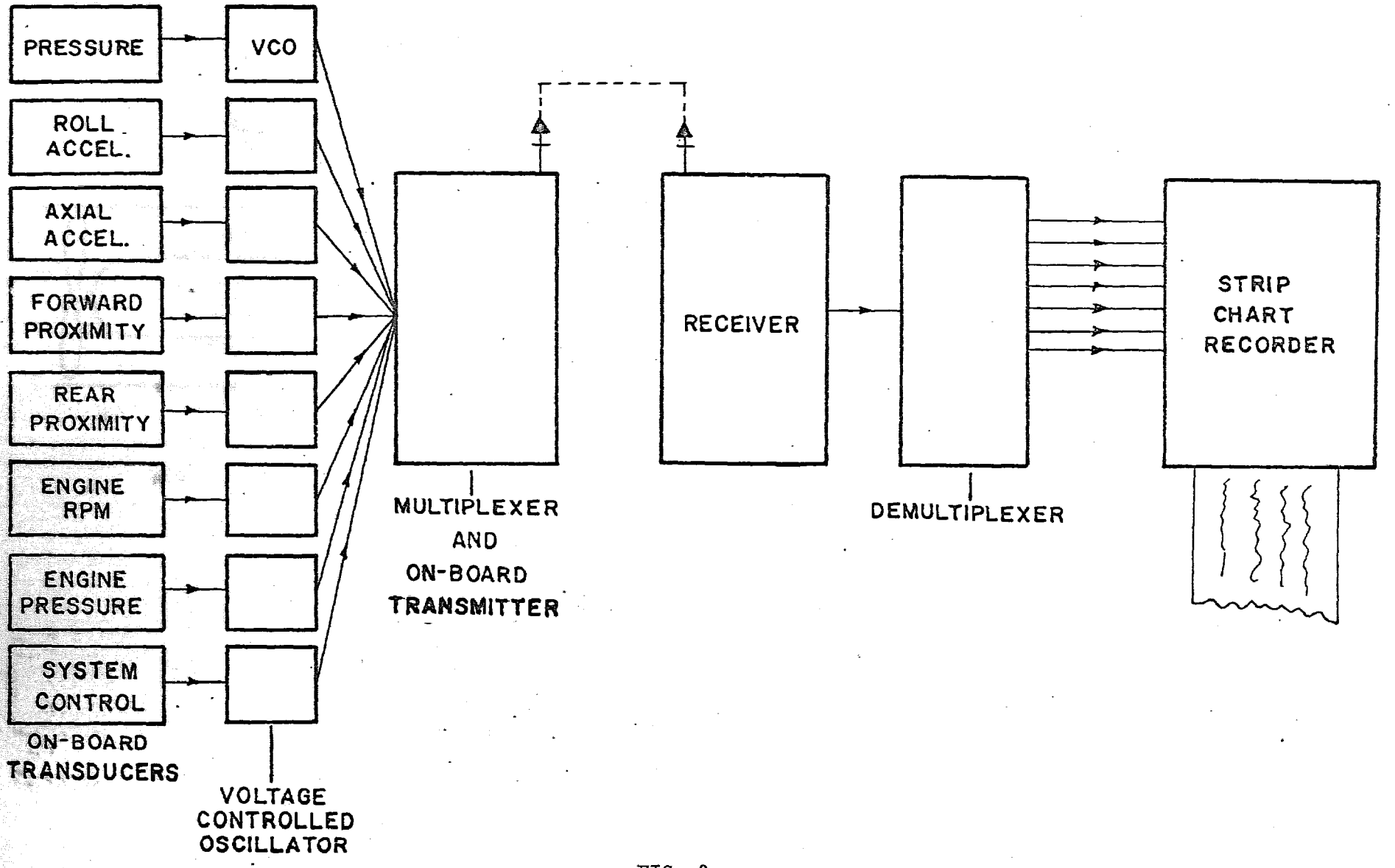

PRESSURE
VCO
ROLL ACCEL.
AXIAL ACCEL.
FORWARD PROXIMITY
REAR PROXIMITY
ENGINE RPM
ENGINE PRESSURE
SYSTEM CONTROL
ON-BOARD TRANSDUCERS
VOLTAGE CONTROLLED OSCILLATOR
MULTIPLEXER AND ON-BOARD TRANSMITTER
RECEIVER
DEMULTIPLEXER
STRIP CHART RECORDER

FIG. 3

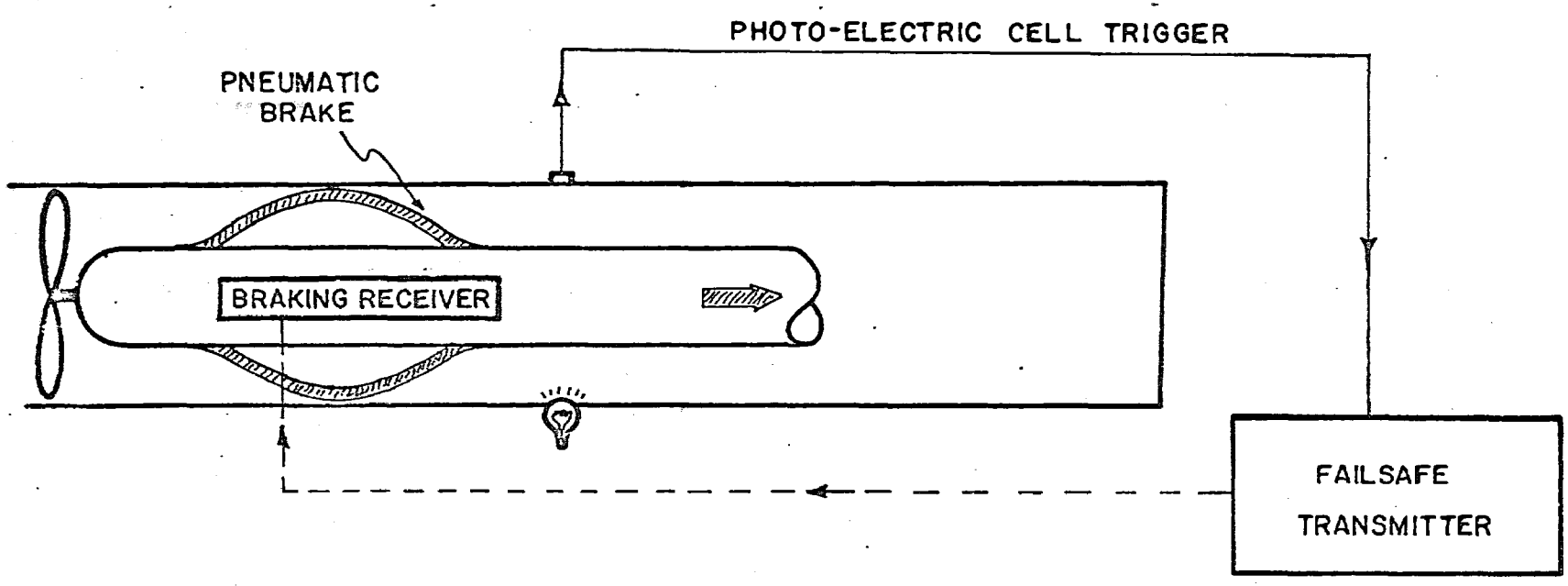
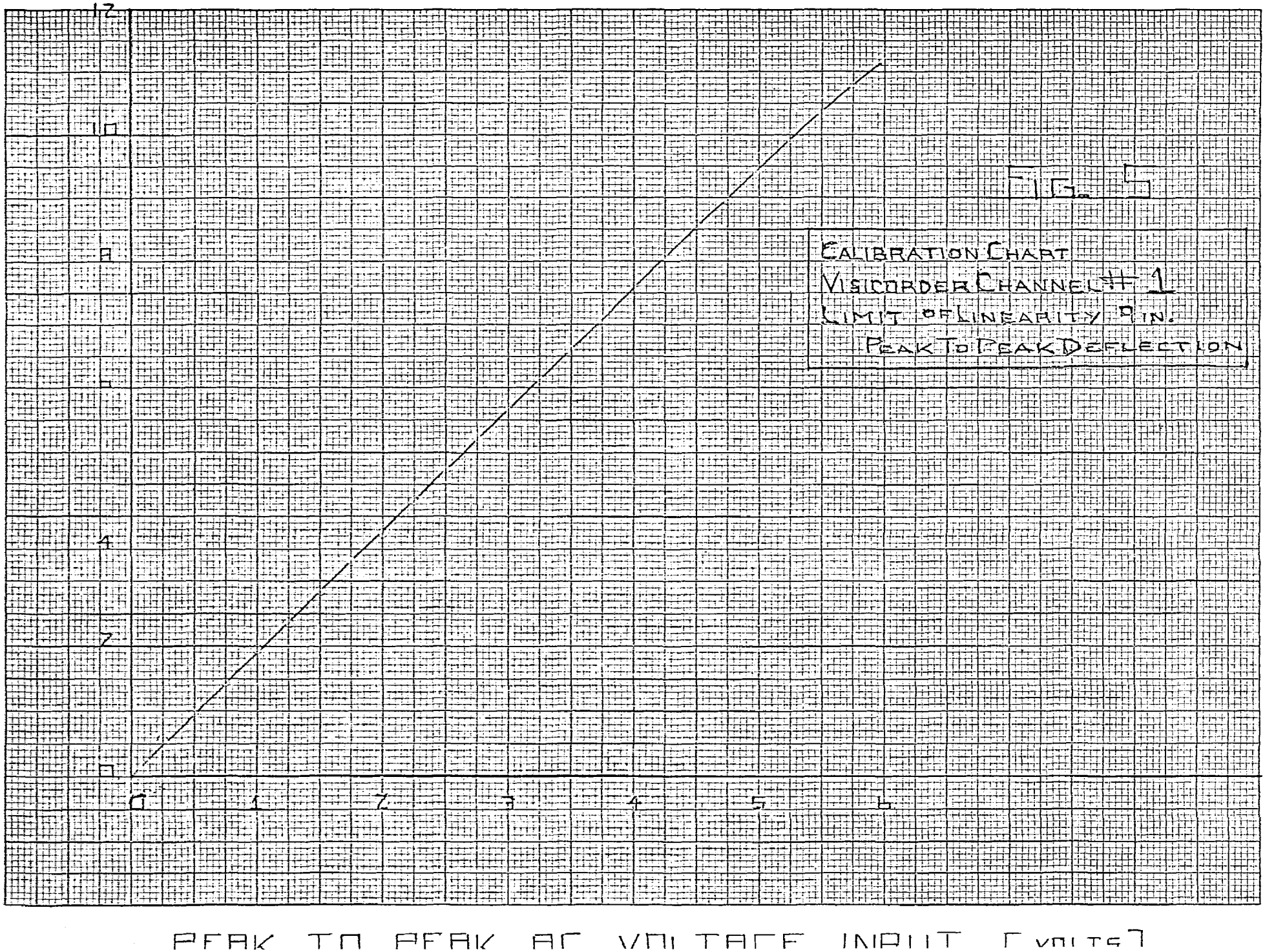


PHOTO-ELECTRIC CELL TRIGGER
PNEUMATIC BRAKE
BRAKING RECEIVER
FAILSAFE TRANSMITTER

FIG. 4

K+E 10 X 10 TO ½ INCH 46 1320
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.



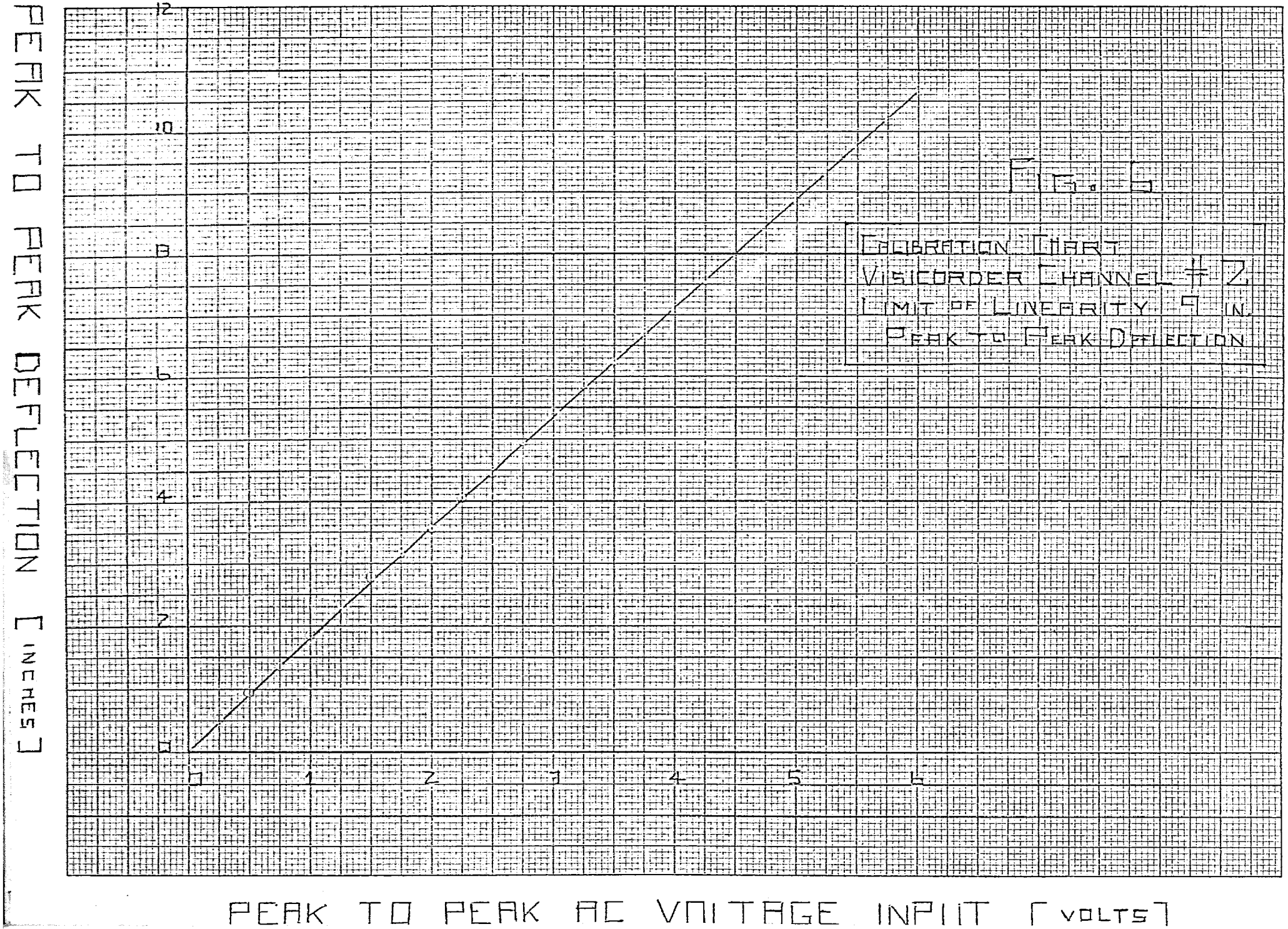
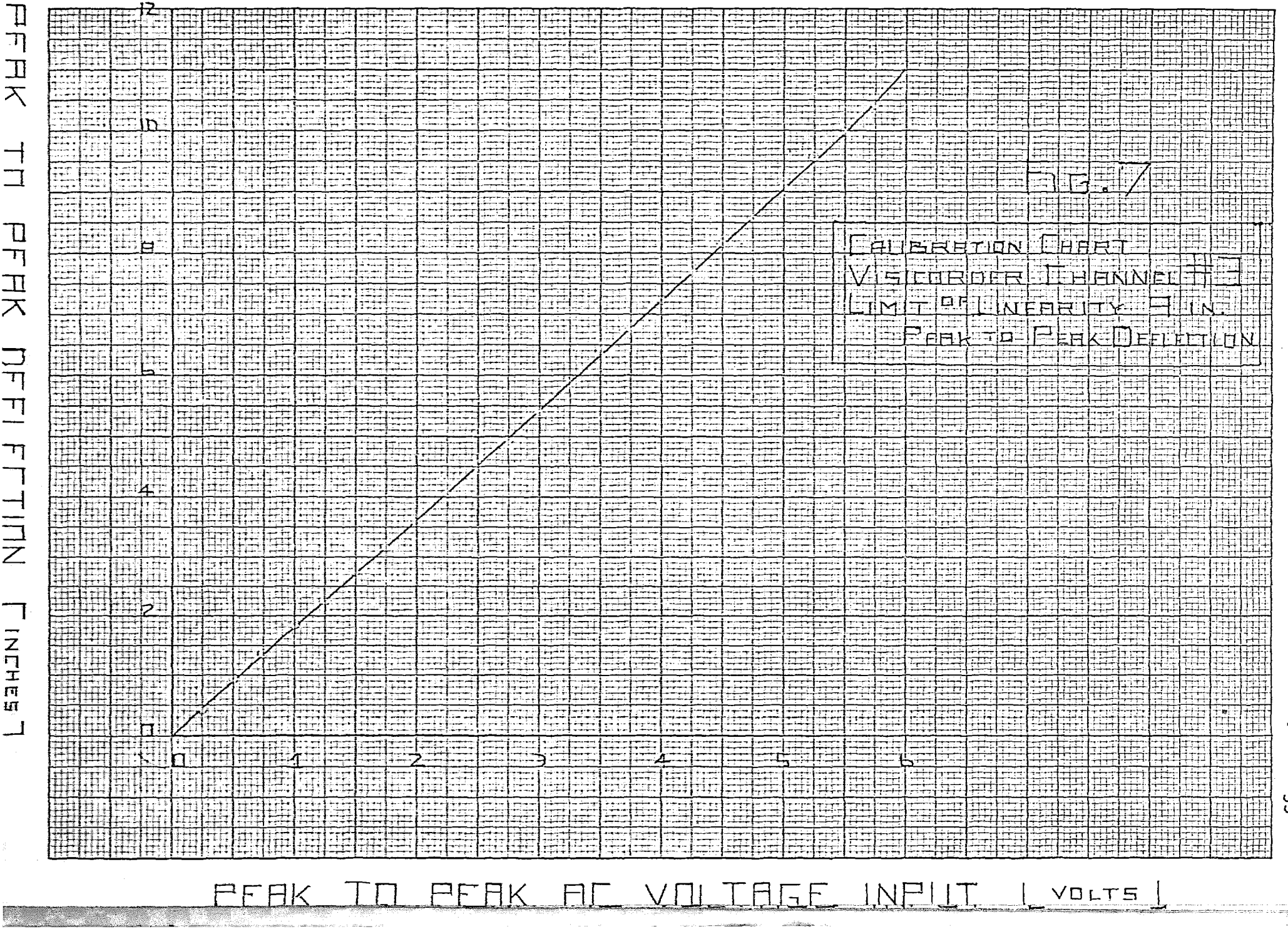
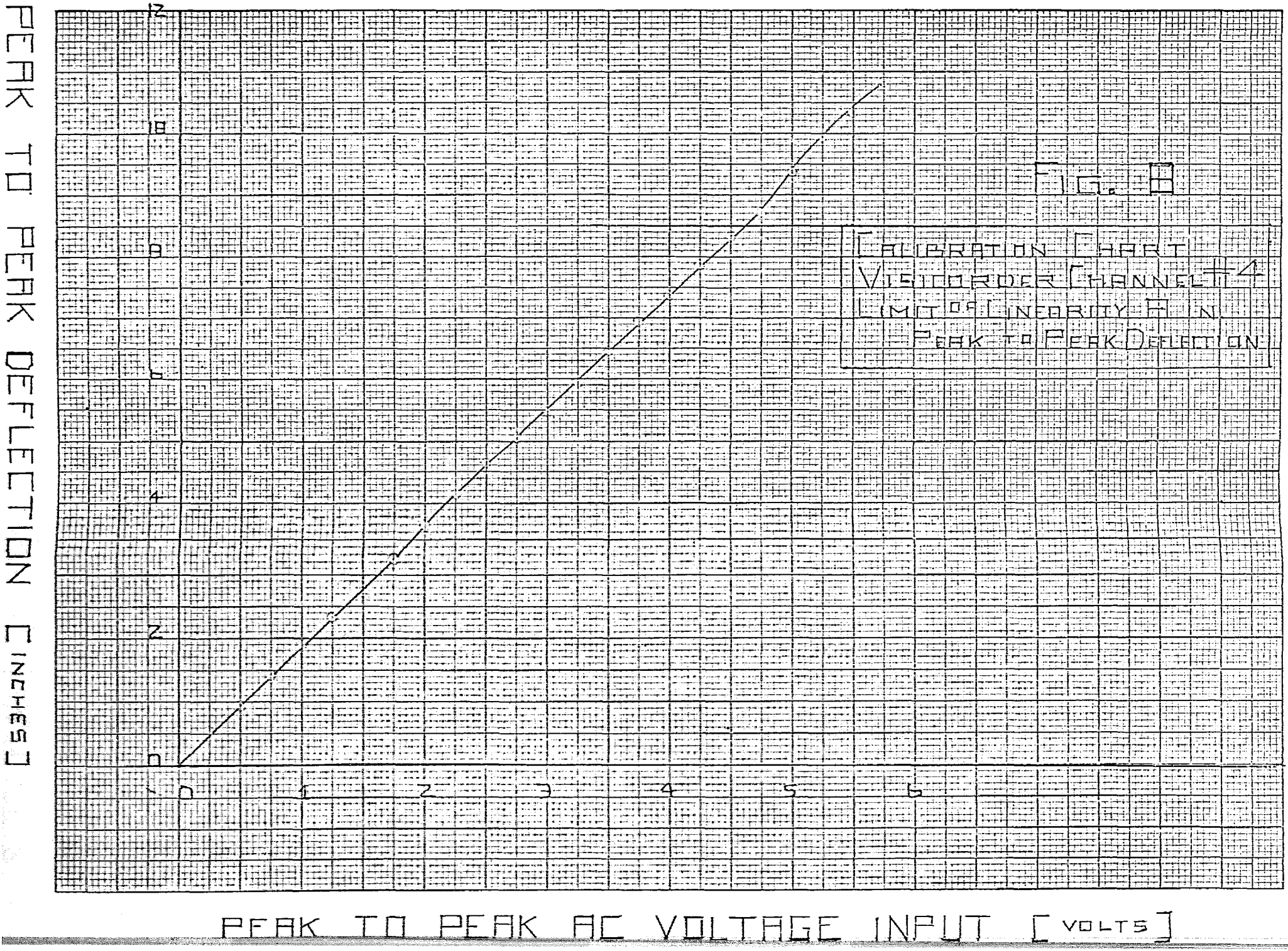


FIG. 5
CALIBRATION CHART
VISICORDER CHANNEL # 2
LIMIT OF LINEARITY 9 IN.
PEAK TO PEAK DEFLECTION
PEAK TO PEAK DEFLECTION [INCHES]
0
2
4
6
8
10
12
0
1
2
3
4
5
6
PEAK TO PEAK AC VOLTAGE INPUT [VOLTS]

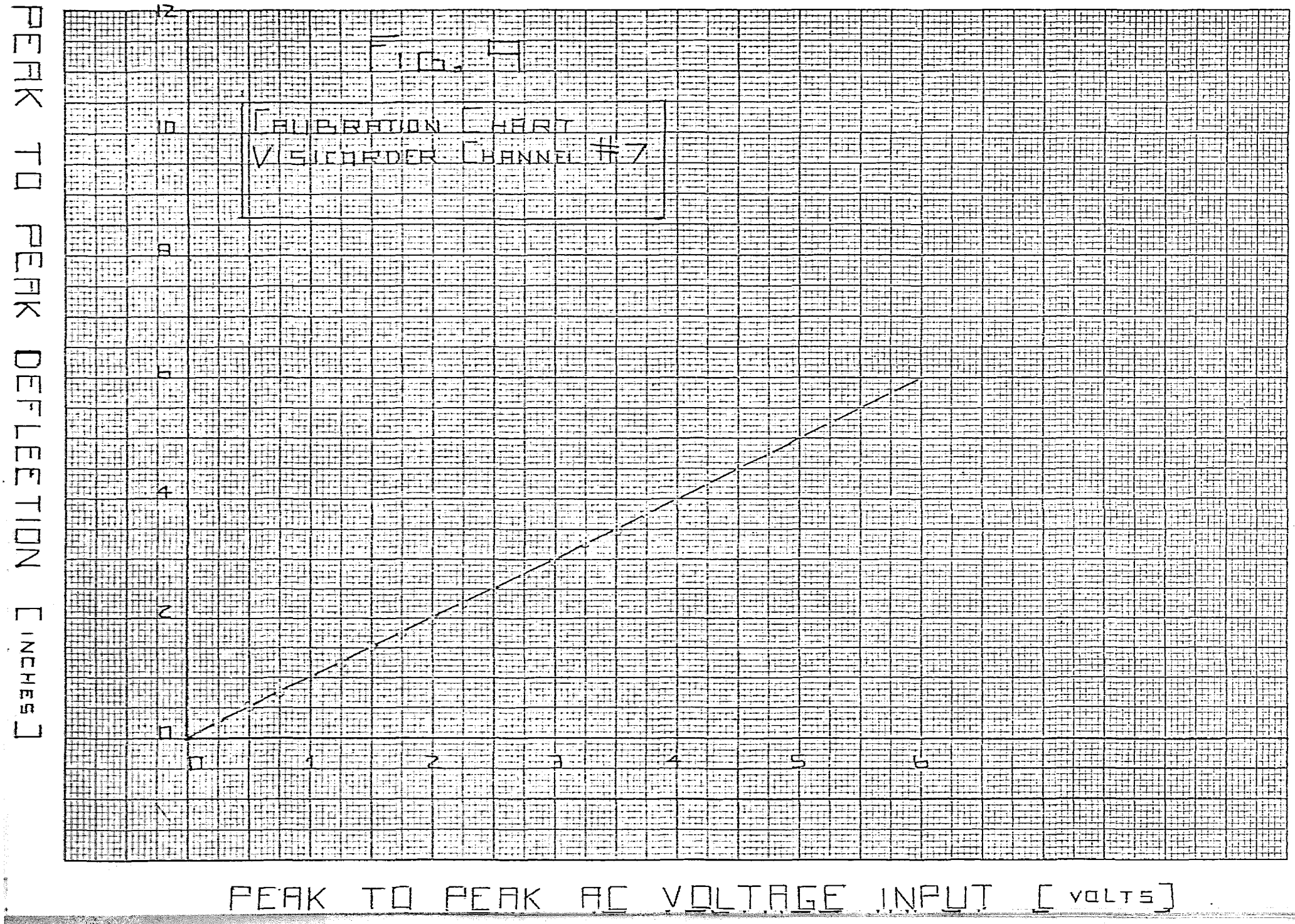
KEUFFEL & ESSER CO.



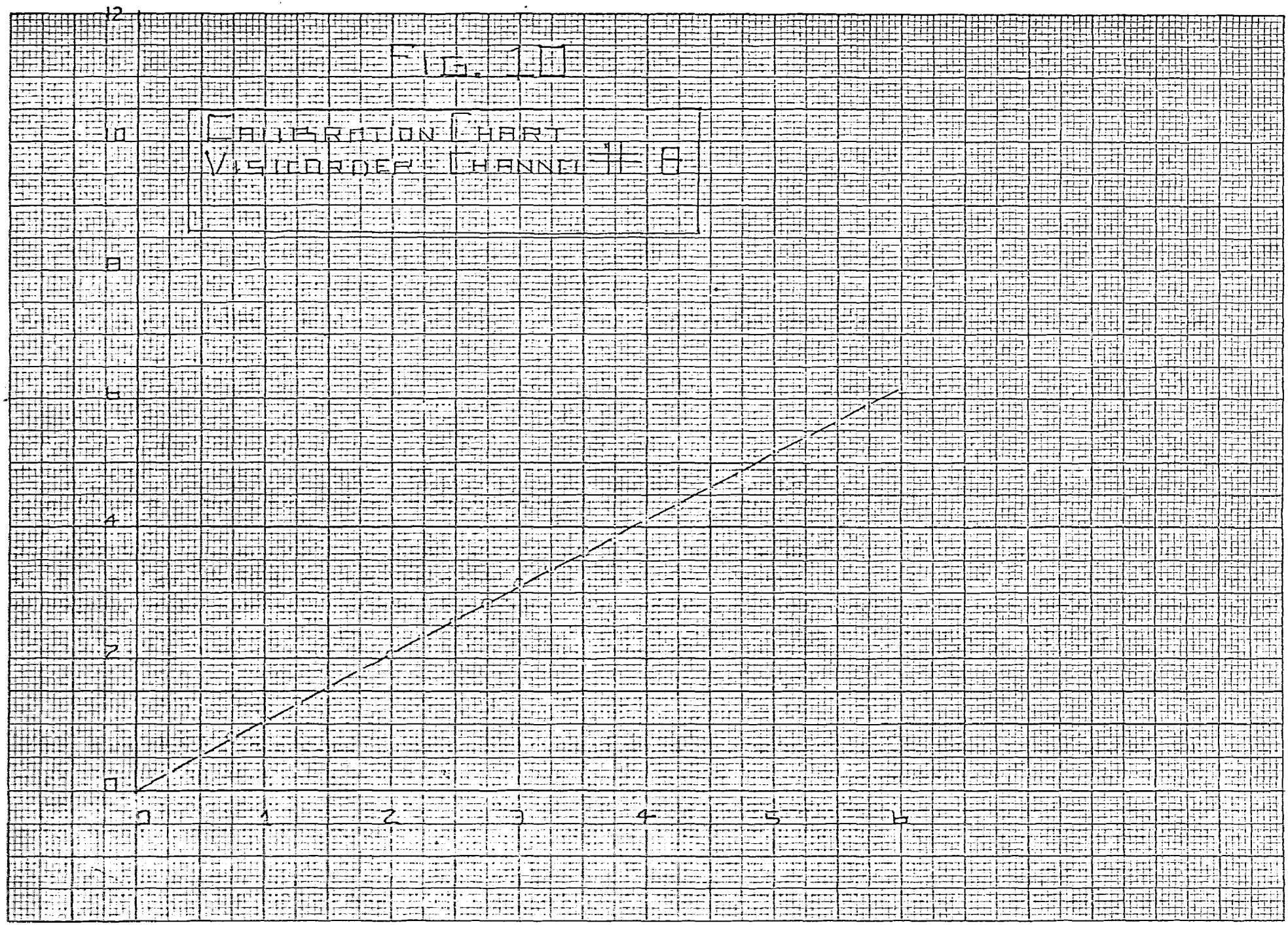
KEUFFEL & ESSER CO.



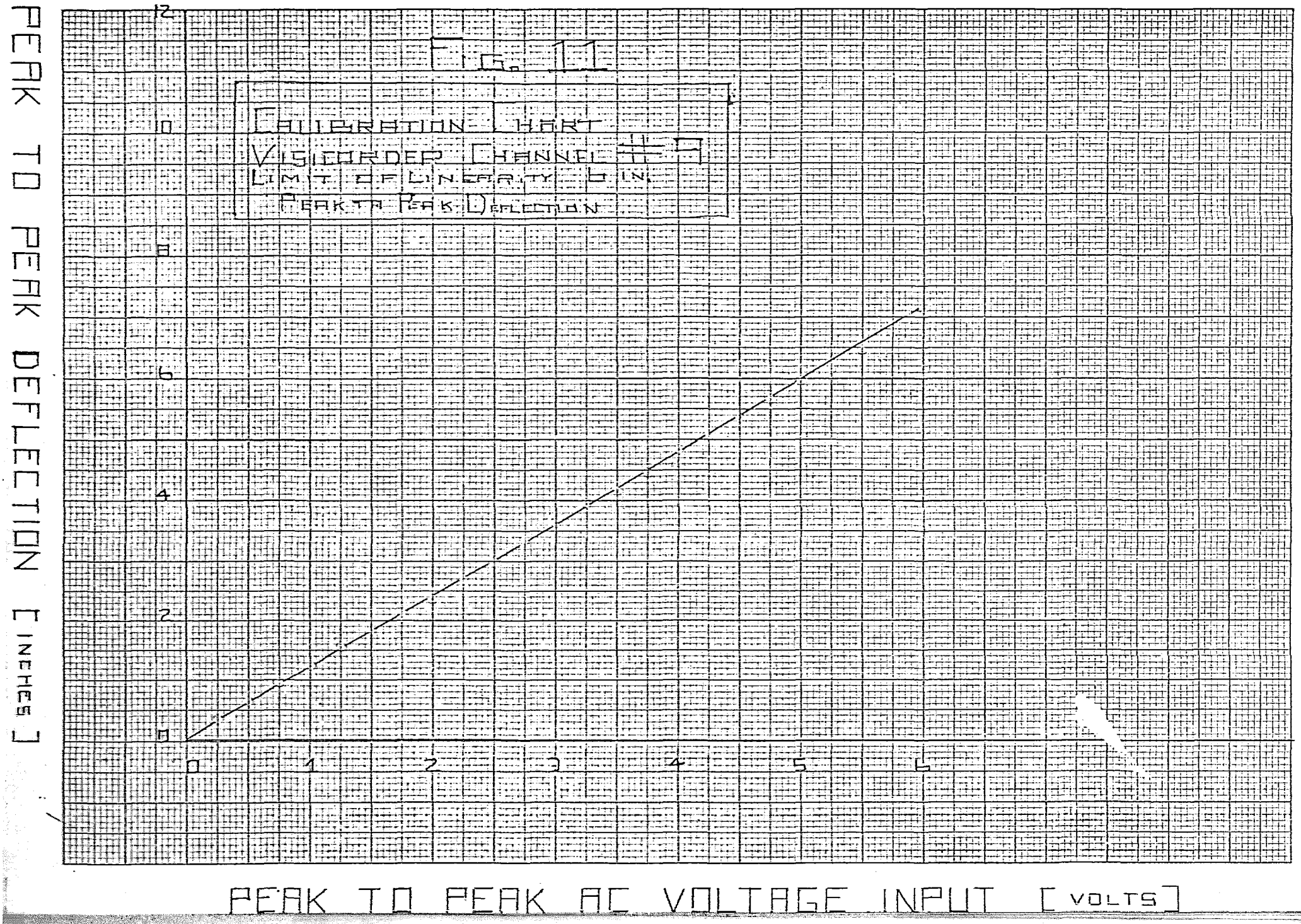
KEUFFEL & ESSER CO.

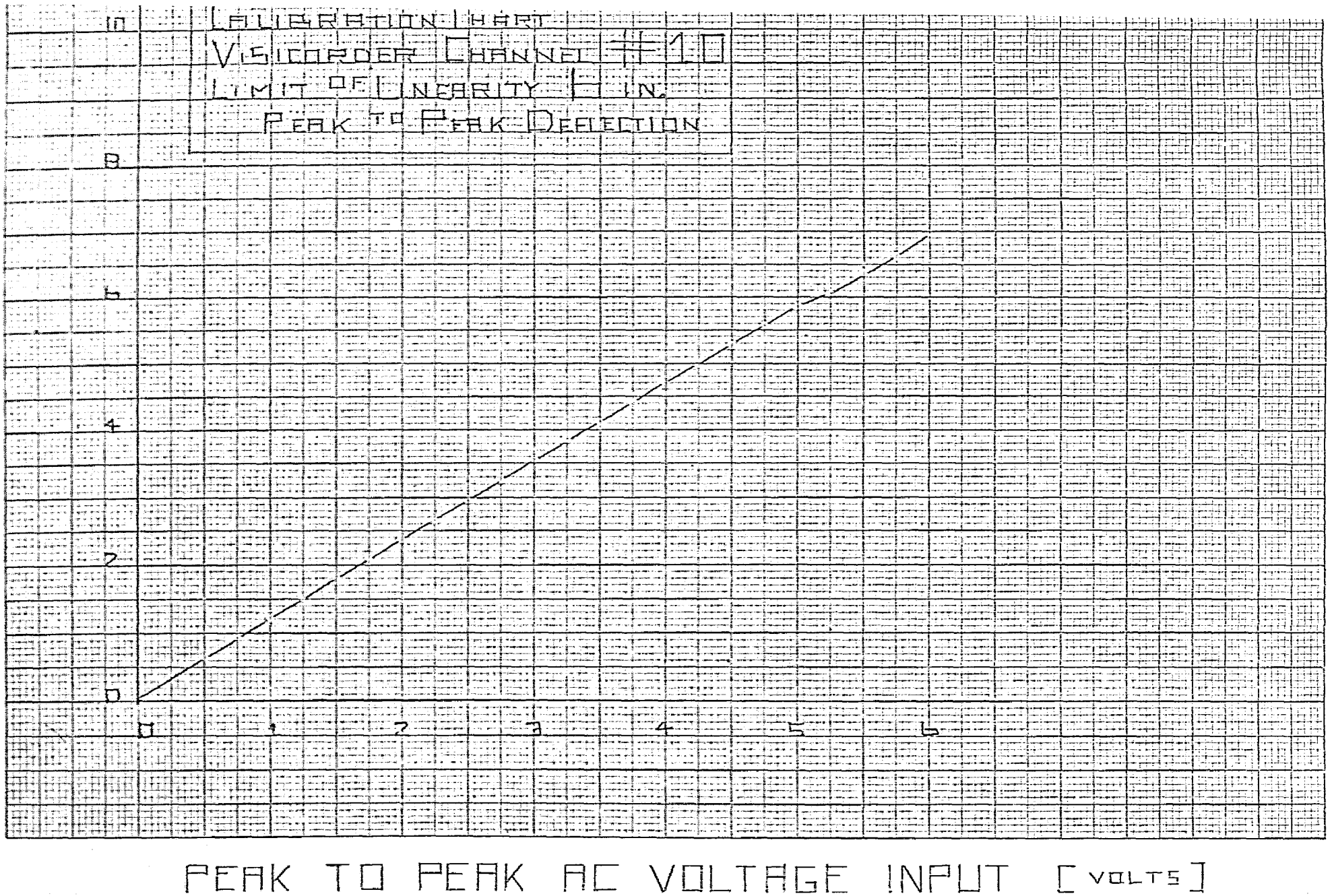


K+E 10 X 10 TO ½ INCH 46 1320
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.



KEUFFEL & ESSER CO.




CALIBRATION CHART
VISICORDER CHANNEL #10
LIMIT OF LINEARITY ± IN.
PEAK TO PEAK DEFLECTION
TO PEAK DEFLECTION [INCHES]
0
2
4
6
8
10
0
1
2
3
4
5
6
PEAK TO PEAK AC VOLTAGE INPUT [VOLTS]

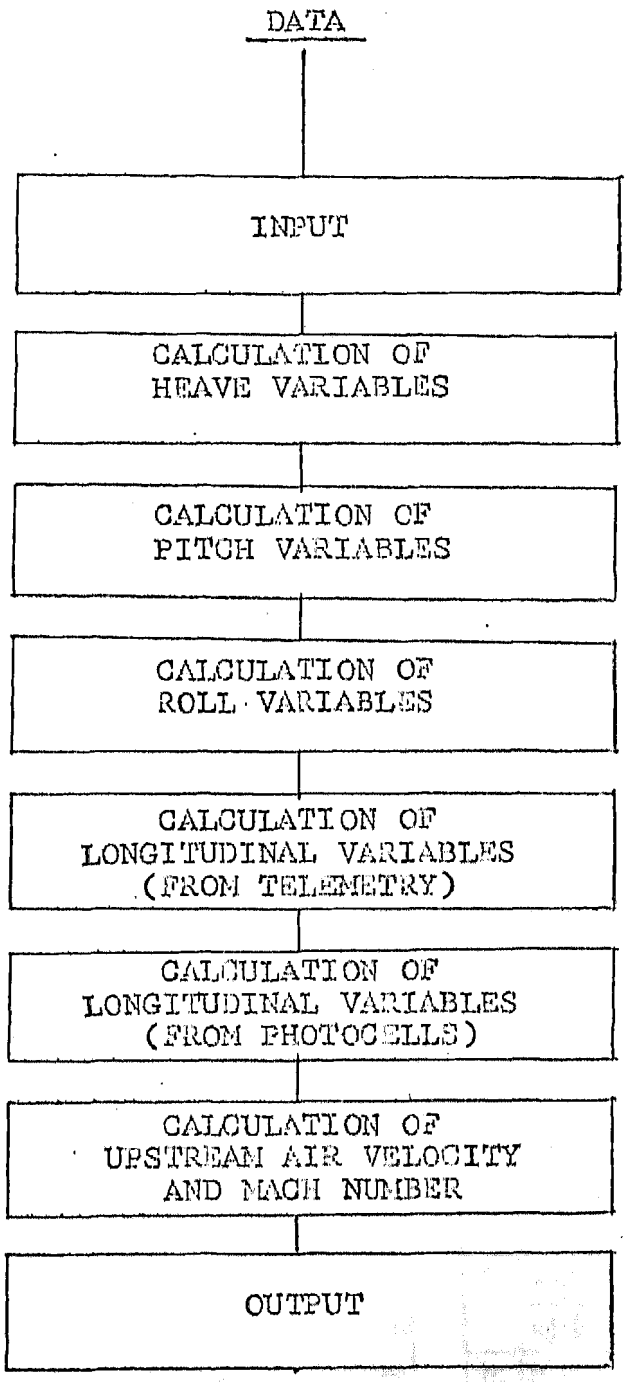

DATA
INPUT
CALCULATION OF HEAVE VARIABLES
CALCULATION OF PITCH VARIABLES
CALCULATION OF ROLL VARIABLES
CALCULATION OF LONGITUDINAL VARIABLES (FROM TELEMETRY)
CALCULATION OF LONGITUDINAL VARIABLES (FROM PHOTOCELLS)
CALCULATION OF UPSTREAM AIR VELOCITY AND MACH NUMBER
OUTPUT

FIG. 13

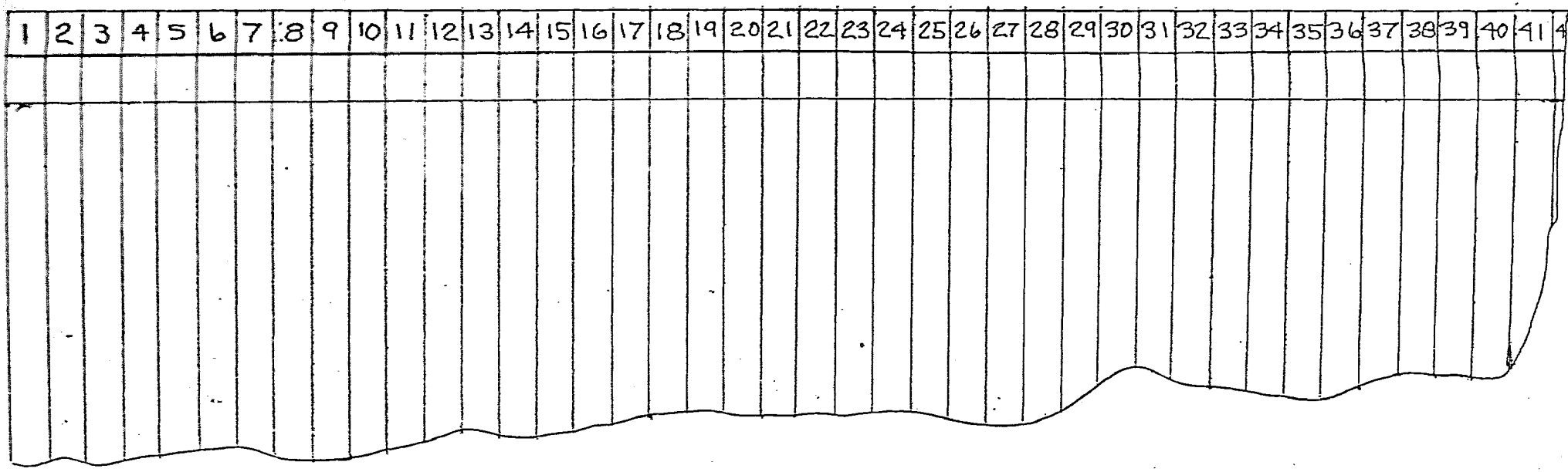


FIG. 14

EXAMPLE OF -0.0157241

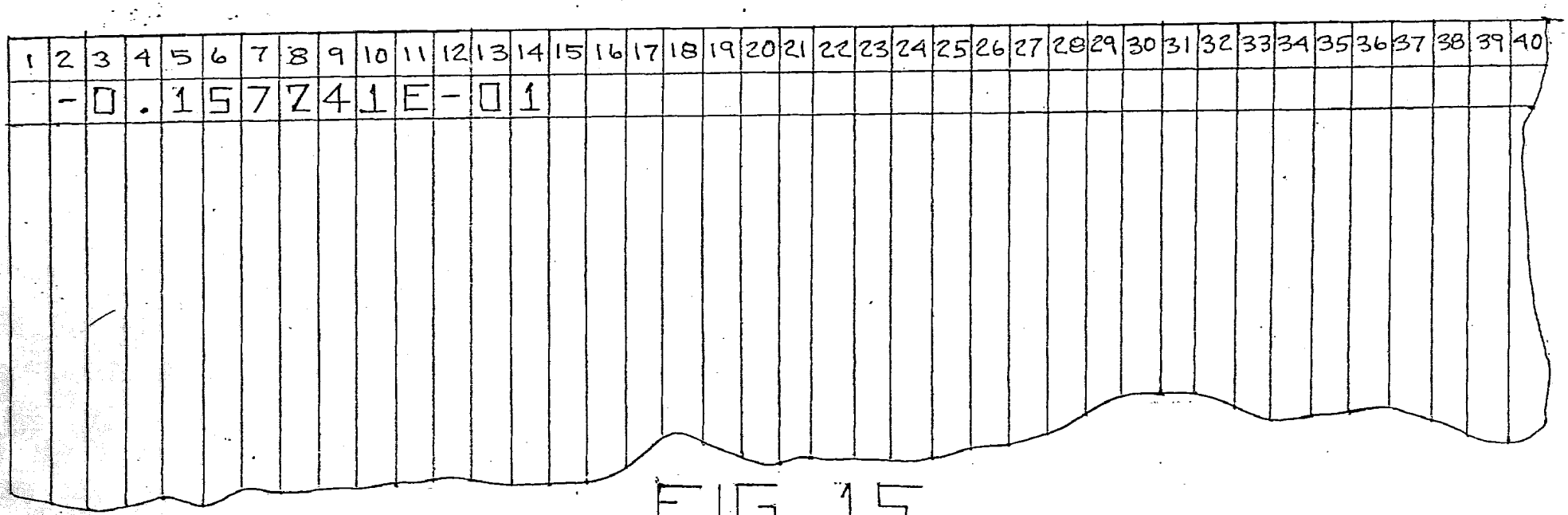


FIG. 15

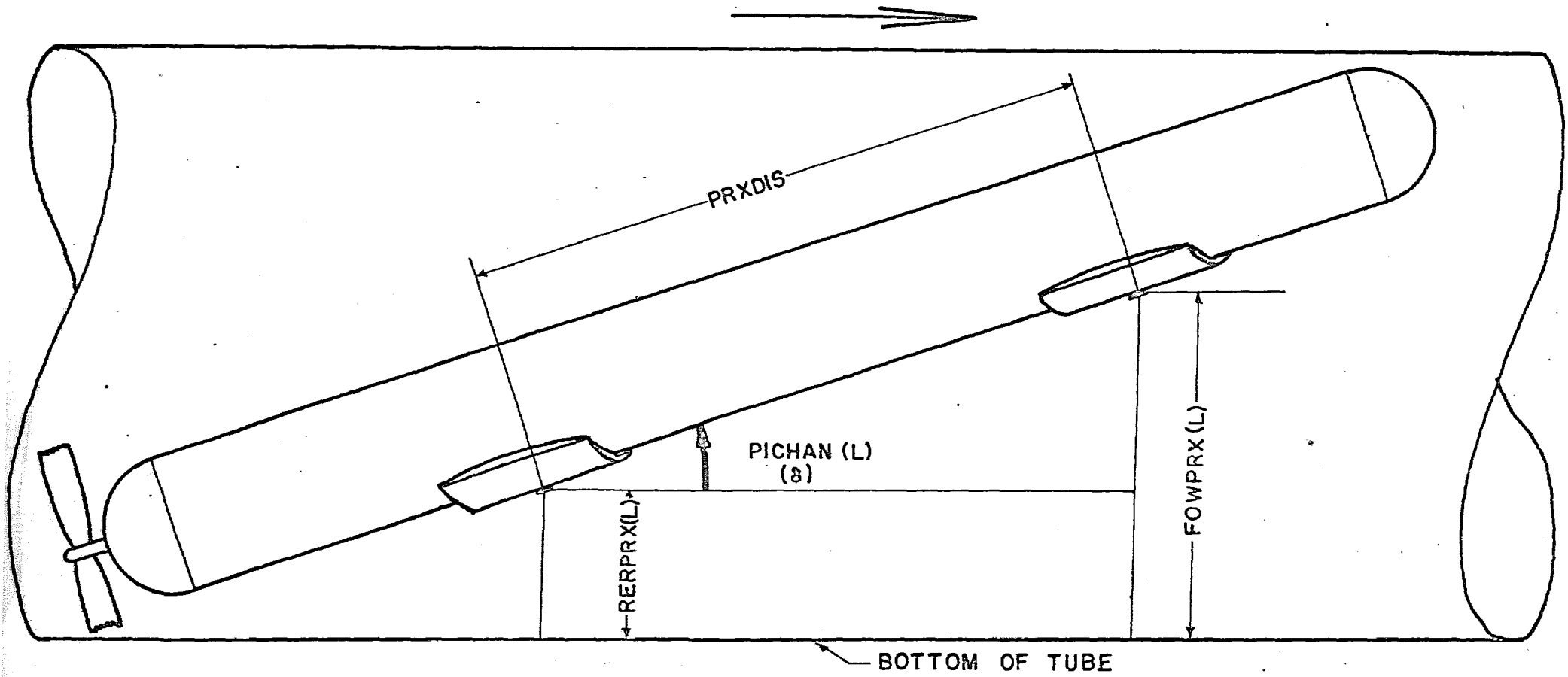


FIG. 16

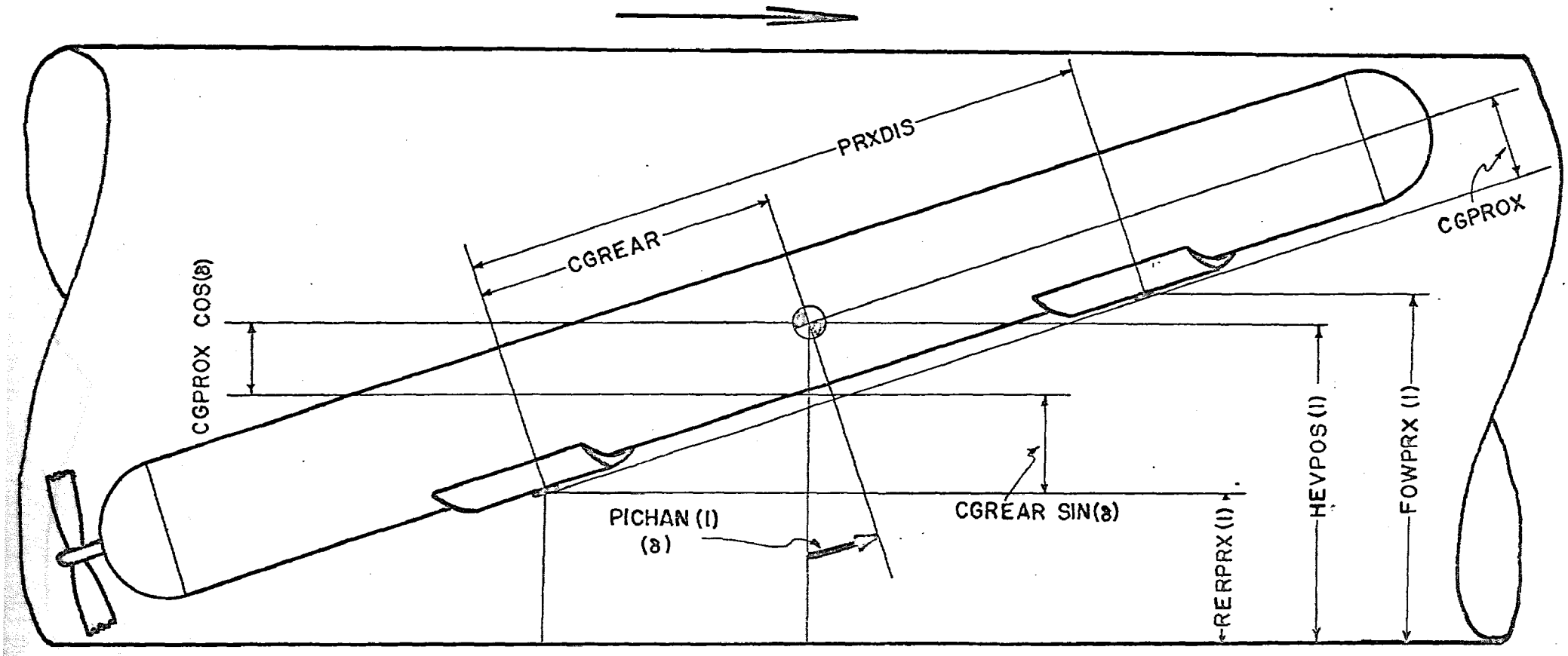

PRXDIS
CGREAR
CGPROX COS(δ)
CGPROX
PICHAN (I)
(δ)
CGREAR SIN(δ)
RERPRX (I)
HEVPOS (I)
FOWPRX (I)

FIG. 17

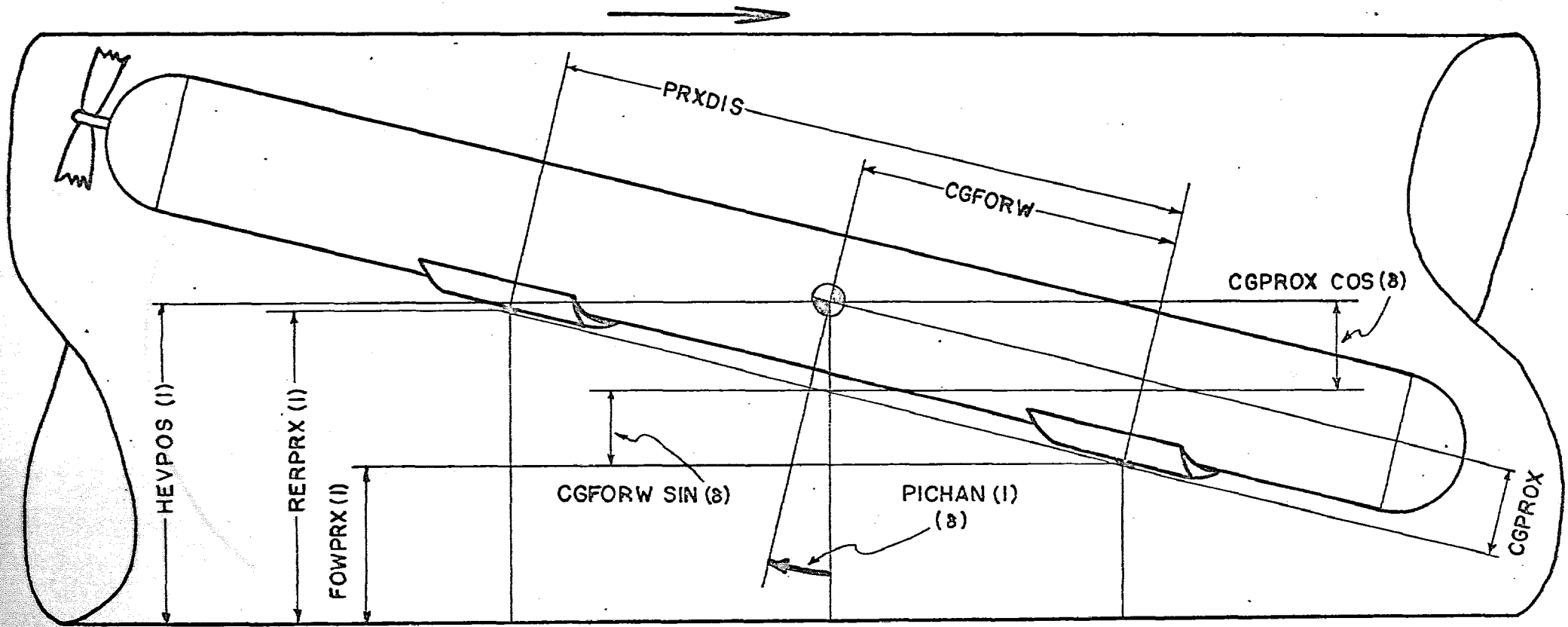

PRXDIS
CGFORW
CGPROX COS (8)
CGPROX
PICHAN (I)
(8)
CGFORW SIN (8)
HEVPOS (I)
RERPRX (I)
FOWPRX (I)

FIG. 18

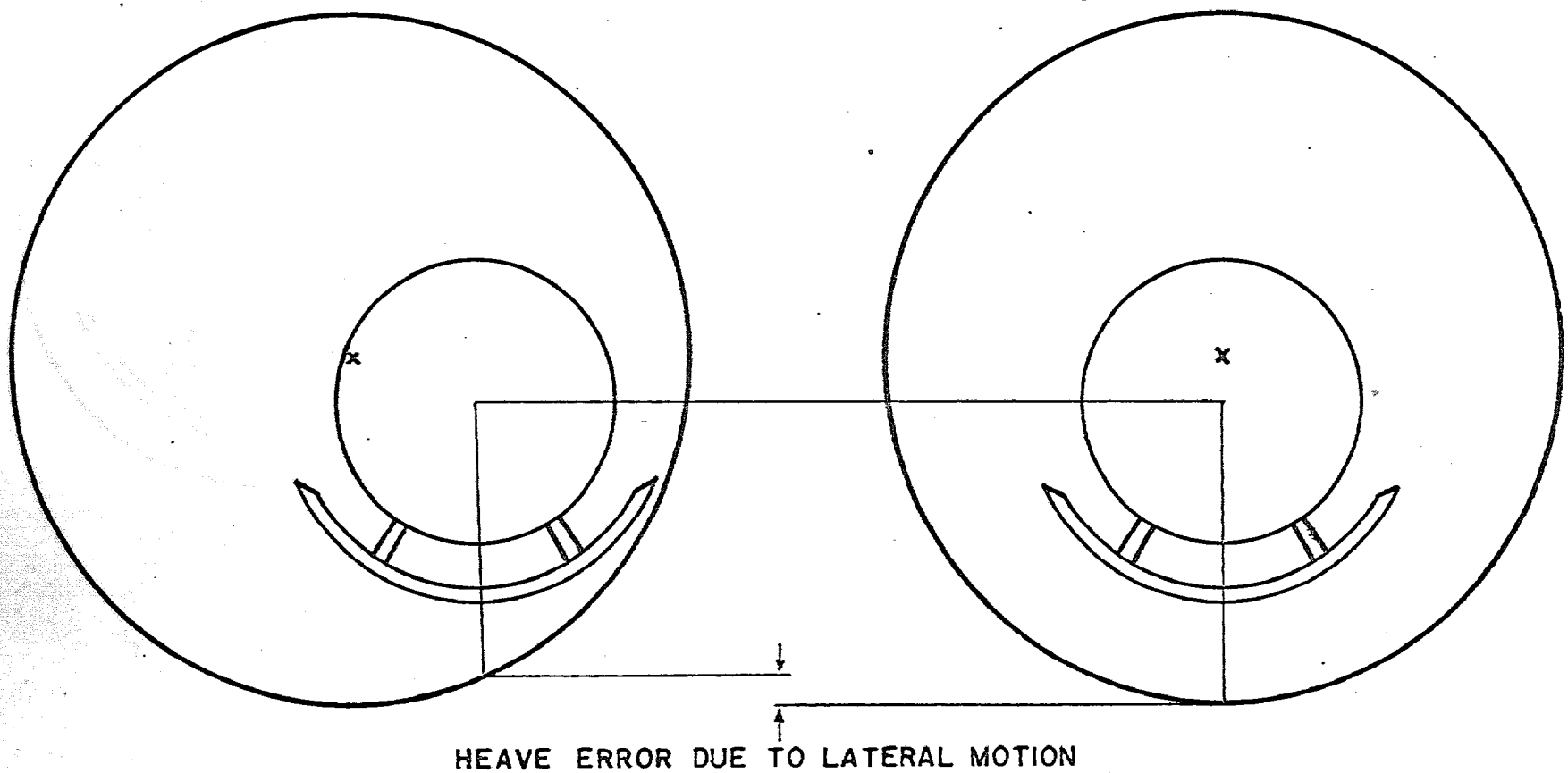


FIG. 19

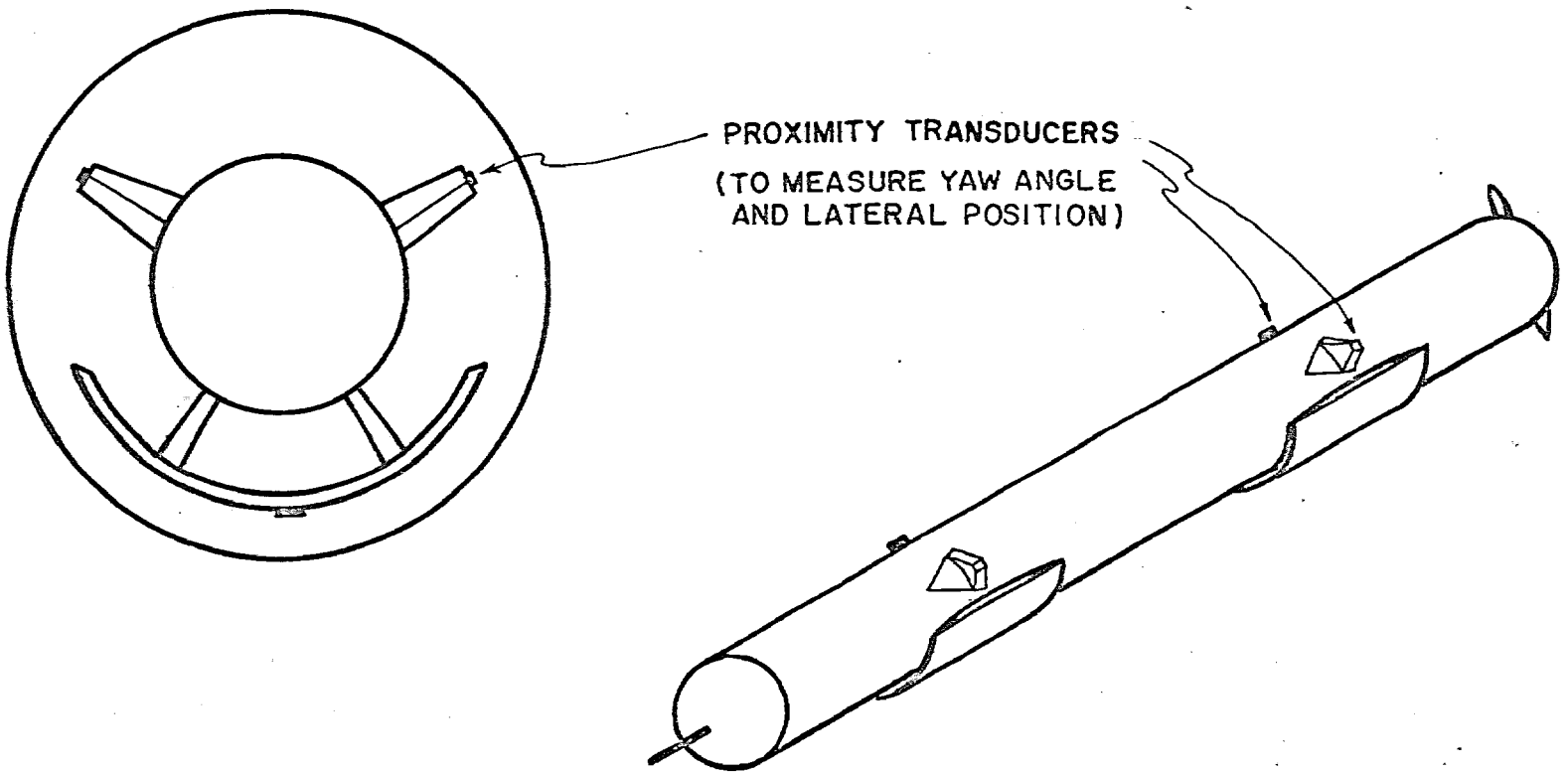

PROXIMITY TRANSDUCERS
(TO MEASURE YAW ANGLE
AND LATERAL POSITION)

FIG. 20

10 January 1969

EIGHT CHANNEL TELEMETRY SYSTEM

WITH

FAILSAFE SYSTEM
(Transmitter and Receiver)

(Engineering Model)

APPENDIX A

ELTECH LABORATORIES, INC.
25 MARCUS BOULEVARD
SMITHTOWN, NEW YORK 11787

This report describes the operational procedures of an eight-channel telemetry system developed for monitoring the in-flight characteristics of vehicles developed under Project Tubeflight.

This report consists of three parts, which are,

a) operational instructions for the telemetry receiver, the vehicle on-board transmitter, and a failsafe transmitter and vehicle on-board receiver;

b) block and circuit diagrams for all transmitters and receivers; and

c) a system linearly study of all eight on-board telemtry channels.

OPERATING INSTRUCTIONS

A. TELEMETRY RECEIVER

The receiver has been pre-tuned for optimum operation with the vehicle transmitter and voltage controlled oscillators (VCO's). No further receiver adjustments should be necessary.

OPERATION:

1) Turn on 115v ac switch. This will activate the FM tuner. Allow five minute warm-up before proceeding further.

2) The 28v dc supply should only be turned on immediately prior to testing or to an actual vehicle run. Without an input signal at 675 MHz, the receiver will pass, random, front end noise to the channel output circuits. While this is in no way harmful to the receiver, the random fluctuations can be damaging to a recorder pen drive.

3) With proper transmitter signal present at the R.F. input, the receiver panel meters or any external dc voltage indicating device will show vehicle sensor status.

4) Check receiver output with various levels of sensor output. See calibration curves for comparison.

The following is a guide for interpreting various receiver output conditions.

1) Random fluctuations on panel meters.

Possible Cause:

a) No R.F. carrier at receiver input.

b) Receiver not tuned to R.F. carrier. (Only slight adjustment of second L.O. frequency would be necessary if this were the cause).

c) Second L.O. not operating. Check output level of L.O. with a power meter. Normal output is approximately 80mw (10mw to 100mw is required for the mixer).

d) Tuner front end not operating - check this out with any available signal in the FM broadcast band (88 to 108 MHz). Apply this directly to the tuner input, bypassing the first mixer.

e) First mixer defective - bench check with an L.O. input of 587 MHz (+10dbm to +20dbm) and an R.F. input of 675 MHz (-20dbm to -90dbm). Use FM tuner to detect the difference frequency of 88 MHz.

2) No discernable meter deflection (0 reading)

Possible Cause:

a) If all VCO's have a zero dc input this would be a normal meter reading.

b) Check for 28 vdc at the filter discriminator deck (bottom shelf).

c) It should be pointed out that the panel meters are in <u>series</u> with the output load (see fig. <u>5</u>). When output plugs are not inserted in the panel jacks, the load is an internal 560Ω resistor. When the

output plugs are in place, then the internal resistor is automatically disconnected and the external load is substituted. Current readings in this case, as in the case with the internal load, will be wholly dependent on the ohmic value of the load.

Knowing the value of the load resistance in ohms, current through the panel meter is simply:

$$I \text{ (ma)} = \frac{E \text{ out (V)}}{R \text{ (K ohms)}}$$

Naturally, for high impedance devices such as oscilloscopes, the panel meters will be indicating 0 current flow. This will not affect the accuracy of the voltage readings.

B. TELEMETRY RECEIVER

FRONT PANEL CONTROLS

1) Composite 8 channel amplitude - This is the FM tuner volume control. Do not alter this setting. Too much signal out of the tuner will saturate the 8 channel pre-amplifier causing intolerable channel intermodulation (cross talk).

2) Second L.O. frequency - This is the frequency control on the FM tuner. It should not, ordinarily, have to be adjusted.

3) Bias potentiometers (adjacent to panel meters) - These control the amount of bias voltage necessary to convert the normally minus - plus output from the discriminator to zero - plus only. DO NOT ALTER SETTINGS.

C. TELEMETRY TRANSMITTER

Before operating the transmitter for external test or for transmission in the tube, be sure the output is connected to the vehicle probes (see fig. 8) or to some other, adequate dummy load (50Ω termination, power meter etc...). Normal output power to the 180 degree hybrid is approximately 15 mw.

For testing with the receiver prior to a vehicle run, connect a variable attenuater (0 to 70 db) between the receiver input and the transmitter.

All testing can now be made as outlined in receiver operating instructions.

If the transmitter does not operate (no power output) and 28 vdc is getting to the transmitter (no power line break) rotate the oscillator stability slug (so marked on transmitter) counter clockwise two or three turns and then back in until output power is noted.

This type of starting problem can occur if ambient temp. is below 50°F or higher than 100°F.

It is only a starting problem and will not occur again during a normal operating period.

D. FAILSAFE TRANSMITTER AND RECEIVER

TRANSMITTER:

1) Set up with external power supply output connected to the input power jack on the rear of the failsafe cabinet. Use the cable supplied.

2) Set output voltage control on the B+ power supply to minimum.

3) Connect RF output to guideway probe or to adequate equivalent load (50 ohm termination, power meter etc. ..) Output power is normally 900mw average (1.8w peak).

4) Turn on +28vdc supply (front panel switch on failsafe cabinet). Allow 30 second warm up before proceeding further.

5) Turn on B+ power supply. Increase voltage output to +225vdc. Use meter to set voltage since the graduations on voltage control are not accurate.

6) Transmitter driver will now be operating into the 50 ohm, 10w load. (See fig. 9).

7) To activate transmission on the failsafe signal, provide a short circuit at the 'BNC' panel jack on left side of cabinet (photo cell input). This will switch the transmitter driver output from the dummy load to the final tripler. The tripler is a passive device and will provide, virtual, instantaneous transmission with input from driver.

FAILSAFE RECEIVER:

Before vehicle run, check reception of the failsafe signal at the failsafe receiver (on the vehicle). Observe 10kHz tone at the input to the braking amplifier.

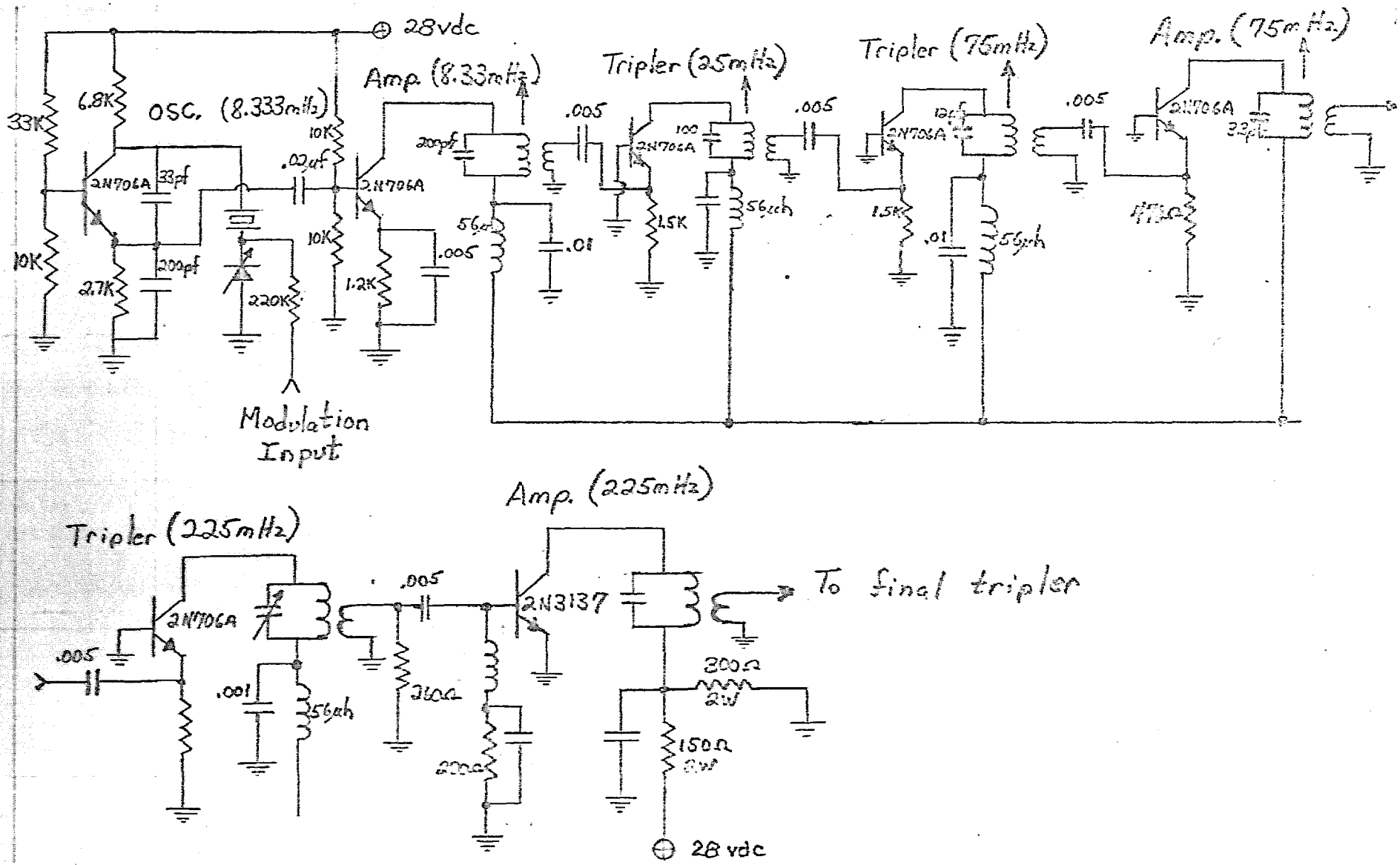
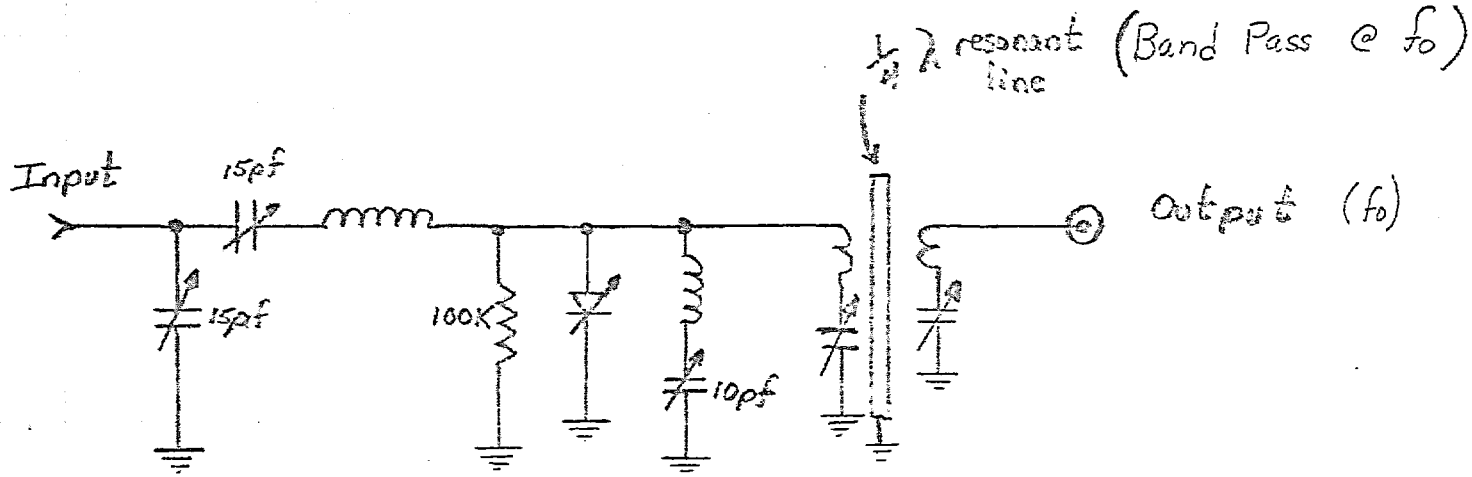


Fig. 1. Telemetry Transmitter



1) Telemetry Transmitter (f_o = 675 mHz)
2) Failsafe Xmtr. (f_o = 704.8 mHz)
3) Local Oscillator (f_o = 586.98 mHz)

Fig. 2. Final Tripler for Varactor Tripler

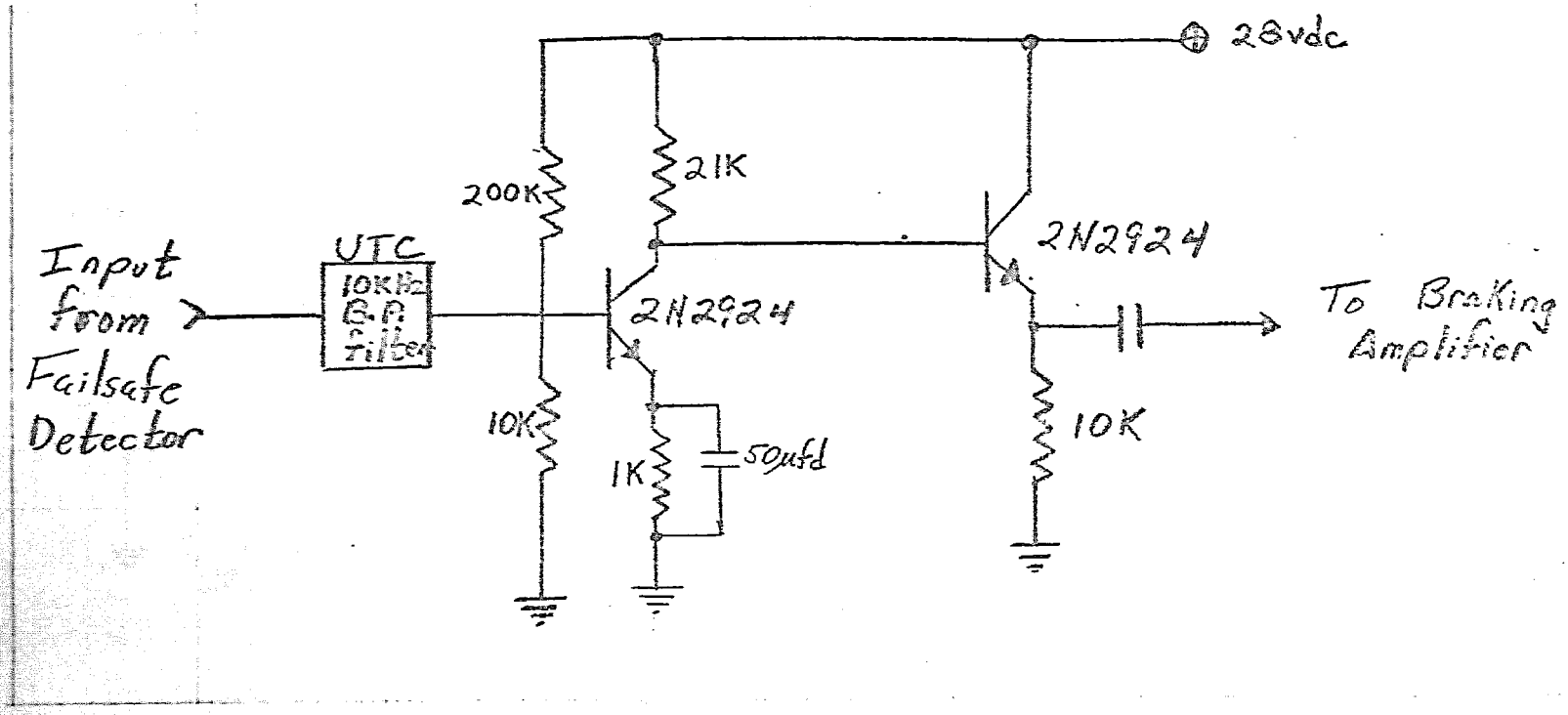


Fig. 3. Vehicle 10 KHz Band Pass Filter and Amplifier

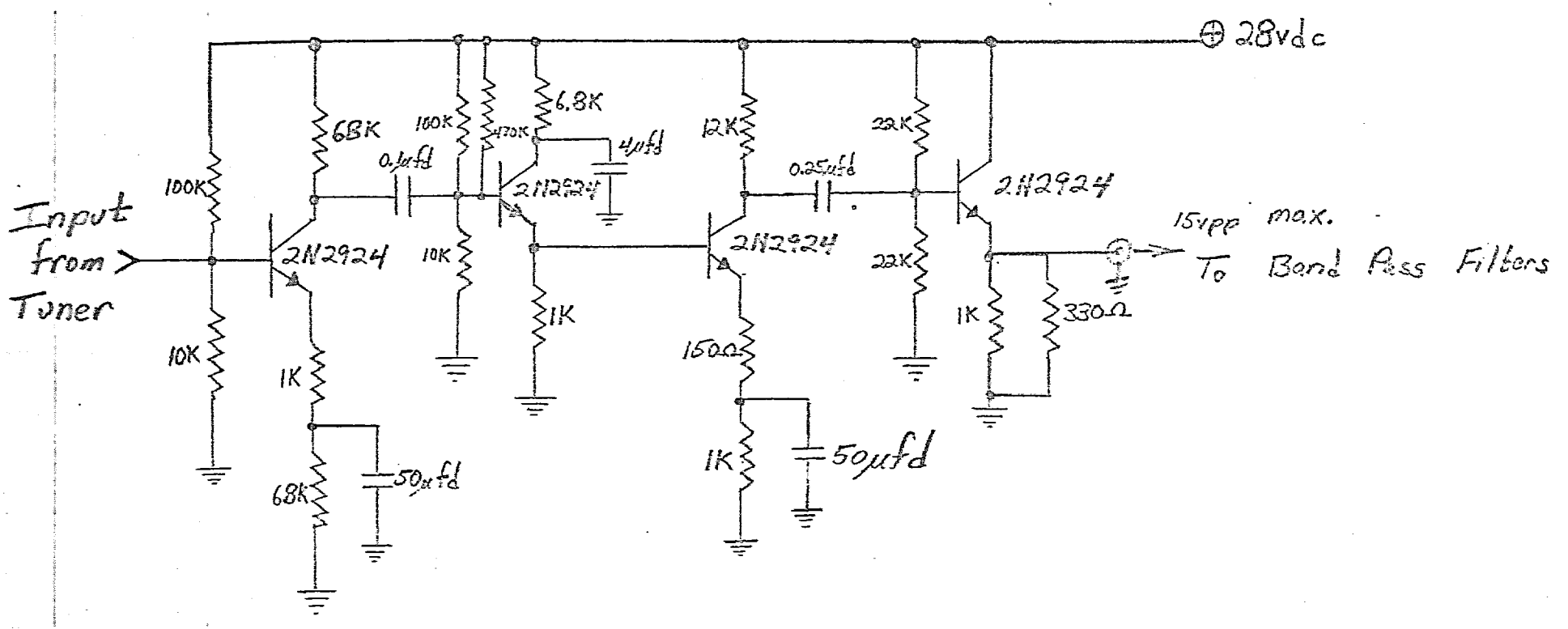


Fig. 4. Receiver: Eight Channel Pre-Amp

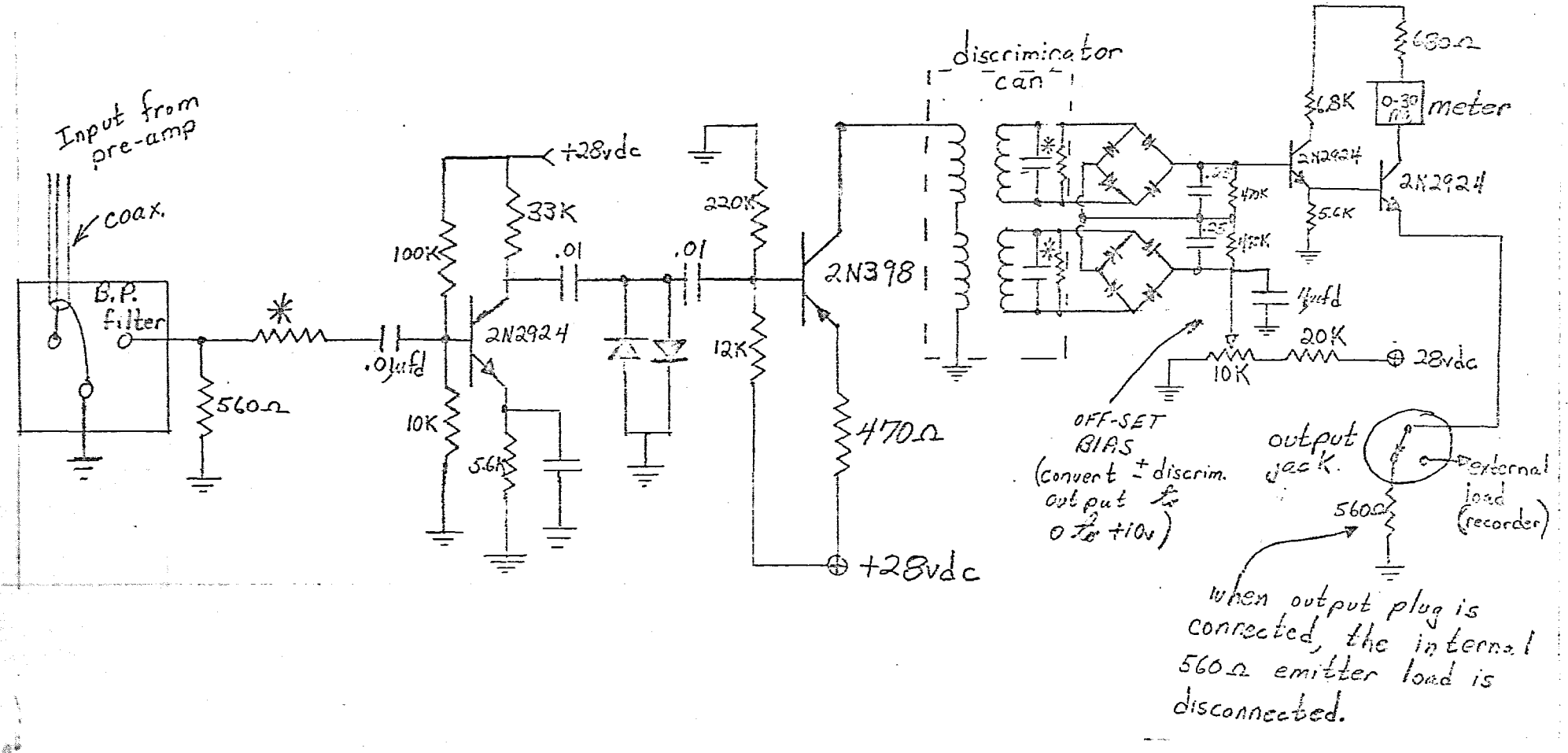


Fig. 5. Receiver: Channel Separation and Detection

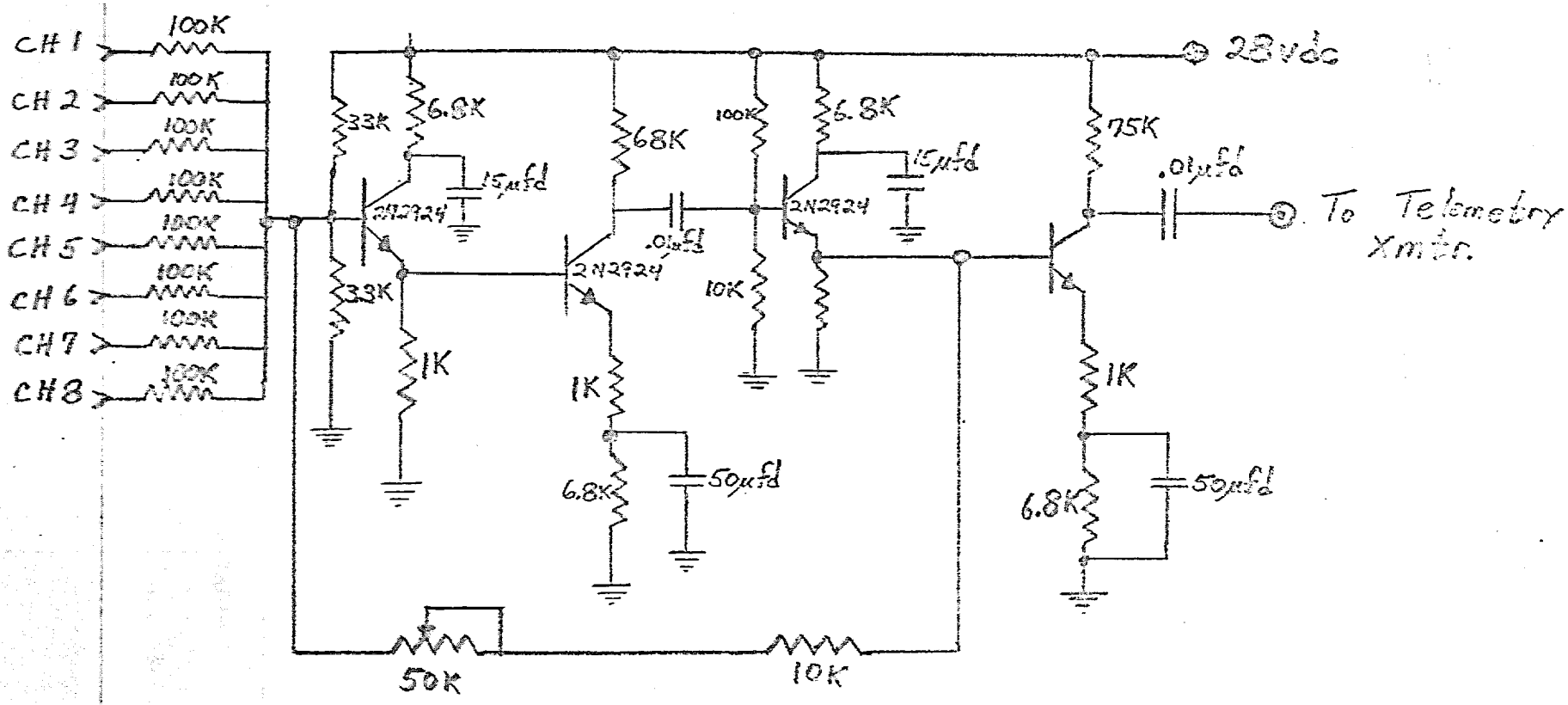


Fig. 6. Vehicle Multiplex Amplifier

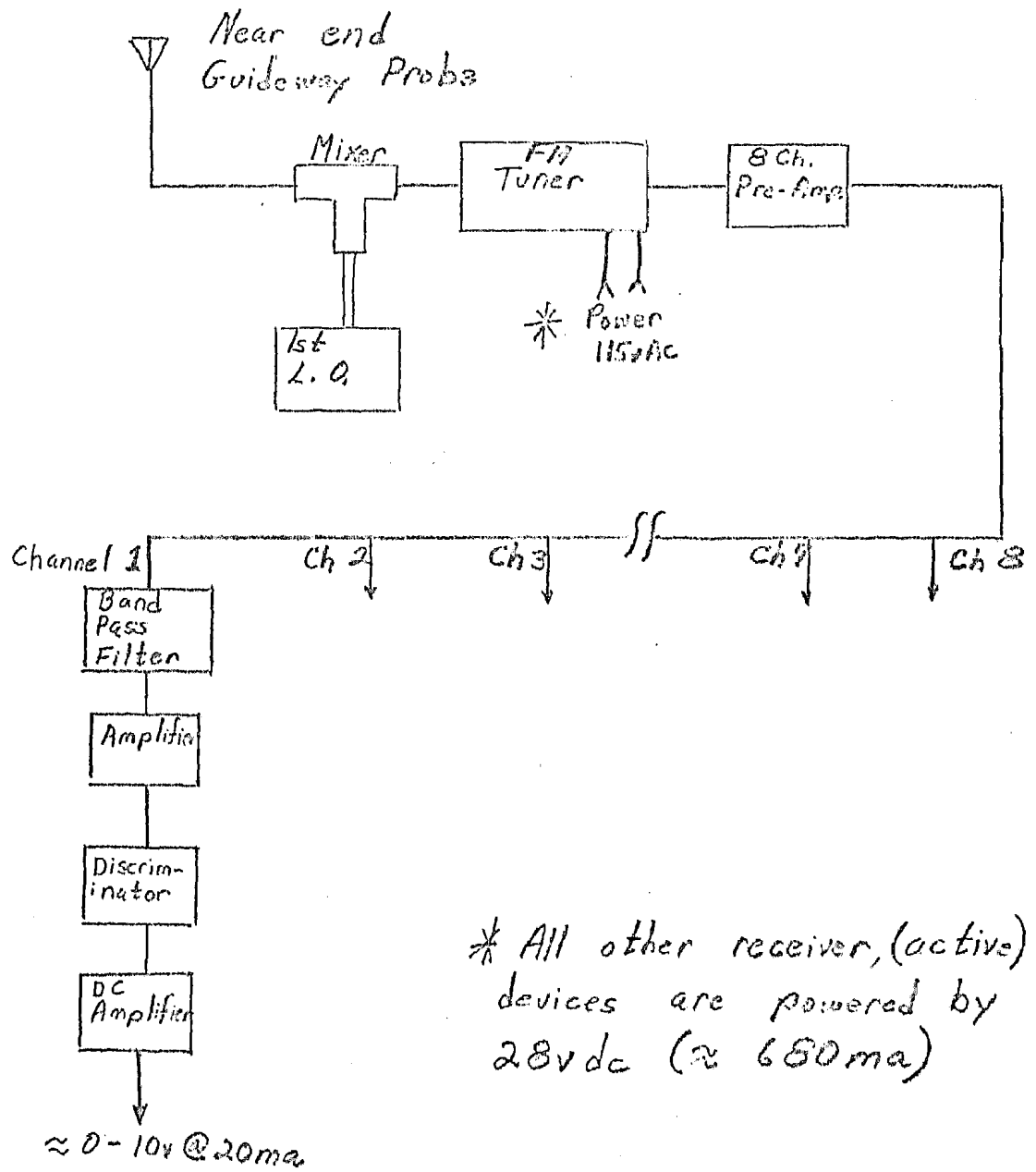


Fig. 7. Receiver Block Diagram

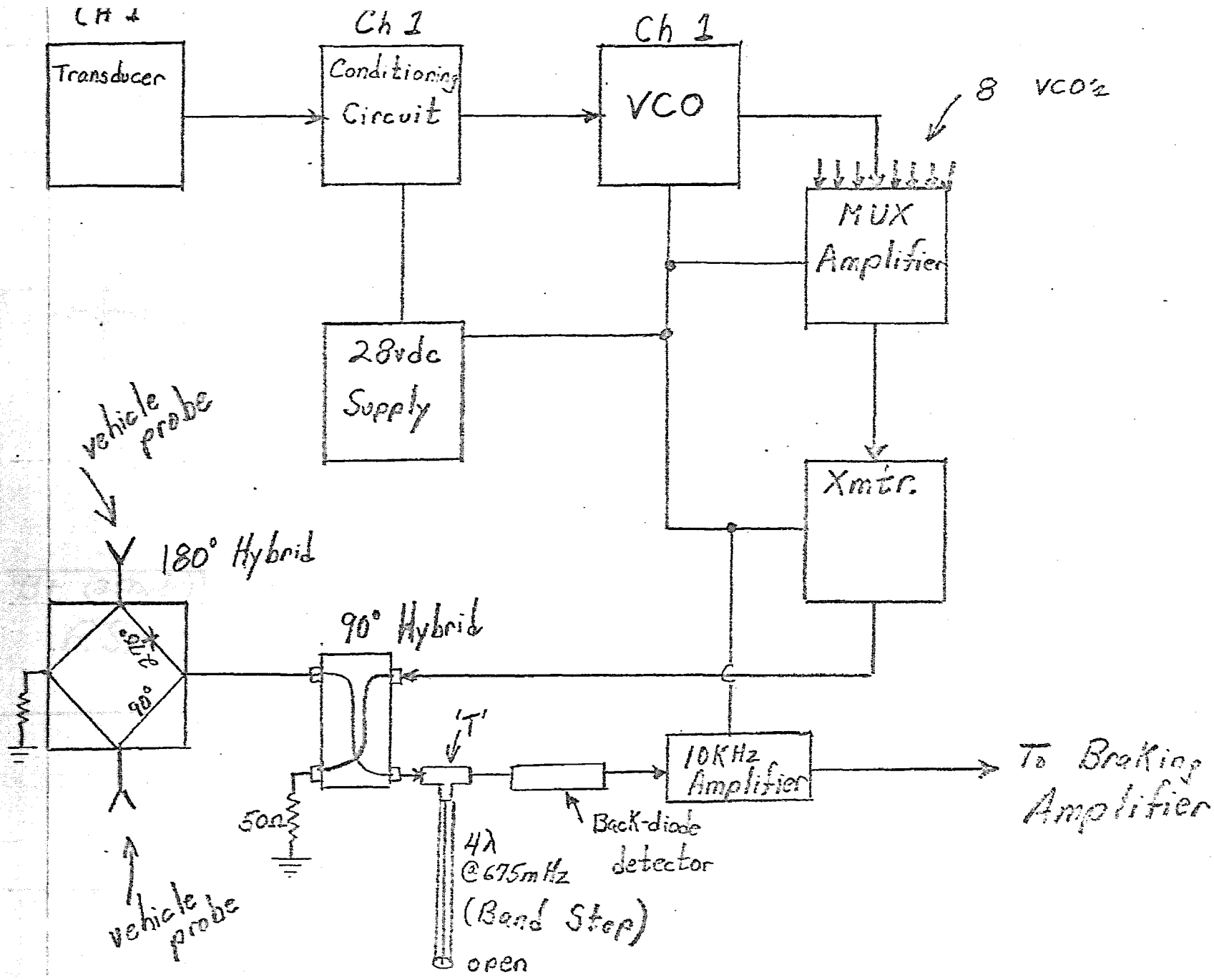


Fig. 8. Vehicle Block Diagram

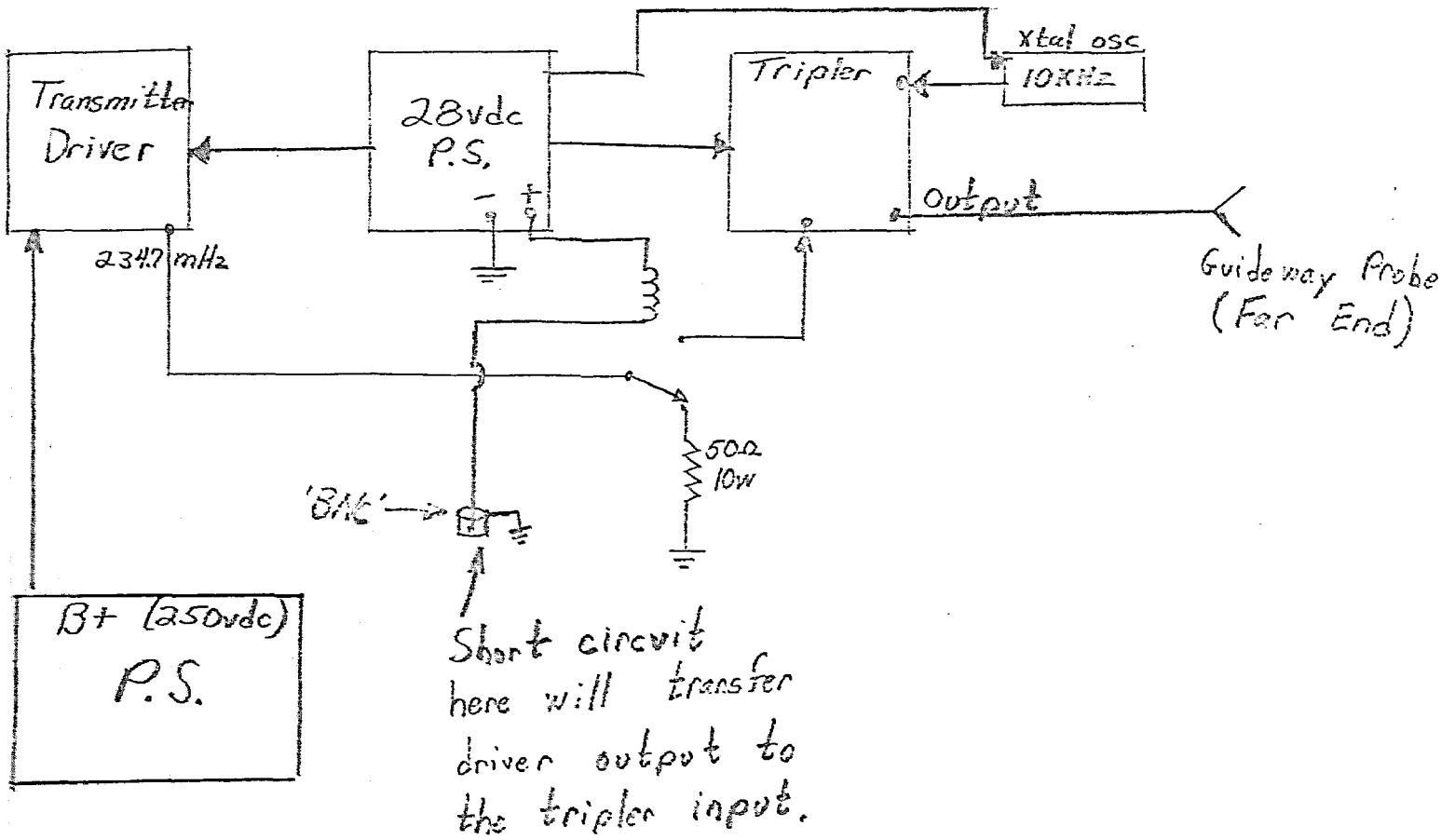


Fig. 9. Failsafe Transmitter

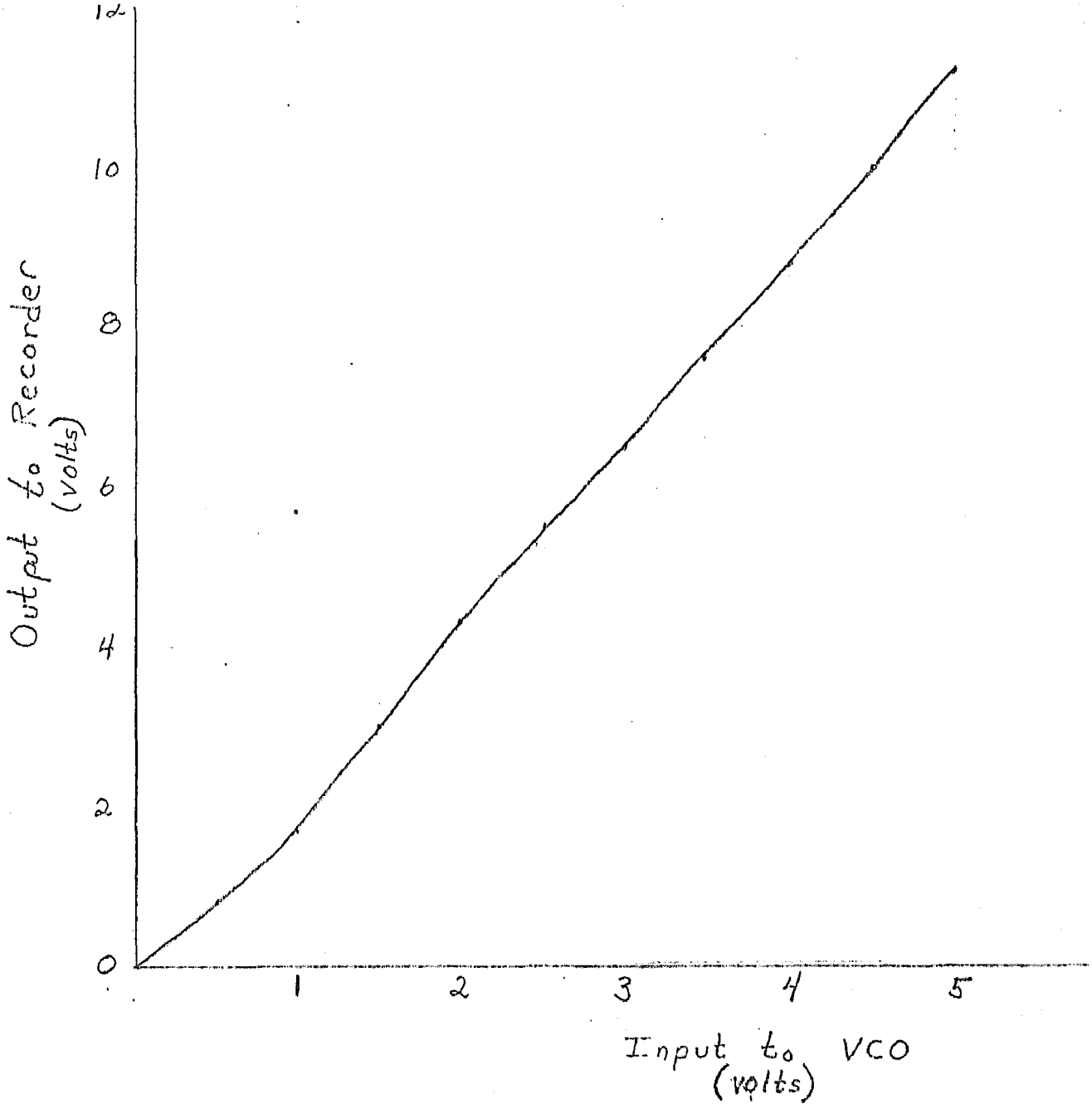


Fig. 10. System Linearity
Channel 1 (1700 Hz)

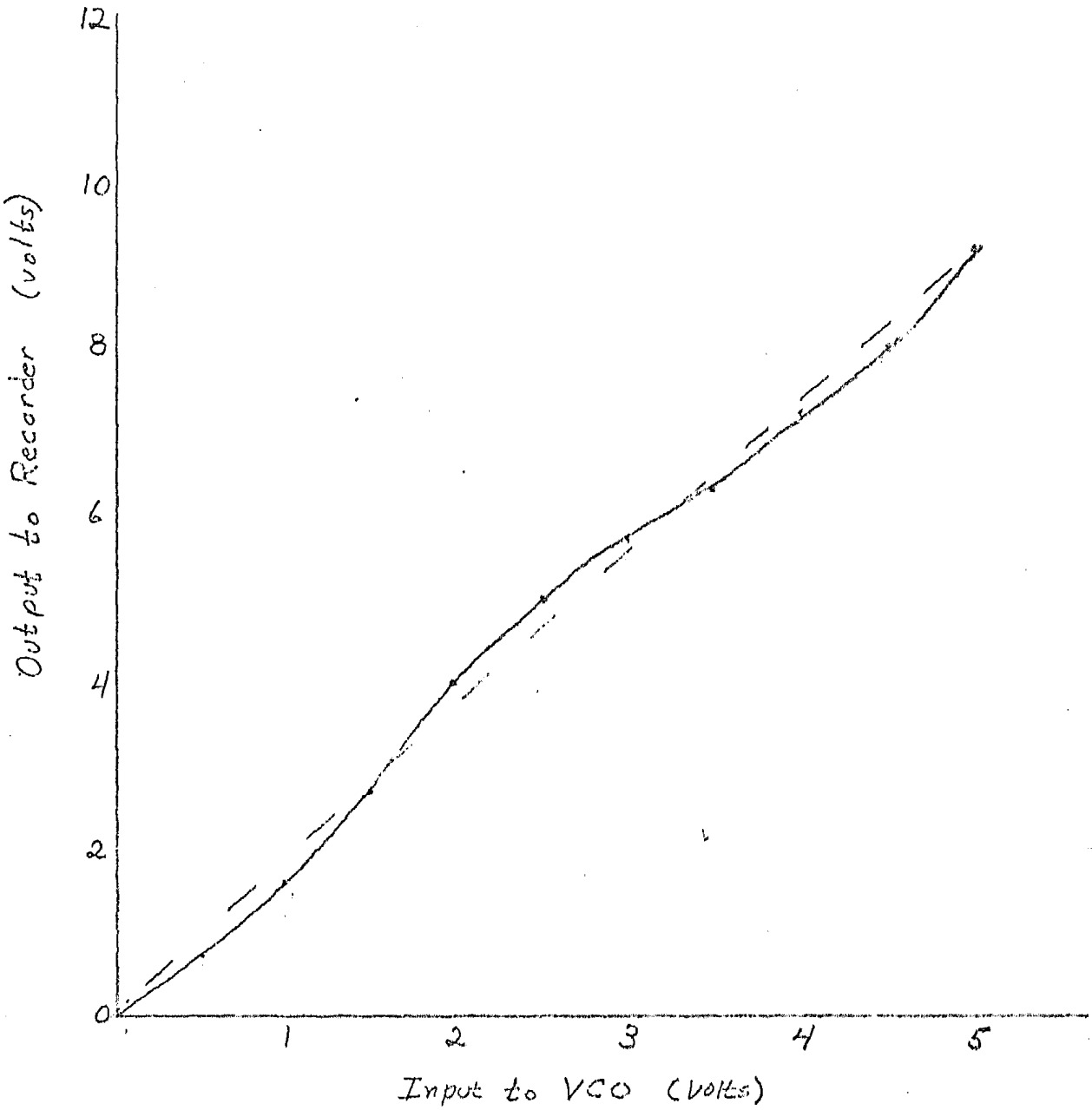


Fig. 11. System Linearity
Channel 2 (2300 Hz)

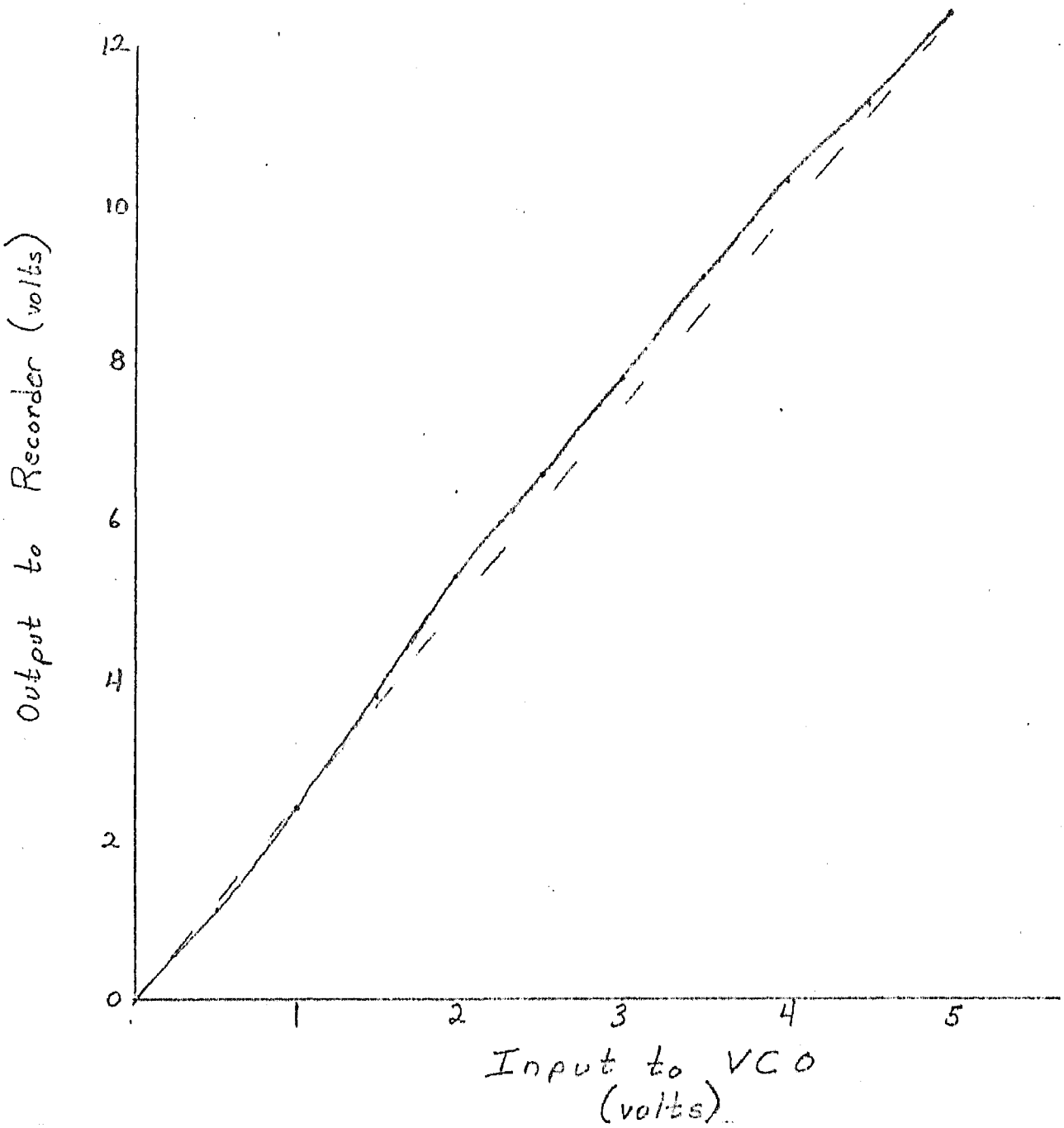


Fig. 12. System Linearity
Channel 3 (3000 Hz)

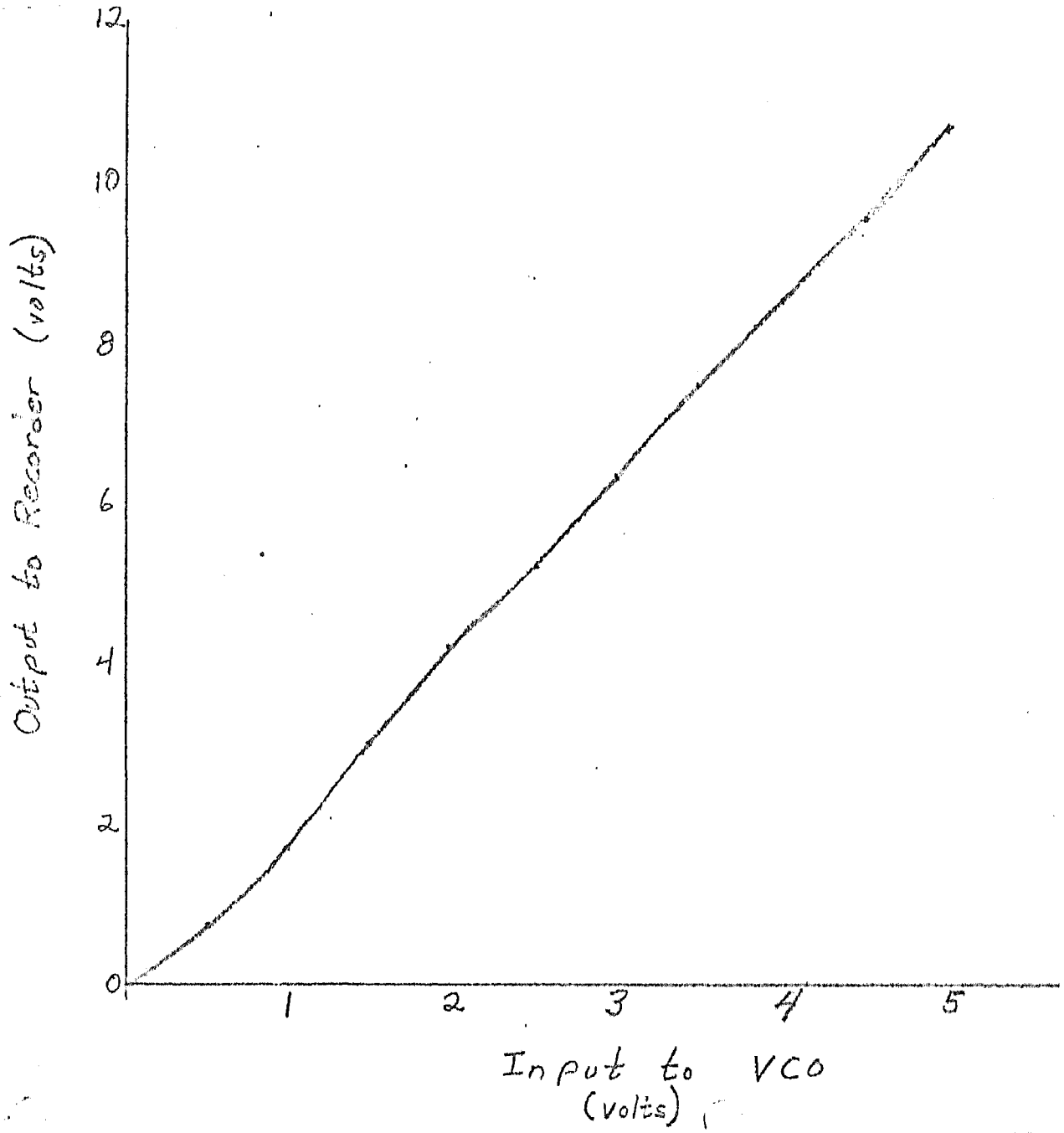


Fig. 13. System Linearity
Channel 4 (3900 Hz)

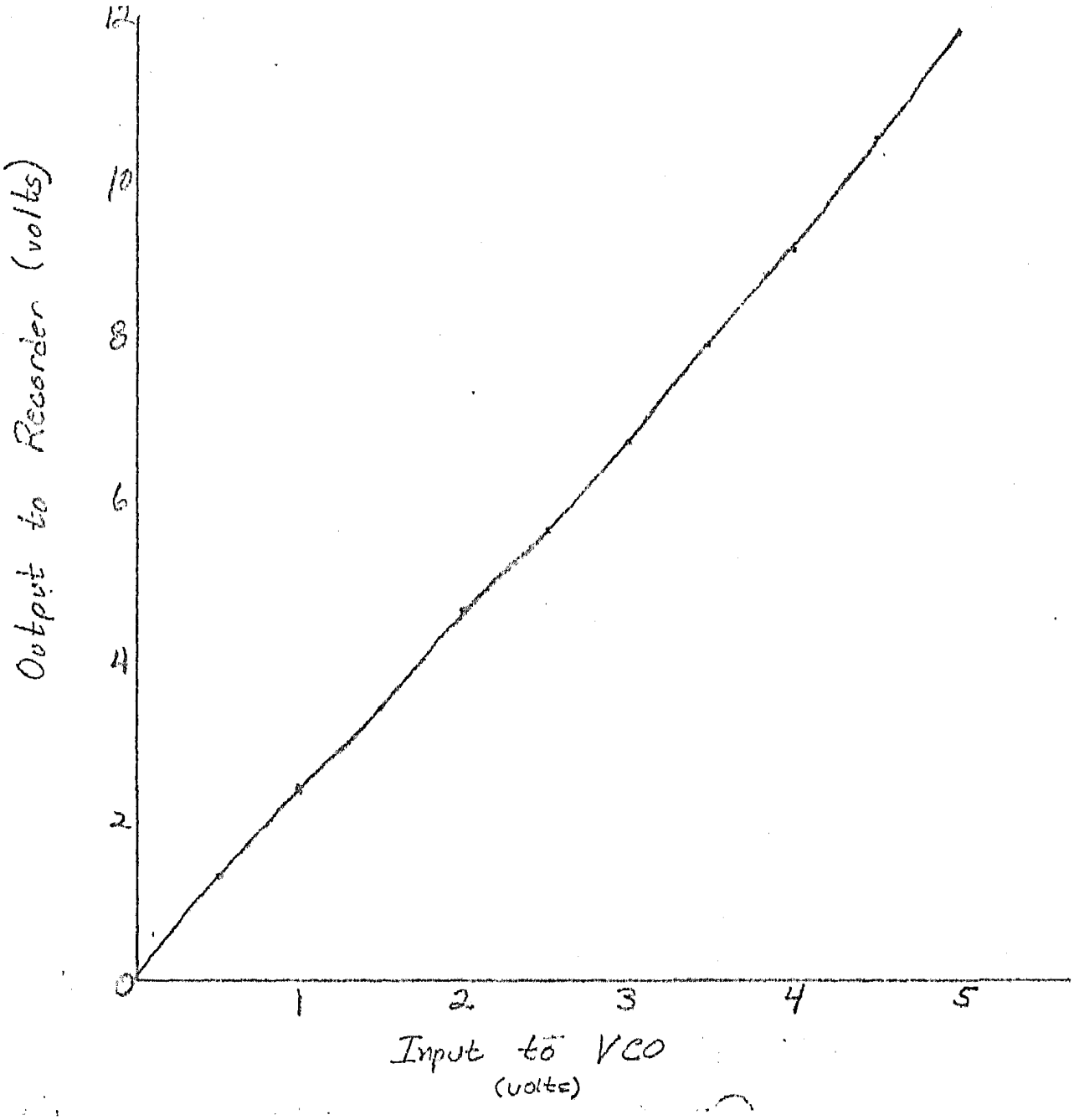


Fig. 14. System Linearity
Channel 5 (5400 Hz)

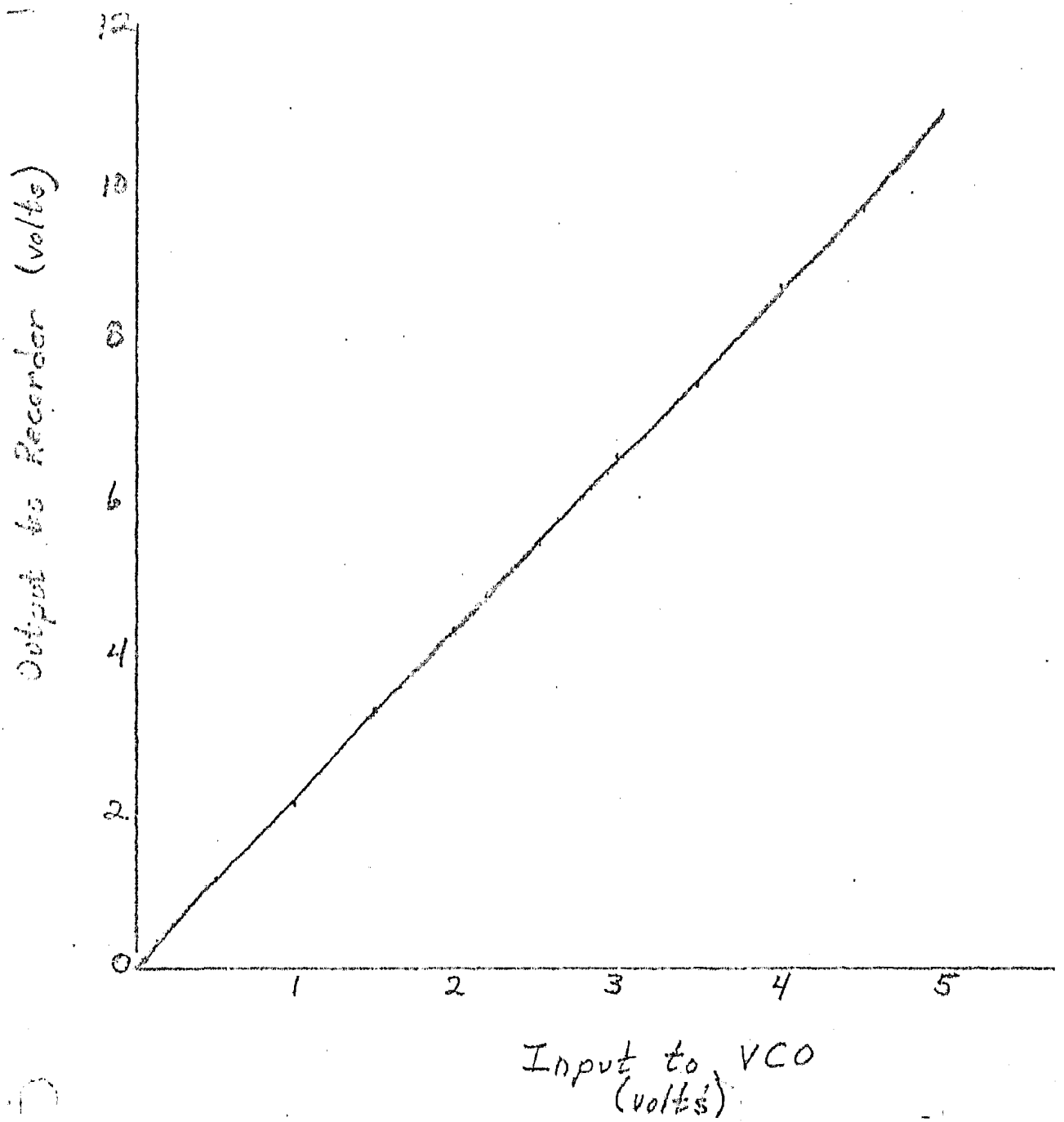


Fig. 15. System Linearity
Channel 6 (7350 Hz)

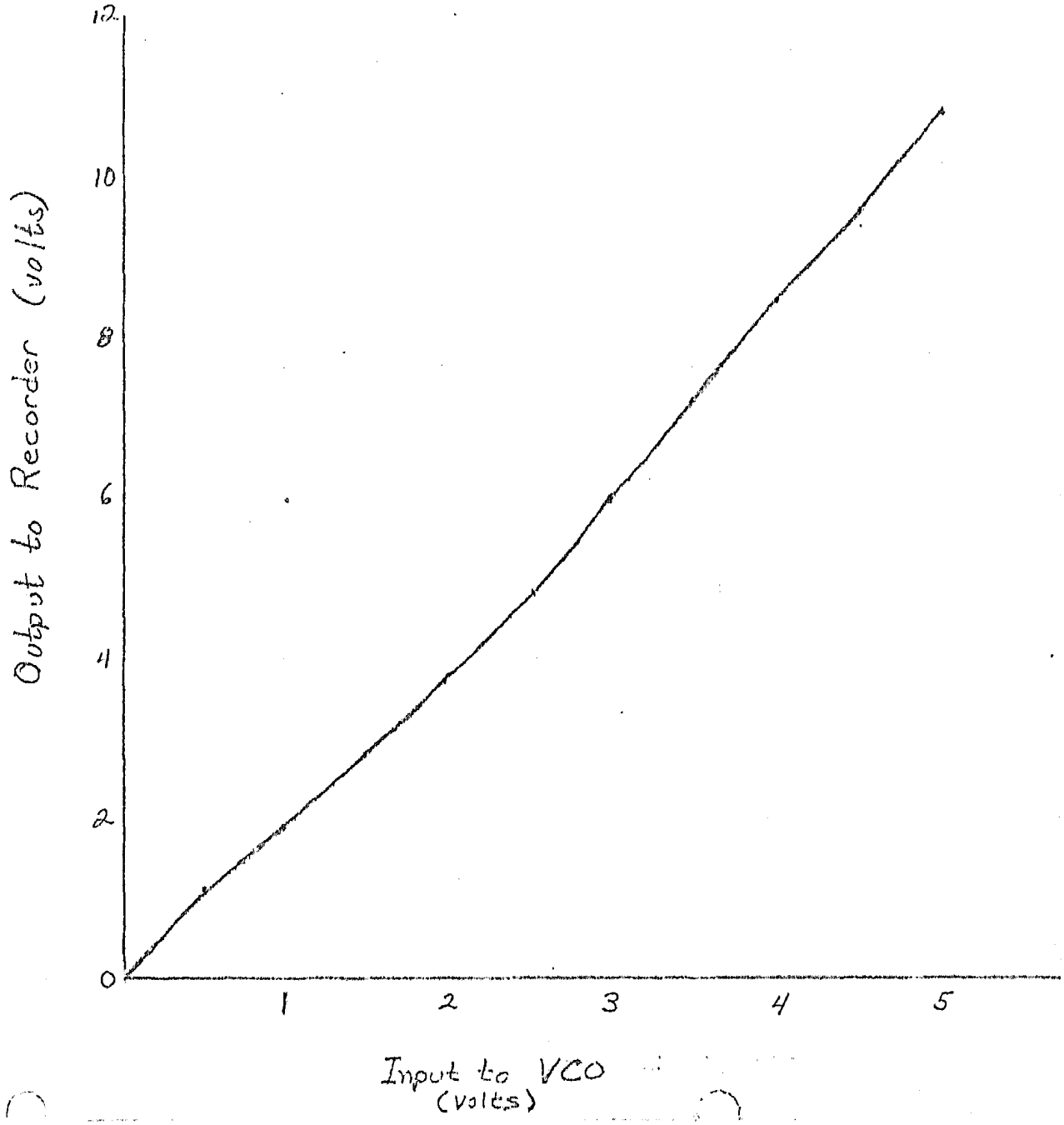


Fig. 16. System Linearity
Channel 7 (10500 Hz)

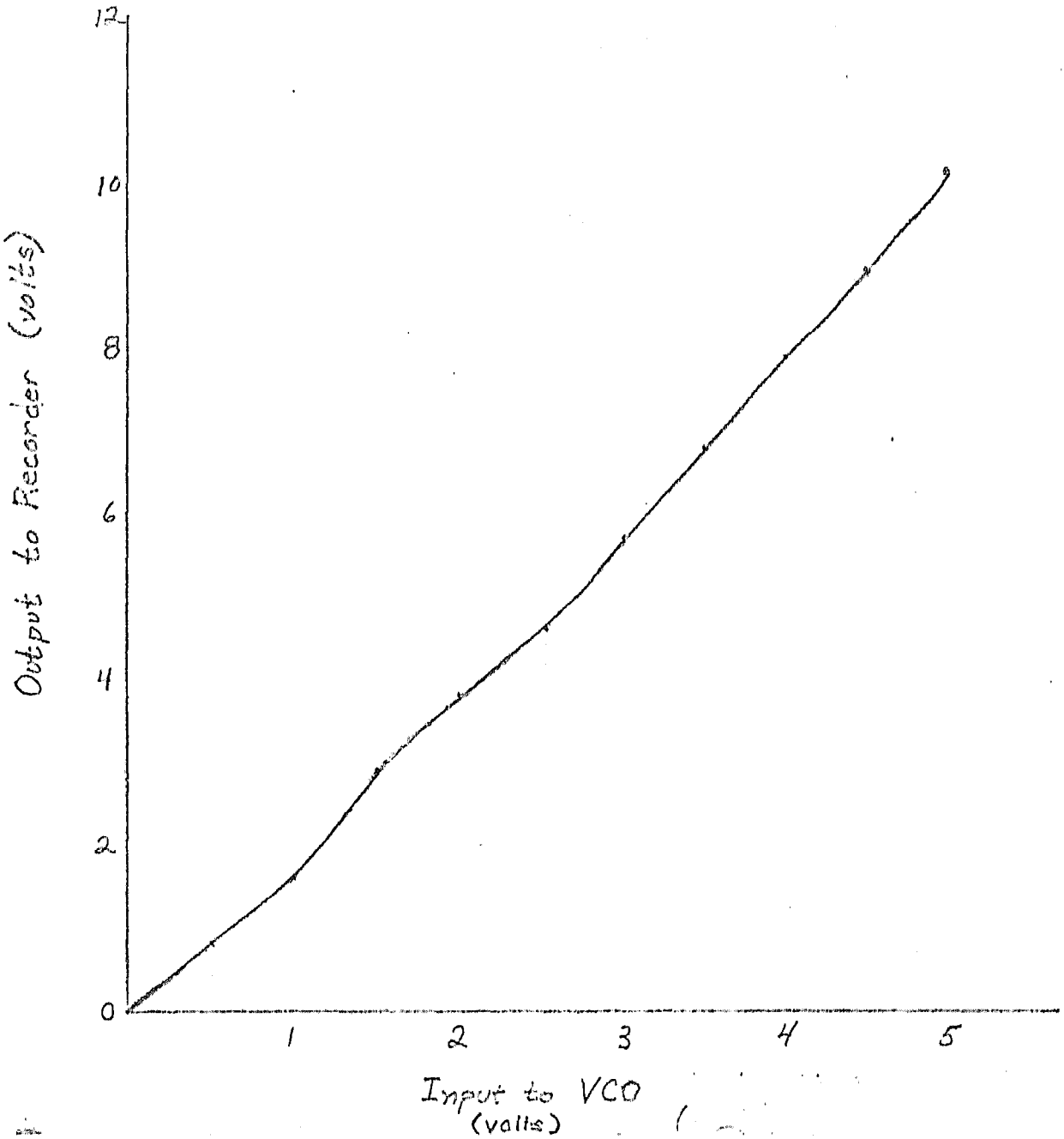


Fig. 17. System Linearity
Channel 8 (14500 Hz)

APPENDIX B

Digital Computer Program

```
/JOB          4153       POWELL,PAGES=200
      DIMENSION ROLLAC(400),ROLLVE(400),ROLLAN(400),FOWPRX(400),RERPRX(4
     100),HEVPOS(400),HEVVEL(400),HEVACC(400),PICHAN(400),PICHVE(400),PI
     2CHAC(400),TUBEAC(400),TUBEAA(400),TUBEVE(400),TUBEPO(400),TUBPOS(4
     300),TUBVEL(400),TUBACC(400),              PRESSR(400),TIMLON(400),AV
     4RLAC(400),AVLGAC(400),FOMACH(400),VEMACH(400),FOVELO(400),AIRVEL(4
     500),PRSRAT(400)
      READ (1,1000) TIME
 1000 FORMAT (1X,E13.6)
      READ (1,1000) TOTIME
      NUM = TOTIME/TIME
      ANUM = TOTIME/TIME
      IF (ANUM-NUM) 999,777,888
  999 NUM = NUM + 1.0
      GO TO 777
  888 NUM = NUM - 1.0
  777 READ (1,1000) (ROLLAC(J),J=1,NUM)
      READ (1,1000) (FOWPRX(J),J=1,NUM)
      READ (1,1000) (RERPRX(J),J=1,NUM)
      READ (1,1000) (TUBEAC(J),J=1,NUM)
      READ (1,1000) (PRESSR(J),J=1,NUM)
      READ (1,1000) TIM
      ITIM = TIM
      READ (1,1000) (TIMLON(J),J=1,ITIM)
      READ (1,1000) (TUBPOS(J),J=1,ITIM)
      READ (1,1000) FOWINT
      READ (1,1000) RERINT
      READ (1,1000) ROLINT
      READ (1,1000) PRSINT
      READ (1,1000) START
      READ (1,1000) TEMP
      READ (1,1000) TOTPRS
      READ (1,1000) PRXDIS
      READ (1,1000) CGFORW
      READ (1,1000) CGREAR
      READ (1,1000) CGPROX
      WRITE (3,1)
      WRITE (3,2)
      WRITE (3,1000) TIME
      WRITE (3,3)
      WRITE (3,1000) TOTIME
      WRITE (3,4)
      WRITE (3,1000) (ROLLAC(J),J=1,NUM)
      WRITE (3,5)
      WRITE (3,1000) (FOWPRX(J),J=1,NUM)
      WRITE (3,6)
      WRITE (3,1000) (RERPRX(J),J=1,NUM)
      WRITE (3,7)
      WRITE (3,1000) (TUBEAC(J),J=1,NUM)
      WRITE (3,9)
      WRITE (3,1000) (PRESSR(J),J=1,NUM)
      WRITE (3,10)
      WRITE (3,1000) TIM
      WRITE (3,11)
      WRITE (3,1000) (TIMLON(J),J=1,ITIM)
      WRITE (3,12)
      WRITE (3,1000) (TUBPOS(J),J=1,ITIM)
      WRITE (3,13)
      WRITE (3,1000) FOWINT
      WRITE (3,14)
```

```
      WRITE (3,1000) RERINT
      WRITE (3,15)
      WRITE (3,1000) ROLINT
      WRITE (3,16)
      WRITE (3,1000) PRSINT
      WRITE (3,18)
      WRITE (3,1000) START
      WRITE (3,19)
      WRITE (3,1000) TEMP
      WRITE (3,20)
      WRITE (3,1000) TOTPRS
      WRITE (3,21)
      WRITE (3,1000) PRXDIS
      WRITE (3,25)
      WRITE (3,1000) CGFORW
      WRITE (3,26)
      WRITE (3,1000) CGREAR
      WRITE (3,27)
      WRITE (3,1000) CGPROX
    1 FORMAT (54H1*******************      DATA   INPUT      ************)
    2 FORMAT (41H0*******TIME UNIT , TIME BETWEEN READINGS)
    3 FORMAT (26H0*******TOTAL TIME OF TEST)
    4 FORMAT (38H0*******ROLL ACCELERATIONS VERSUS TIME)
    5 FORMAT (58H0*******HEIGHT OF FORWARD PROXIMITY TRANSDUCER VERSUS T
     1IME)
    6 FORMAT (55H0*******HEIGHT OF REAR PROXIMITY TRANSDUCER VERSUS TIME
     1)
    7 FORMAT (69H0*******LONGITUDINAL ACCELERATION, UNCORRECTED FOR PITC
     1H, VERSUS TIME)
    9 FORMAT (63H0*******PRESSURE DIFFERENTIAL FOWARD OF THE VEHICLE VER
     1SUS TIME)
   10 FORMAT (48H0*******NUMBER OF PHOTOCELL LONGITUDINAL PICKUPS)
   11 FORMAT (58H0*******TIME TO PHOTOCELL PICKUPS, MEASURED FROM THE ST
     1ART)
   12 FORMAT (60H0*******DISTANCE FROM STARTING POSITION TO PHOTOCELL PI
     1CKUPS)
   13 FORMAT (54H0*******INITIAL HEIGHT OF FORWARD PROXIMITY TRANSDUCER)
   14 FORMAT (51H0*******INITIAL HEIGHT OF REAR PROXIMITY TRANSDUCER)
   15 FORMAT (26H0*******INITIAL ROLL ANGLE)
   16 FORMAT (37H0*******INITIAL PRESSURE DIFFERENTIAL)
   18 FORMAT (37H0*******INITIAL LONGITUDINAL POSITION)
   19 FORMAT (31H0*******AIR TEMPERATURE IN TUBE)
   20 FORMAT (30H0*******TOTAL PRESSURE IN TUBE)
   21 FORMAT (46H0*******DISTANCE BETWEEN PROXIMITY TRANSDUCERS)
   25 FORMAT (63H0*******DISTANCE FROM FORWARD PROXIMITY TRANSDUCER TO C
     1.G. LINE)
   26 FORMAT (60H0*******DISTANCE FROM REAR PROXIMITY TRANSDUCER TO C.G.
     1 LINE)
   27 FORMAT (55H0*******DISTANCE FROM C.G. TO PROXIMITY TRANSDUCER LINE
     1)
C     ***************************************************************
C     ***************************************************************
C     CALCULATION OF HEAVE VARIABLES
      DO 1012 I=1,NUM
      A = FOWPRX(I)
      B = RERPRX(I)
      IF (A-B) 1001,1002,1002
 1001 C = (B-A)/PRXDIS
      D = 1-C**2
      E = SQRT(D)
```

```
      HEVPOS(I) = A+CGPROX*E+CGFORW*C
      GO TO 1003
 1002 C = (A-B)/PRXDIS
      D = 1-C**2
      E = SQRT(D)
      HEVPOS(I) = B+CGPROX*E+CGREAR*C
 1003 K = I-1
      IF (K) 1004,1004,1008
 1004 AZERO = FOWINT
      BZERO = RERINT
      IF (AZERO-BZERO) 1005,1006,1006
 1005 CZERO = (BZERO-AZERO)/PRXDIS
      DZERO = 1-CZERO**2
      EZERO = SQRT(DZERO)
      CGINIT = AZERO+CGPROX*EZERO+CGFORW*CZERO
      GO TO 1007
 1006 CZERO = (AZERO-BZERO)/PRXDIS
      DZERO = 1-CZERO**2
      EZERO = SQRT(DZERO)
      CGINIT = BZERO+CGPROX*EZERO+CGREAR*CZERO
 1007 HEVVEL(I) = (HEVPOS(I)-CGINIT)/TIME
      GO TO 1009
 1008 HEVVEL(I) = (HEVPOS(I)-HEVPOS(K))/TIME
 1009 IF (K) 1010,1010,1011
 1010 HEVACC(I) = HEVVEL(I)/TIME
      GO TO 1012
 1011 HEVACC(I) = (HEVVEL(I)-HEVVEL(K))/TIME
 1012 CONTINUE
C     ******************************************************************
C     ******************************************************************
C     CALCULATION OF PITCH VARIABLES
      DO 1018 L=1,NUM
      M = L-1
      IF (M) 1013,1013,1014
 1013 PAINIT = ARSIN((FOWINT-RERINT)/PRXDIS)
      PICHAN(L) = ARSIN((FOWPRX(L)-RERPRX(L))/PRXDIS)
      PICHVE(L) = (PICHAN(L)-PAINIT)/TIME
      GO TO 1015
 1014 PICHAN(L) = ARSIN((FOWPRX(L)-RERPRX(L))/PRXDIS)
      PICHVE(L) = (PICHAN(L)-PICHAN(M))/TIME
 1015 IF (M) 1016,1016,1017
 1016 PICHAC(L) = PICHVE(L)/TIME
      GO TO 1018
 1017 PICHAC(L) = (PICHVE(L)-PICHVE(M))/TIME
 1018 CONTINUE
C     ******************************************************************
C     ******************************************************************
C     CALCULATION OF ROLL VARIABLES
      DO 1021 N=1,NUM
      NN = N-1
      IF (NN) 1019,1019,1020
 1019 AVRLAC(N) = ROLLAC(N)/2.0
      ROLLVE(N) = AVRLAC(N)*TIME
      ROLLAN(N) = 0.5*AVRLAC(N)*(TIME**2.)
      GO TO 1021
 1020 AVRLAC(N) = (ROLLAC(N)+ROLLAC(NN))/2.0
      ROLLVE(N) = ROLLVE(NN)+AVRLAC(N)*TIME
      ROLLAN(N) = ROLLVE(NN)*TIME+0.5*AVRLAC(N)*(TIME**2.) + ROLLAN(NN)
 1021 CONTINUE
C     ******************************************************************
```

```
C     ****************************************************************
C     CALCULATION OF LONGITUDINAL VARIABLES  (AS PER ON BOARD READINGS)
      DO 1024 IJ=1,NUM
      JI = IJ-1
      IF (JI) 1022,1022,1023
 1022 TUBEAA(IJ) = TUBEAC(IJ)/COS(PICHAN(IJ))
      AVLGAC(IJ) = TUBEAA(IJ)/2.0
      TUBEVE(IJ) = AVLGAC(IJ)*TIME
      TUBEPO(IJ) = 0.5*AVLGAC(IJ)*(TIME**2.)
      GO TO 1024
 1023 TUBEAA(IJ) = TUBEAC(IJ)/COS(PICHAN(IJ))
      AVLGAC(IJ) = (TUBEAA(IJ)+TUBEAA(JI))/2.0
      TUBEVE(IJ) = TUBEVE(JI)+AVLGAC(IJ)*TIME
      TUBEPO(IJ) = TUBEVE(JI)*TIME+0.5*AVLGAC(IJ)*(TIME**2.)+TUBEPO(JI)
 1024 CONTINUE
C     ****************************************************************
C     ****************************************************************
C     CALCULATION OF LONGITUDINAL VARIABLES (AS PER PHOTOCELL READINGS)
      DO 1027 MM=1,ITIM
      LK = MM-1
      IF (LK) 1025,1025,1026
 1025 TUBVEL(MM) = TUBPOS(MM)/TIMLON(MM)
      TUBACC(MM) = TUBVEL(MM)/TIMLON(MM)
      GO TO 1027
 1026 TUBVEL(MM) = (TUBPOS(MM)-TUBPOS(LK))/(TIMLON(MM)-TIMLON(LK))
      TUBACC(MM) = (TUBVEL(MM)-TUBVEL(LK))/(TIMLON(MM)-TIMLON(LK))
 1027 CONTINUE
C     ****************************************************************
C     ****************************************************************
C     CALCULATION OF FLUID VELOCITY FORWARD OF THE VEHICLE
      SUPER = (-2.)/7.
      SOUND = 49.02*SQRT(TEMP)
      DO 1028 KK=1,NUM
      VEHACH(KK) = TUBEVE(KK)/SOUND
      PRSRAT(KK) = 1.0-PRESSR(KK)/TOTPRS
      ABC = 5.0*(PRSRAT(KK)**SUPER-1.0)
      FOMACH(KK) = SQRT(ABC)
      FOVELO(KK) = FOMACH(KK)*SOUND
 1028 AIRVEL(KK) = TUBEVE(KK)-FOVELO(KK)
      WRITE (3,100)
      WRITE (3,102)
      WRITE (3,103)
      WRITE (3,104)
      WRITE (3,105)
      WRITE (3,106)
      WRITE (3,107)
      WRITE (3,108)
      WRITE (3,111)
      WRITE (3,112)
      WRITE (3,113)
      WRITE (3,114)
      WRITE (3,115)
      WRITE (3,117)
      WRITE (3,118)
      WRITE (3,120)
      WRITE (3,121)
      WRITE (3,122)
      WRITE (3,123)
      WRITE (3,124)
      WRITE (3,125)
```

```
      WRITE (3,126)
      WRITE (3,127)
      WRITE (3,128)
      WRITE (3,129)
      WRITE (3,130)
      WRITE (3,131)
      WRITE (3,132)
      WRITE (3,133)
      WRITE (3,134)
      WRITE (3,136)
      WRITE (3,137)
      WRITE (3,138)
      WRITE (3,139)
      WRITE (3,140)
      WRITE (3,141)
      WRITE (3,142)
      WRITE (3,143)
      WRITE (3,144)
      WRITE (3,145)
      WRITE (3,146)
      WRITE (3,147)
      WRITE (3,148)
      WRITE (3,149)
      WRITE (3,151)
      WRITE (3,152)
      WRITE (3,153)
  100 FORMAT (54H1**********************TERMINOLOGY*******************)
  102 FORMAT (97H   AIRVEL( )------ABSOLUTE VELOCITY OF THE AIR FOWARD O
     1F THE VEHICLE AT TIME INTERVAL ( ), FT/SEC)
  103 FORMAT (85H   AVLGAC( )------AVERAGE LONGITUDINAL ACCELERATION IN
     1A TIME INTERVAL( ), FT/SEC/SEC)
  104 FORMAT (78H   AVRLAC( )------AVERAGE ROLL ACCELERATION IN A TIME I
     1NTERVAL( ), RAD/SEC/SEC)
  105 FORMAT (45H   CGINIT---------INITIAL VEHICULAR HEAVE, FT)
  106 FORMAT(101H   CGFORW---------LONGITUDINAL DISTANCE FROM FOWARD PRO
     1XIMITY TRANSDUCER TO THE CENTER OF GRAVITY, FT)
  107 FORMAT (87H   CGPROX---------VERTICAL DISTANCE FROM CENTER OF GRAV
     1ITY TO PROXIMITY TRANSDUCERS, FT)
  108 FORMAT (99H   CGREAR---------LONGITUDINAL DISTANCE FROM REAR PROXI
     1MITY TRANSDUCER TO THE CENTER OF GRAVITY, FT)
  111 FORMAT(100H   FOMACH( )------MACH NUMBER OF VEHICLE RELATIVE TO AI
     1R FORWARD OF THE VEHICLE AT TIME INTERVAL ( ))
  112 FORMAT(104H   FOVELO( )------VELOCITY OF VEHICLE RELATIVE TO AIR F
     1OWARD OF THE VEHICLE AT TIME INTERVAL ( ), FT/SEC)
  113 FORMAT (75H   FOWINT---------INITIAL HEAVE POSITION OF FOWARD PROX
     1IMITY TRANSDUCER, FT)
  114 FORMAT (94H   FOWPRX( )------HEIGHT OF FORWARD PROXIMITY TRANSDUCE
     1R AT TIME INTERVAL ( ), FT, POSITIVE UP)
  115 FORMAT(103H   HEVACC( )------HEAVE ACCELERATION OF CENTER OF GRAVI
     1TY AT TIME INTERVAL ( ), FT/SEC/SEC, POSITIVE UP)
  117 FORMAT (92H   HEVPOS( )------HEAVE POSITION OF CENTER OF GRAVITY
     1AT TIME INTERVAL ( ), FT, POSITIVE UP)
  118 FORMAT (95H   HEVVEL( )------HEAVE VELOCITY OF CENTER OF GRAVITY A
     1T TIME INTERVAL ( ), FT/SEC, POSITIVE UP)
  120 FORMAT (44H   NUM------------NUMBER OF DATA TIME POINTS)
  121 FORMAT (42H   PAINIT---------INITIAL PITCH ANGLE, RAD)
  122 FORMAT (88H   PICHAC( )------PITCH ACCELERATION AT TIME INTERVAL (
     1 ), RAD/SEC/SEC, POSITIVE NOSE UP)
  123 FORMAT (73H   PICHAN( )------PITCH ANGLE AT TIME INTERVAL ( ), RAD
     1, POSITIVE NOSE UP)
```

```
 124  FORMAT (80H   PICHVE( )------PITCH VELOCITY AT TIME INTERVAL ( ),
     1RAD/SEC, POSITIVE NOSE UP)
 125  FORMAT (70H   PRESSR( )------PRESSURE DIFFERENTIAL AT TIME INTERVA
     1L ( ), LB/IN/IN)
 126  FORMAT (57H   PRSINT---------INITIAL PRESSURE DIFFERENTIAL, LB/IN/
     1IN)
 127  FORMAT (62H   PRSRAT( )------PRESSURE RATIO, P/PTOT, AT TIME INTER
     1VAL ( ))
 128  FORMAT (60H   PRXDIS---------DISTANCE BETWEEN PROXIMITY TRANSDUCER
     1S, FT)
 129  FORMAT (73H   RERINT---------INITIAL HEAVE POSITION OF REAR PROXIM
     1ITY TRANSDUCER, FT)
 130  FORMAT (91H   RERPRX( )------HEIGHT OF REAR PROXIMITY TRANSDUCER A
     1T TIME INTERVAL ( ), FT, POSITIVE UP)
 131  FORMAT (41H   ROLINT---------INITIAL ROLL ANGLE, RAD)
 132  FORMAT (88H   ROLLAC( )------ROLL ACCELERATION AT TIME INTERVAL (
     1),RAD/SEC/SEC, POSITIVE CLOCKWISE)
 133  FORMAT (74H   ROLLAN( )------ROLL ANGLE AT TIME INTERVAL ( ), RAD,
     1 POSITIVE CLOCKWISE)
 134  FORMAT (81H   ROLLVE( )------ROLL VELOCITY AT TIME INTERVAL ( ), R
     1AD/SEC, POSITIVE CLOCKWISE)
 136  FORMAT (48H   SOUND----------SPEED OF SOUND IN TUBE, FT/SEC)
 137  FORMAT (51H   START----------INITIAL LONGITUDINAL POSITION, FT)
 138  FORMAT (70H   TEMP-----------TOTAL TEMPERATURE OF  AT REST  AIR IN
     1TUBE, DEGREES R)
 139  FORMAT (58H   TIM------------NUMBER OF LONGITUDINAL PHOTOCELL PICK
     1UPS)
 140  FORMAT (60H   TIME-----------TIME UNIT FOR DIVIDING INTO INTERVALS
     1, SEC)
 141  FORMAT (91H   TIMLON( )------TIME TO LONGITUDINAL POSITIONS OF PHO
     1TOCELLS, FROM STARTING POSITION, SEC)
 142  FORMAT (41H   TOTIME---------TOTAL TIME OF TEST, SEC)
 143  FORMAT (50H   TOTPRS---------TOTAL PRESSURE IN TUBE, LB/IN/IN)
 144  FORMAT(111H   TUBACC( )------LONGITUDINAL ACCELERATION AT PHOTOCEL
     1L PICKUP AVERAGED IN RANGE, FT/SEC/SEC, POSITIVE FORWARD)
 145  FORMAT(114H   TUBEAA( )------LONGITUDINAL ACCELERATION AT TIME INT
     1ERVAL ( ) CORRECTED FOR PITCH, FT/SEC/SEC, POSITIVE FORWARD)
 146  FORMAT(116H   TUBEAC( )------LONGITUDINAL ACCELERATION AT TIME INT
     1ERVAL ( ) UNCORRECTED FOR PITCH, FT/SEC/SEC, POSITIVE FORWARD)
 147  FORMAT(102H   TUBEPO( )------LONGITUDINAL POSITION AT TIME INTERVA
     1L ( ) CORRECTED FOR PITCH, FT, POSITIVE FORWARD)
 148  FORMAT(106H   TUBEVE( )------LONGITUDINAL VELOCITY AT TIME INTERVA
     1L ( ) CORRECTED FOR PITCH, FT/SEC, POSITIVE FORWARD)
 149  FORMAT(104H   TUBPOS( )------LONGITUDINAL DISTANCE TO PHOTOCELL PI
     2CKUP FROM STARTING POSITION, FT, POSITIVE FORWARD)
 151  FORMAT(107H   TUBVEL( )------LONGITUDINAL VELOCITY AT PHOTOCELL PI
     1CKUP AVERAGED IN THE RANGE, FT/SEC, POSITIVE FORWARD)
 152  FORMAT (89H   VEMACH( )------ACTUAL MACH NUMBER OF VEHICLE RELATIV
     1E TO THE TUBE AT TIME INTERVAL ( ))
 153  FORMAT (58H                 ------
     1    )
      WRITE (3,1500)
 1500 FORMAT (54H1                                DATA   OUTPUT   SCHEDULE   )
      WRITE (3,1501)
 1501 FORMAT (1H0)
      WRITE (3,1502)
 1502 FORMAT (1H0,4X,4HTIME,11X,6HTUBEPO,9X,6HROLLAN,9X,6HHEVPOS,9X,6HPI
     1CHAN,9X,6HVEMACH/20X,6HTUBEVE,9X,6HROLLVE,9X,6HHEVVEL,9X,6HPICHVE,
     20X,6HAIRVEL/20X,6HTUBEAA,9X,6HROLLAC,9X,6HHEVACC,9X,6HPICHAC)
      WRITE (3,1501)
```

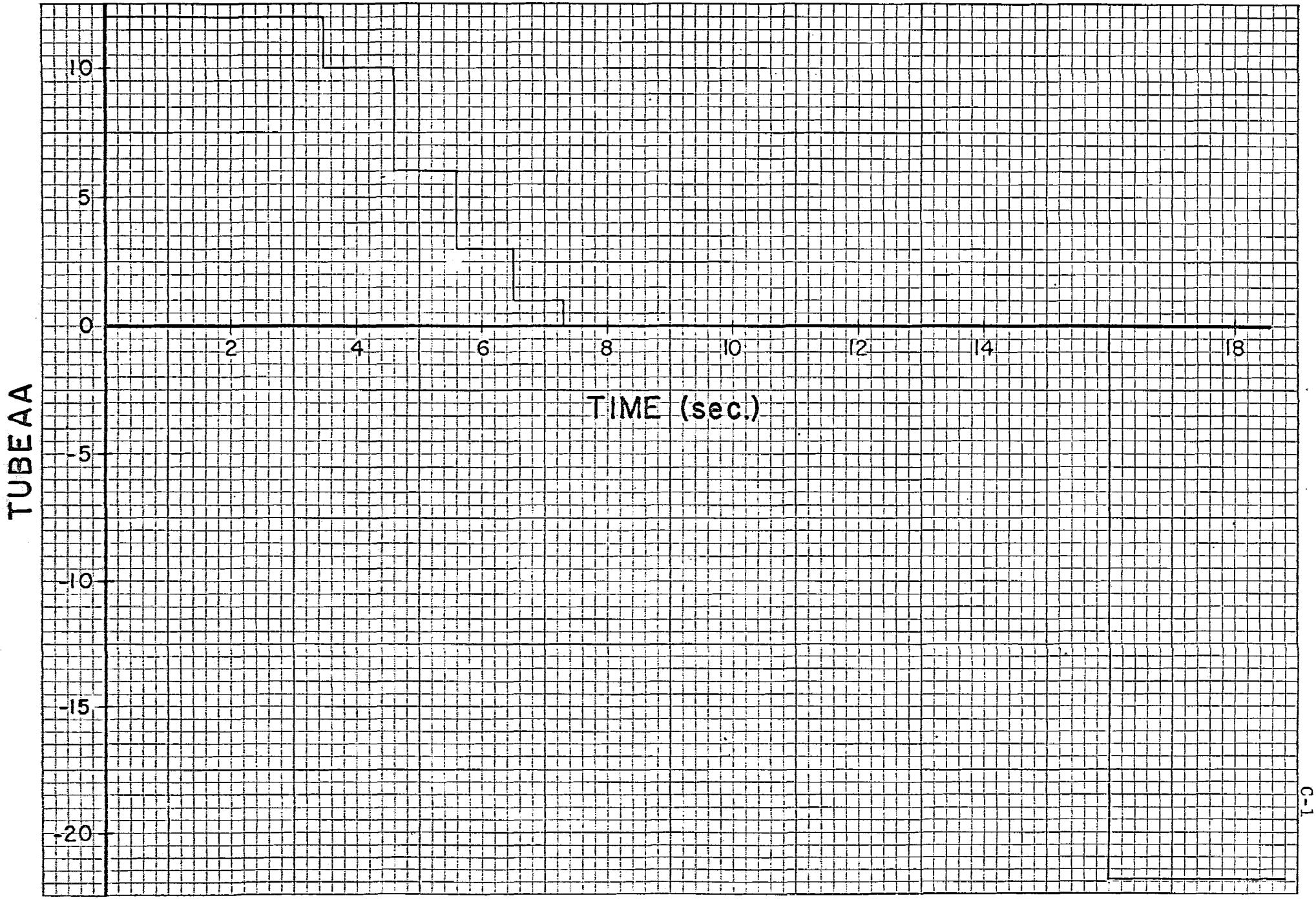
```
88          WRITE (3,1501)
89          KSEC = 0
90          SEC = 0.0
91          BEGIN = 0.0
92          WRITE (3,1505) SEC,START,ROLINT,CGINT,PAINT,BEGIN,BEGIN,BEGI
           1N,BEGIN,BEGIN
93     1505 FORMAT (1H0,4X,F7.4,5X,F10.4,5X,F10.4,5X,F10.4,5X,F10.4,5X,F10.4/1
           17X,F10.4,5X,F10.4,5X,F10.4,5X,F10.4,5X,F10.4/20X,4H----,11X,4H----
           1,11X,4H----,11X,4H----)
94     1503 FORMAT (1H0,4X,F7.4,5X,F10.4,5X,F10.4,5X,F10.4,5X,F10.4,5X,F10.4/1
           17X,F10.4,5X,F10.4,5X,F10.4,5X,F10.4,5X,F10.4/17X,F10.4,5X,F10.4,5X
           2,F10.4,5X,F10.4)
95          KKKK = 1000.0*TIME
96          DO 1504 JK=1,NUM
97          KSEC = KSEC + KKKK
98          SEC = KSEC/1000.0
99          WRITE (3,1503) SEC,TUBEPO(JK),ROLLAN(JK),HEVPOS(JK),PICHAN(JK),VEM
           1ACH(JK),TUBEVE(JK),ROLLVE(JK),HEVVEL(JK),PICHVE(JK),AIRVEL(JK),TUB
           2EAA(JK),ROLLAC(JK),HEVACC(JK),PICHAC(JK)
00     1504 CONTINUE
01          WRITE (3,1506)
02     1506 FORMAT (54H1                    DATA  OUTPUT  SCHEDULE              )
03          WRITE (3,1501)
04          WRITE (3,1507)
05     1507 FORMAT (1H0,4X,6HTUBPOS,9X,6HTUBVEL,9X,6HTUBACC)
06          WRITE (3,1501)
07          WRITE (3,1501)
08          VEL = 0.00000
09          WRITE (3,1508) START,VEL
10     1508 FORMAT (1H0,4X,F10.4,5X,F10.4,8X,4H----)
11          DO 1510 KJ = 1,ITIM
12          WRITE (3,1509) TUBPOS(KJ),TUBVEL(KJ),TUBACC(KJ)
13     1509 FORMAT (1H0,4X,F10.4,5X,F10.4,5X,F10.4)
14     1510 CONTINUE
15          CALL EXIT
16          END

     /DATA
```

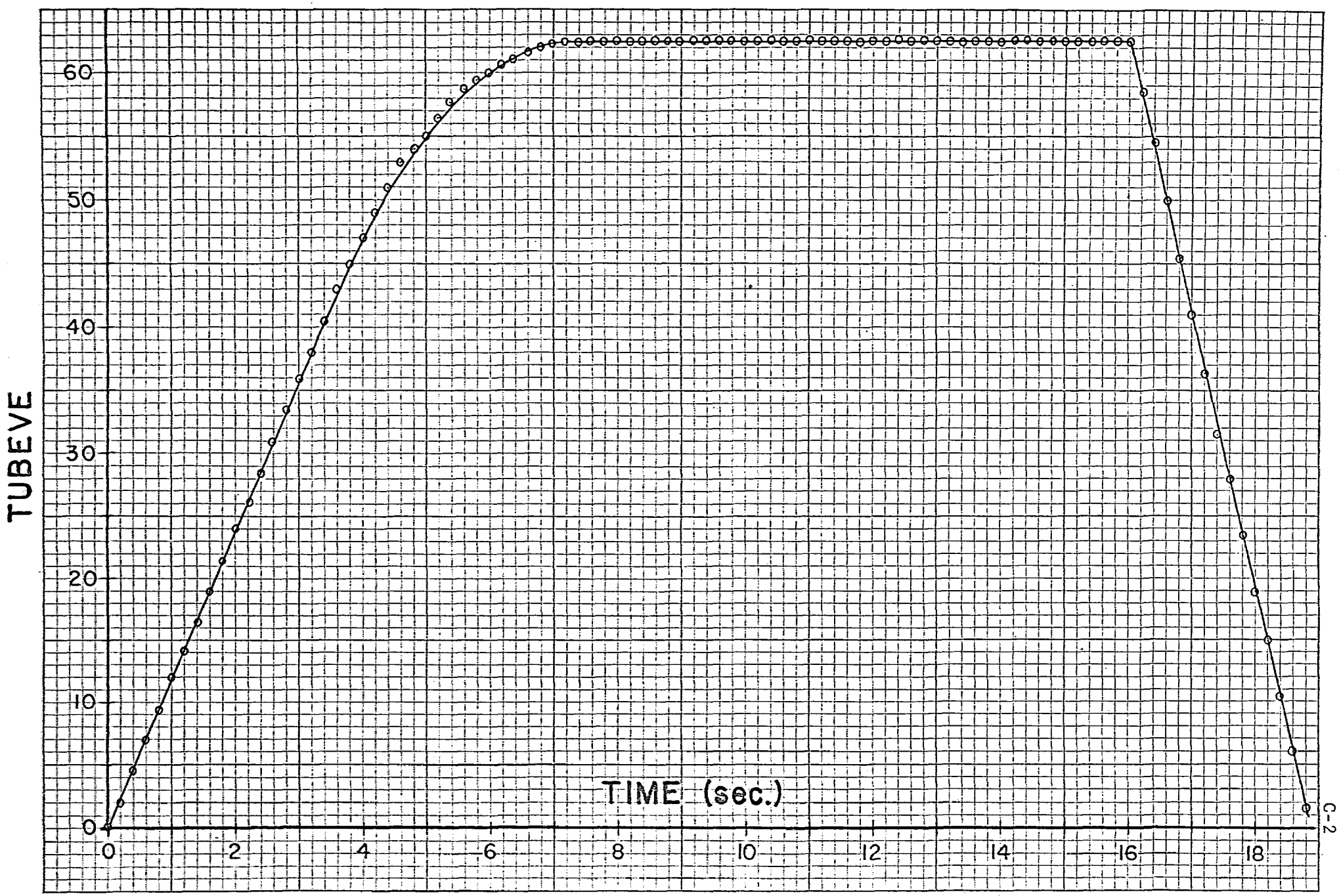
APPENDIX C

Plots Analyzing Computer Output Reliability

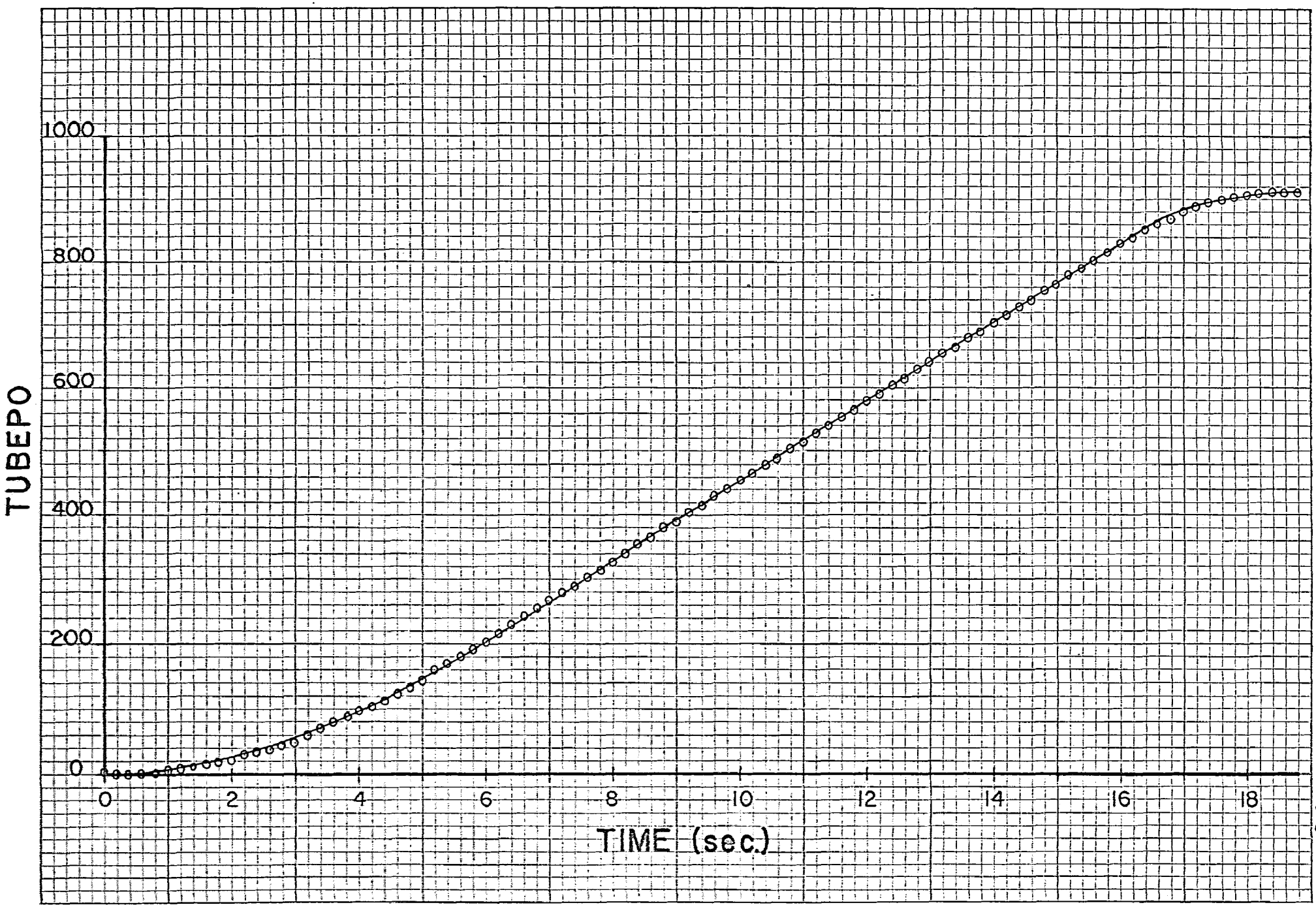
KEUFFEL & ESSER CO.



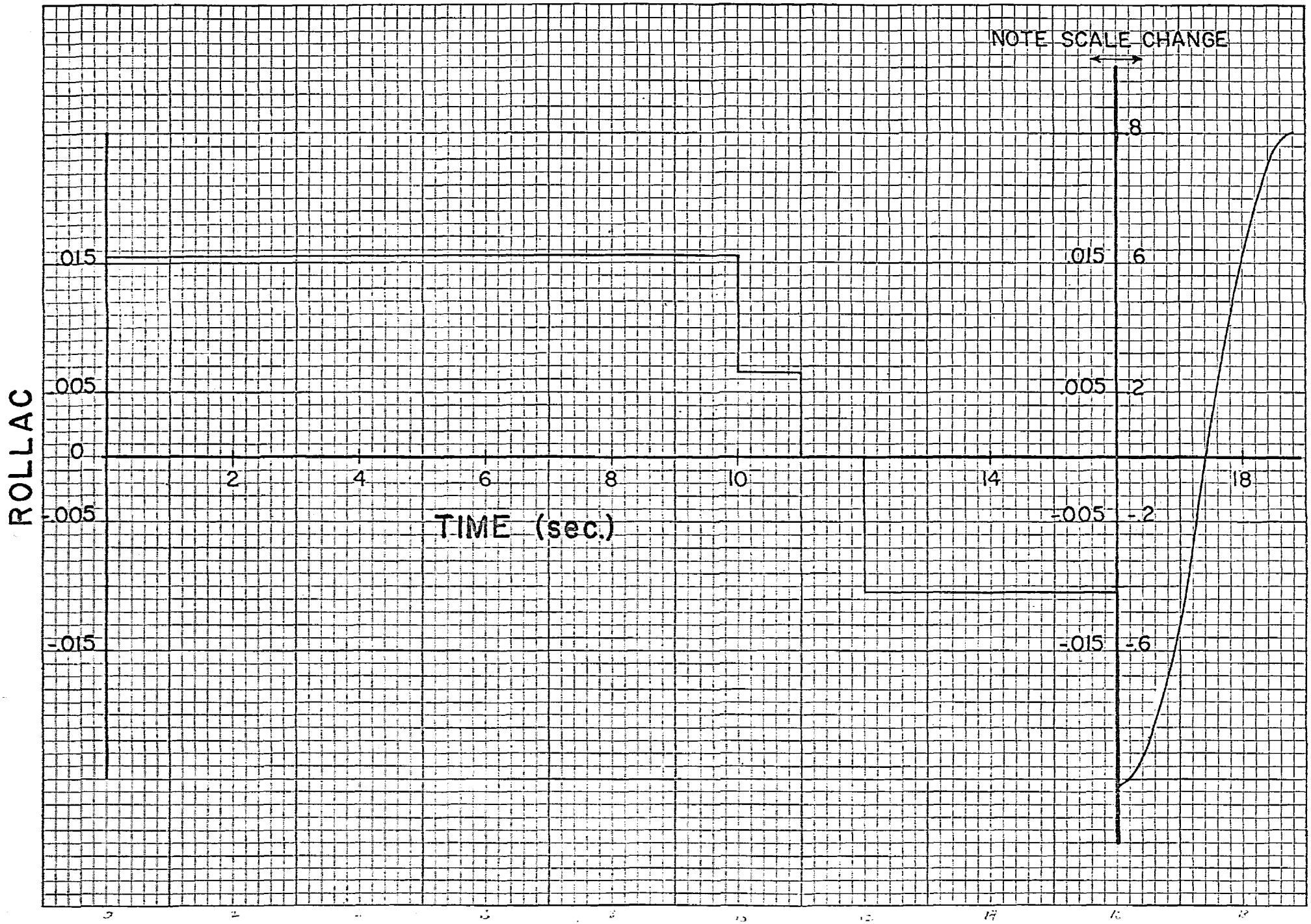
KEUFFEL & ESSER CO.



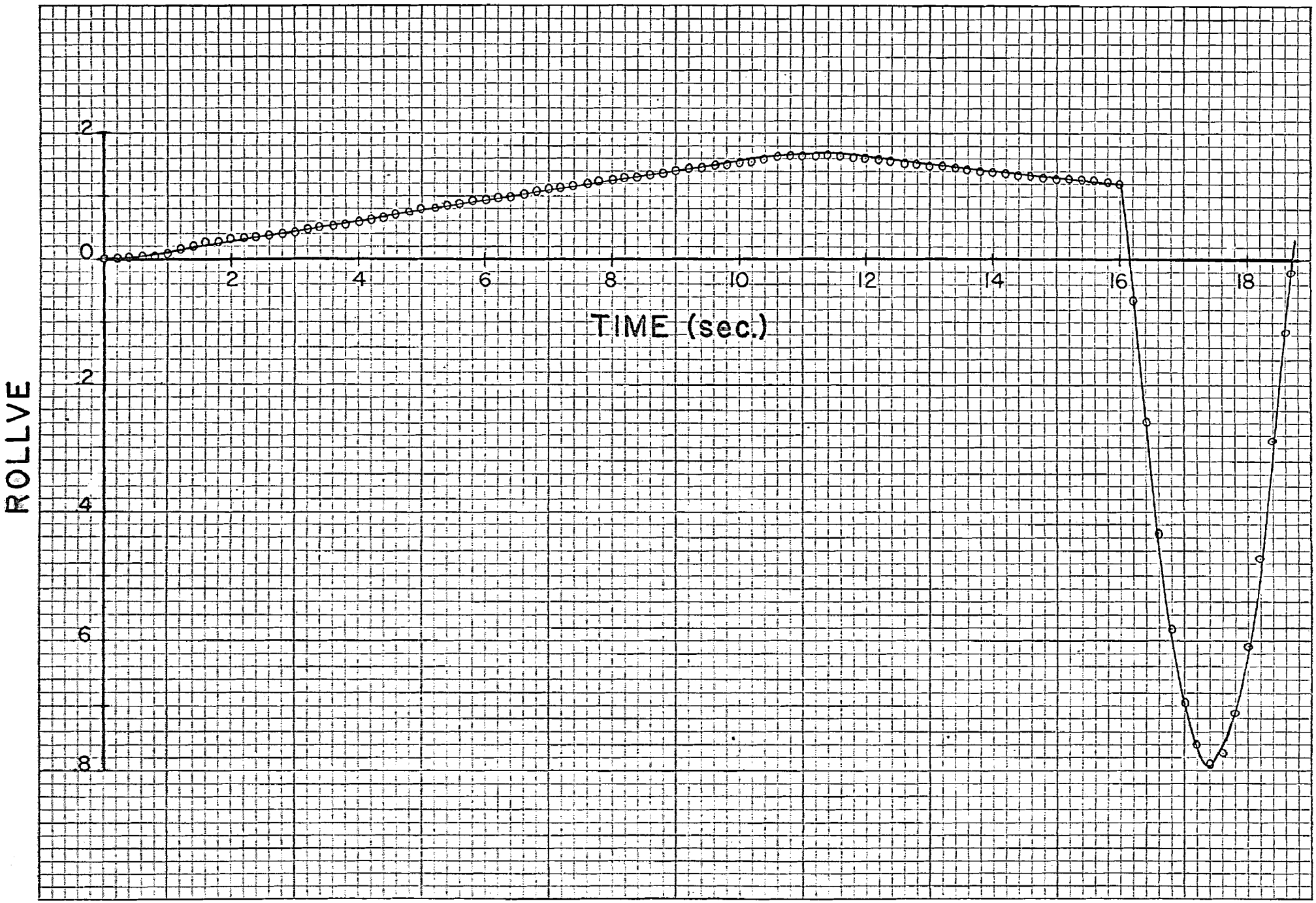
KEUFFEL & ESSER CO.



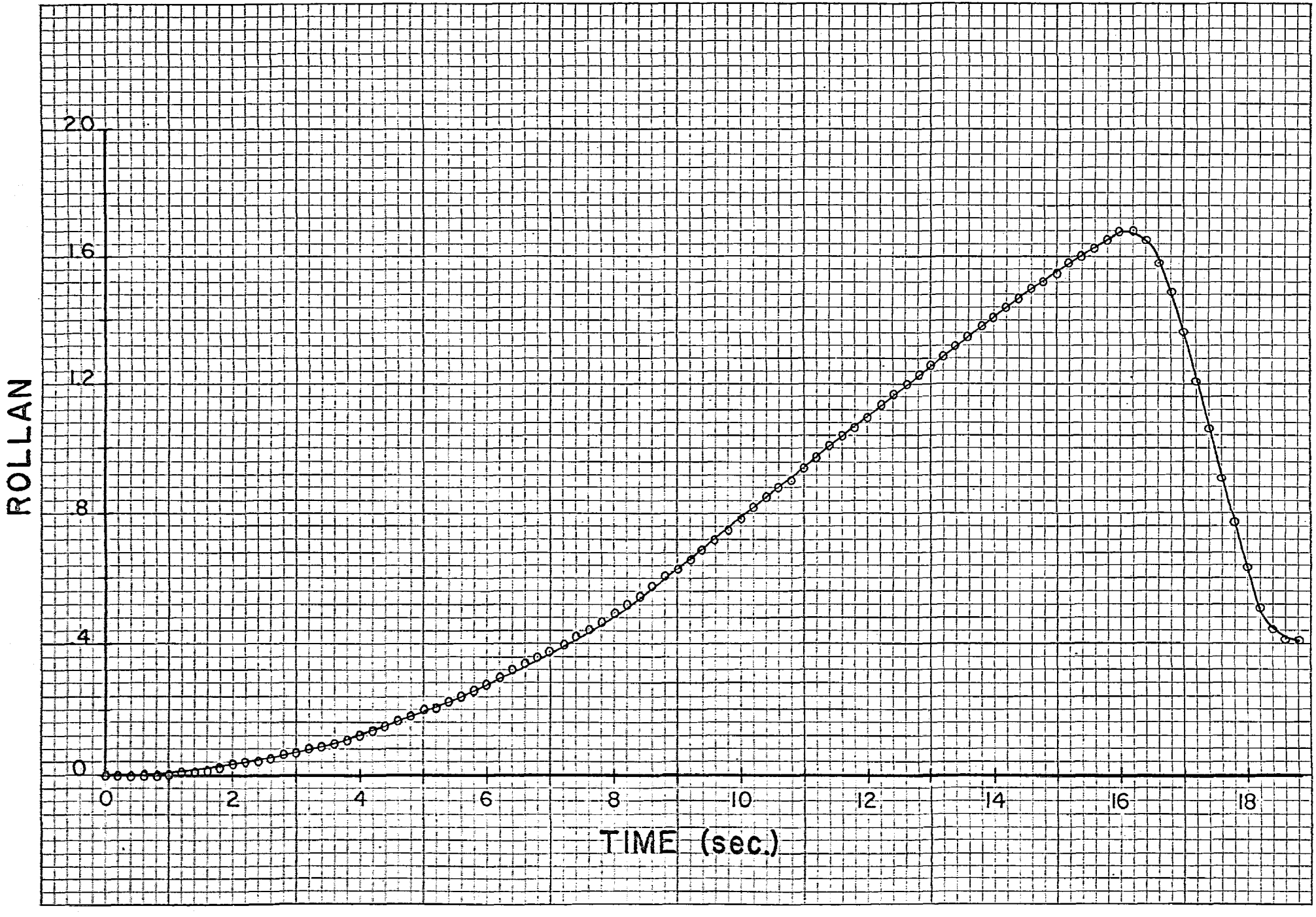
K+E 10 X 10 TO THE INCH 46 0700
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.



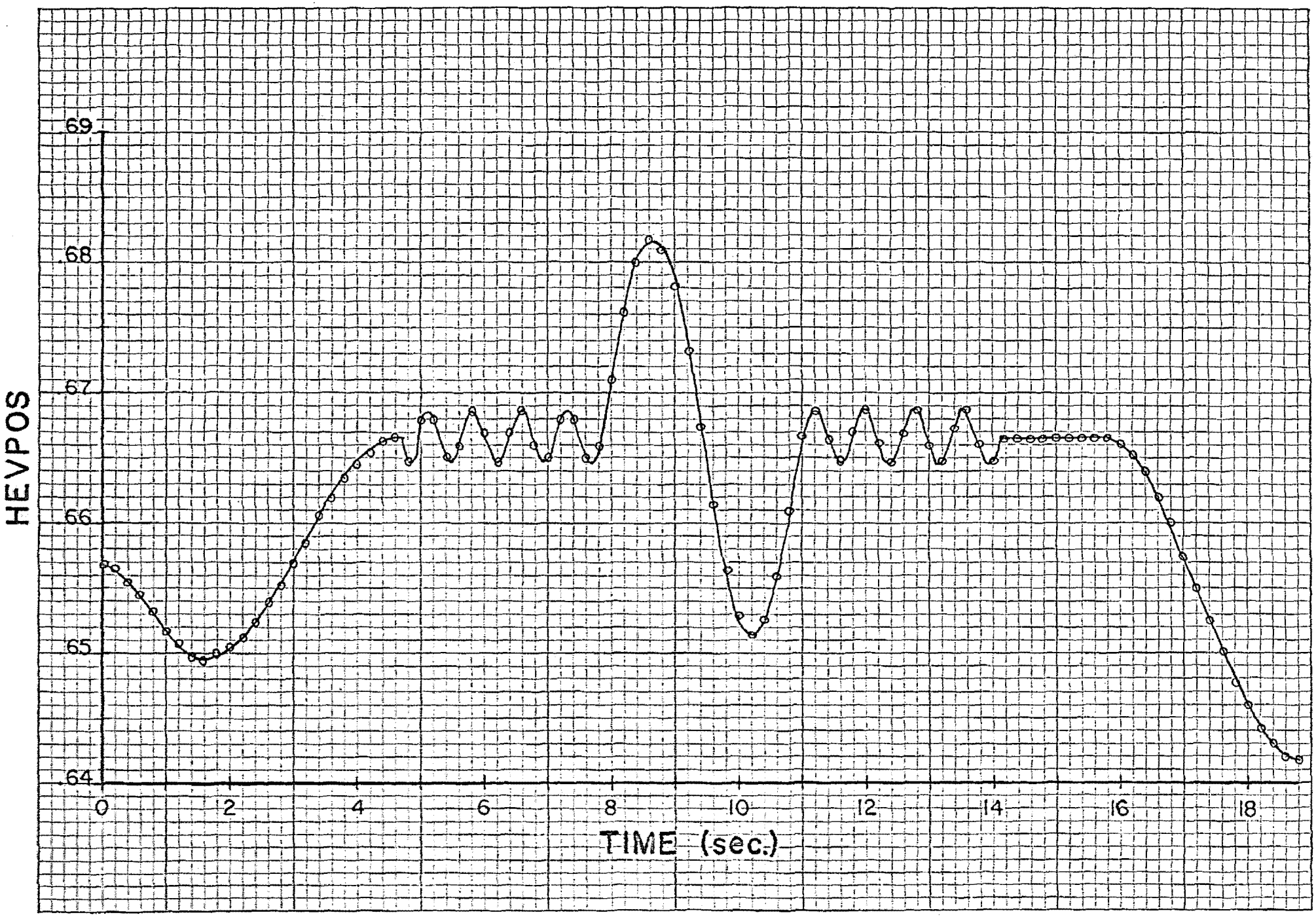
K+E 10 X 10 TO THE INCH 46 0700
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.



K+E 10 X 10 TO THE INCH 46 0700
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.

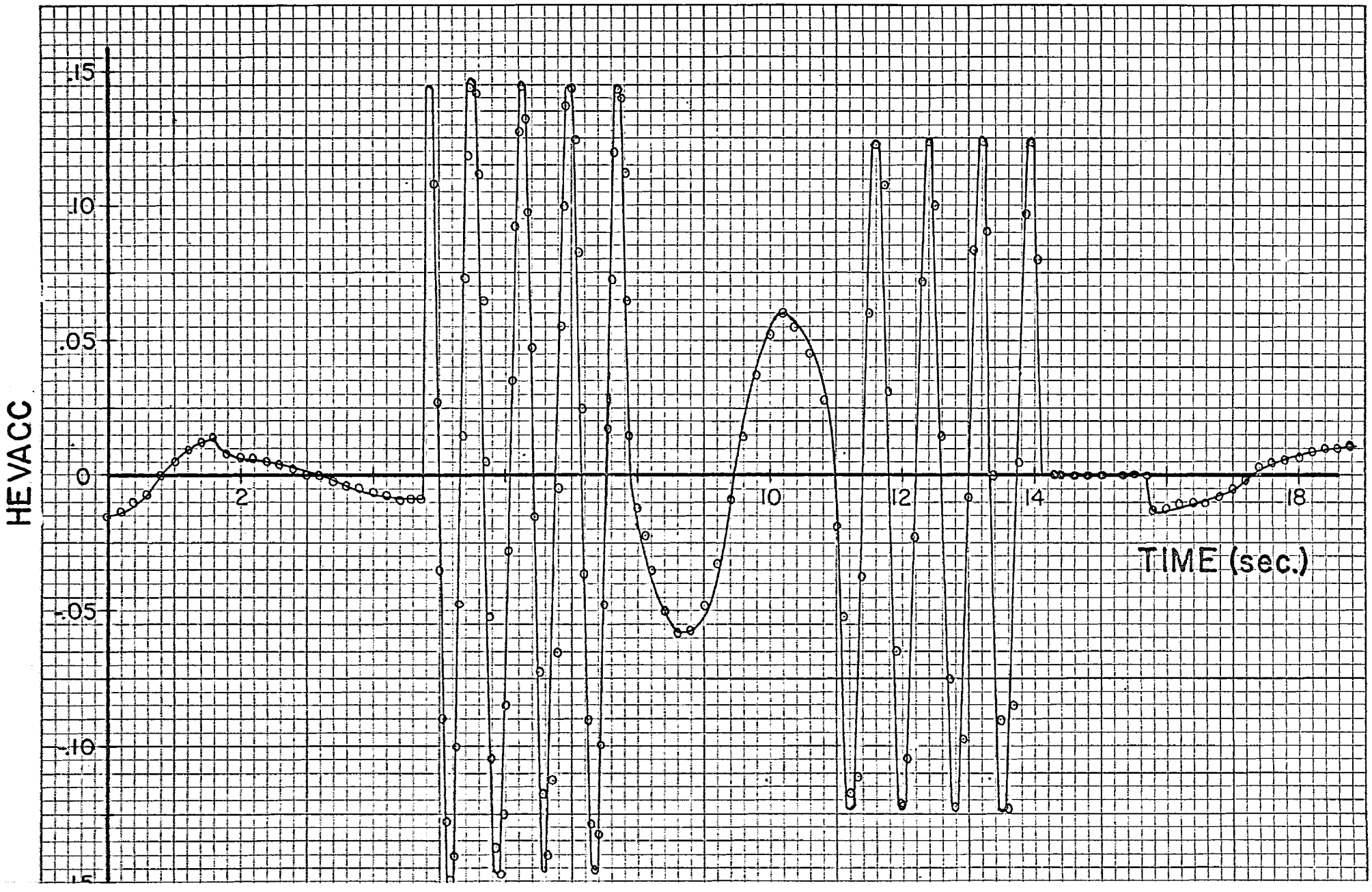


K+E 10 X 10 TO THE INCH 46 0700
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.

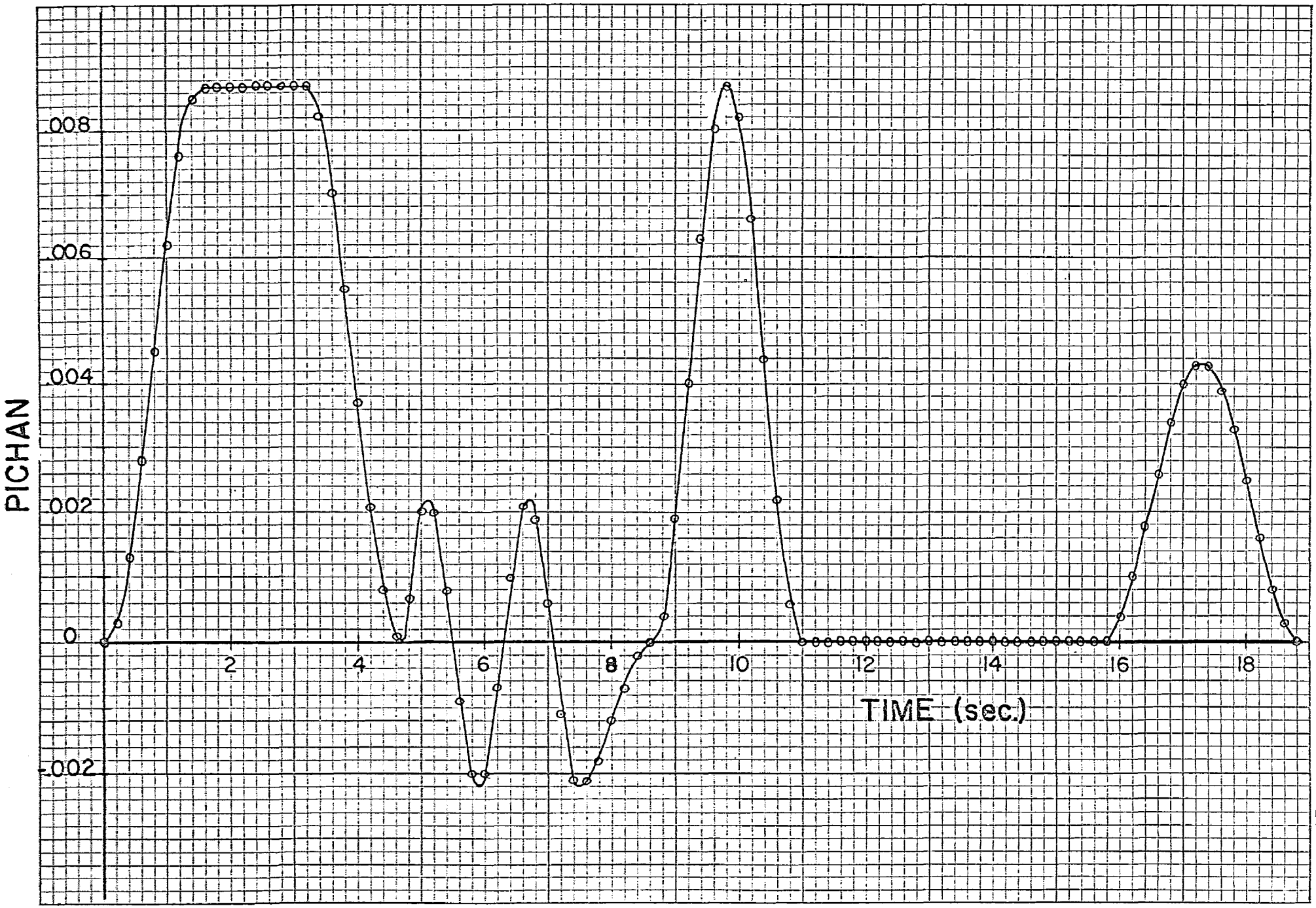
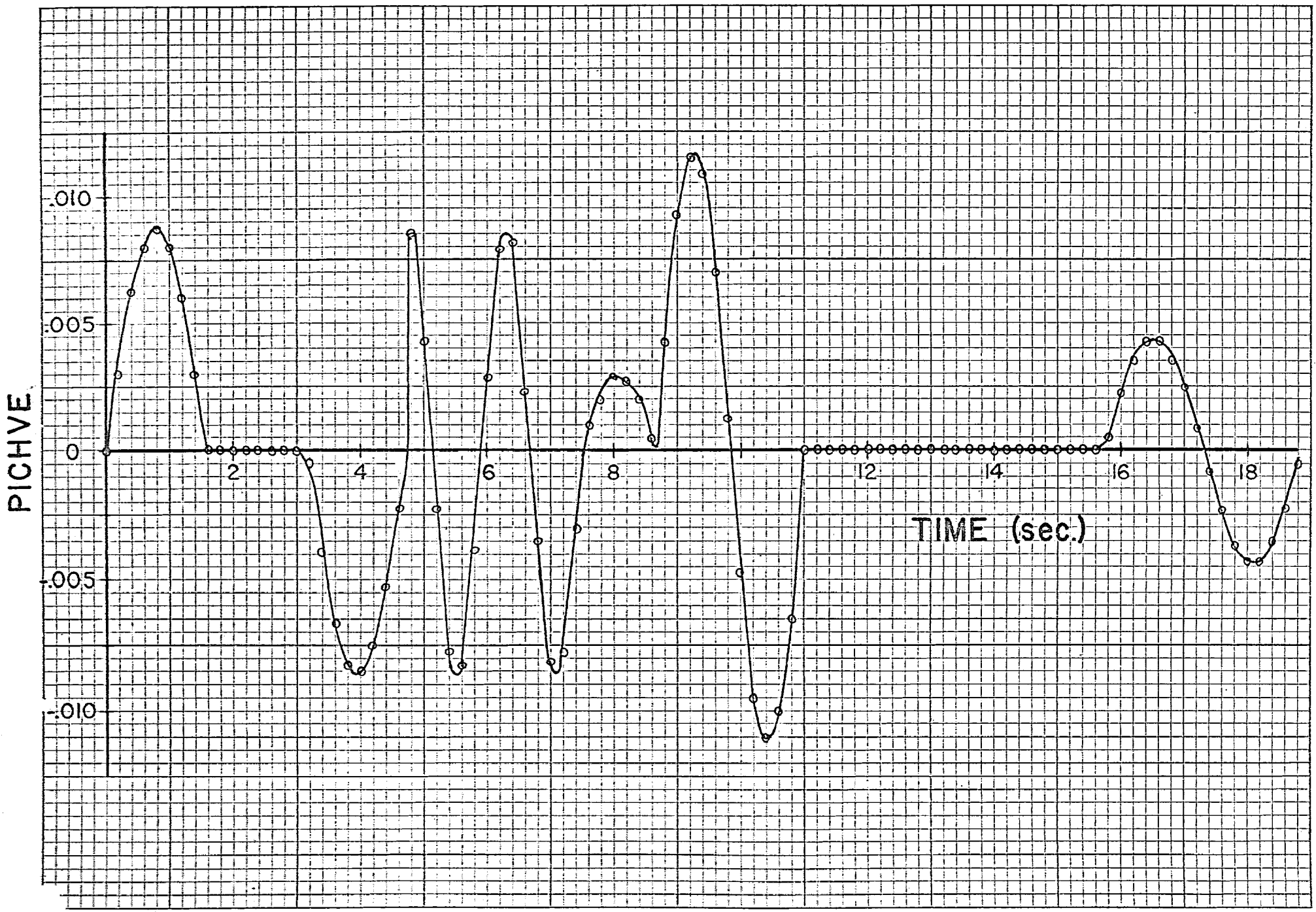


K+E 10 X 10 TO THE INCH 46 0700
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.

K+E 10 X 10 TO THE INCH 46 0700
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.



K&E 7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.



K+E 10 X 10 TO THE INCH 46 0700
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.