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1.0 INTRODUCTION

1.1 The Micro-Radian autocollimator is an electro-optical instrument that uses its own collimated light to accurately measure small angular displacements of an external reflector.

1.1.1 The autocollimator functions by projecting its beam of light onto the reflector and measuring changes in the direction of the reflection.

1.1.2 Although the reflector is essential to the operation, it is not supplied except as an accessory. Usually the reflector is an integral part of the equipment that is subject to rotational, torsional or flexural movement.

1.1.3 The autocollimator does not constrain or interact with the equipment bearing the reflector.

2.0 COMPONENTS

2.1 The autocollimator consists of an optical head and an electronic unit.

2.1.1 The optical head contains the optical elements, the light sources, a silicon photodetector, a preamplifier, and an aiming mechanism.

2.1.2 The electronic unit contains regulated power supplies, a lamp driving oscillator, a synchronous detector, a gain control and a digital panel meter. The meter displays the analog output voltage. A push button circuit breaker is located on the rear of the electronic unit.

2.1.2.1 A BNC connector on the front panel supplies an analog output for interfacing the autocollimator with computers, recorders and oscilloscopes.

3.0 CONFIGURATION, DIMENSIONS

3.1 The Micro-Radian optical head is compact, rigid, and stable, with a cylindrical shape, and a one-inch (25.4 mm) aperture (See Fig. 1). The low internal head dissipation results in a low warm-up drift, and symmetry provides the ability to follow ambient temperature changes with very little thermal distortion.

3.1.1 The optical head may be mounted in any position.

3.2 The electronic unit is supplied in a cabinet configuration. The cabinet for a single axis instrument measures:

10.25 inches wide, 3.5 inches high, 11 inches deep
(260 mm wide, 90 mm high, 283 mm deep)

The cabinet for a dual-axis instrument measures:

14.2 inches wide, 4.5 inches high, 11 inches deep
(360 mm wide, 115 mm high, 283 mm deep)

4.0 SOLID STATE

4.1 All active devices in both the optical head and the electronic unit are solid state.

4.1.1 The 2 light sources are light-emitting diodes (630 nm), modulated 180 degrees out of phase. Their probable life is several decades.

4.1.1.1 The light does not harm the eyes when looking into the barrel.

5.0 RESOLUTION

5.1 The ability of an autocollimator to resolve small angular changes is not directly related to the size of the aperture. The light returning from the reflector and re-entering the autocollimator forms an image in the vicinity of a slit, behind which is a photo-sensitive detector. Rotation of the reflector causes the return image to move across the slit and changes the amount of light falling on the detector. Therefore, image movement, not image sharpness, is what is being resolved. The detector is so sensitive that an objective lens focal length of only a few inches provides sufficient image movement for resolving less than a tenth of a second of arc (0.5 microradian). Even when looking at a mirror 6 mm in diameter, the resolution remains better than one second (5 microradians).

5.1.1 In astronomy, by way of distinction, resolution refers to the ability of a telescope to separate star images, and is therefore a function of the aperture size.

6.0 MEASURING AXIS

6.1 This autocollimator will measure angular changes about any one axis, and is known as a single axis autocollimator.

6.2 By rotating the optical head in the clamp that holds the barrel, the measuring axis may be chosen to be vertical, horizontal, or at any angle in between.

6.3 It is often customary to speak of the measuring direction instead of the measuring axis, as by saying that the instrument is set up for azimuth measurements, or elevation measurements.

7.0 MOUNTING

7.1 The optical head is intended to be mounted by clamping the barrel in a stand, fixture, or V-block (See 3.1.1). Circumferential clamping is preferable to V-block clamping.

7.1.1 Warning: Do not clamp too tightly. There is a sliding cell inside the barrel, and even though the barrel wall is 1/4 inch (6.35 mm) thick hardened stainless steel, it can be forced out of round enough to jam the cell, especially in a V-block. If the knurled knob slips and does not drive the dial (other than at the end of travel), ease up on the clamp.

7.1.2 Micro-Radian autocollimator stands are available that exert a sufficient but limited circumferential clamping force. The Model MR-20 stand is kinematically adjustable in 2 axes, with coarse and fine adjustments (See 28.0 and figure 3).

8.0 THE KNOB, DRUM DIAL, AND LINEAR SCALE

8.1 The large knob at the rear of the optical head turns the drum dial and also operates a micrometer screw that changes the aiming direction of the light beam (See 10.0).

8.1.1 The knob is a two-part device. The knurled section drives the micrometer screw through a clutch.

8.1.1.1 The larger, shorter, forward section of the knob drives the micrometer screw directly, and is only to be used for backing off if the micrometer screw has been driven into the stops at either end of its travel.

8.2 One turn of the drum dial changes the aiming direction by 5 seconds of arc (approx. 25 microradians).

8.2.1 The dial is graduated in tenths of a second (approx. 0.5 microradian).

8.2.1.1 Note: 0.5 microradian is 3% larger than 0.1 sec. (See 31.0).

8.3 The linear scale pointer follows the micrometer screw.

8.3.1 Each graduation on the linear scale corresponds to one turn of the dial, so the dial and scale are read just like a micrometer.

8.4 The dial/scale measuring range covers 200 seconds (approx. 1 milliradian), and requires 40 turns of the dial.

8.5 The dial is used for direct measurements (See 14.1), for calibrating the analog output and the error signals (See 14.2 and 14.3), and for fine alignment.

8.6 Autocollimators without dials are made by Micro-Radian for analog and and error signal applications. When used for analog readout, such an instrument is sometimes called an angle transducer. The same instrument used as an error detector might be called a signal autocollimator or a nulling autocollimator. The size can be reduced to 23 mm X 30.5 mm X 53 mm (0.9 X 1.2 X 2.05 inches).

9.0 PRINCIPLES OF OPERATION

9.1 The optical schematic of the autocollimator is shown in Fig. 2.

9.1.1 In Fig. 2a, M is the external mirror, L is the objective lens, W is an optical wedge, S_1 and S_2 are light sources, and R_1 and R_2 are reflecting surfaces. R_1 and R_2 are separated by a small gap or slit which admits return light to the photodector D.

9.1.2 The wedge W is moveable to the left and right by means of the knob and lead screw. In Fig. 2a, W is shown in its center position.

9.1.3 S_1 and S_2 are modulated out of phase. S_1 lights on the positive alternations of the applied power, and S_2 lights on the negative alternations.

9.1.4 The direction of mirror rotation is sensed according to the phase of the light reaching D.

9.2 If M is rotated as in Fig. 2b, the same emergent ray as in Fig. 2a now returns too high. In this case, moving the wedge toward the slit (Fig. 2e) causes the emergent ray to fall perpendicularly on M and return on itself.

9.3 If M is rotated as in Fig. 2d, the same emergent ray as in Fig. 2a now returns too low. In this case, moving the wedge toward the slit (Fig. 2e) causes the emergent ray to fall perpendicularly on M and return on itself.

9.4 The relation between mirror rotation and wedge travel is inherently linear. Therefore, the dial and scale have uniform graduations without any need for a cam, sine bar, or other correcting mechanism.

9.5 The dial/scale readings are independent of the mirror distance because the light is collimated.

10.0 VARIABLE AIM

10.1 The term "variable aim" has been adopted to describe the fact that the Micro-Radian autocollimator aligns by varying its aiming direction in order to look perpendicularly at the mirror, as in Figs. 2a, 2c, and 2e. This patented feature is unique.

11.0 ALIGNMENT

11.1 When conditions are as shown in Figs. 2a, 2c, and 2e, the autocollimator is said to be aligned, or nulled, on the mirror.

11.1.1 Alignment corresponds to a zero readout on the digital display.

11.1.2 Alignment corresponds to the zero cross-over point on the analog output.

11.2 Alignment also requires that the reflection be approximately centered in the non-measuring direction (often called the orthogonal direction).

11.2.1 The best procedure for centering the return image in the non-measuring direction is to rotate the autocollimator 90° in its stand and adjust for an approximate null, then rotate back to the measuring position (See 29.9).

12.0 CROSS-COUPLING

12.1 When mirror rotation in the orthogonal direction causes a readout in the measuring direction, cross-coupling is said to be present. It occurs when the return image is moving slightly slantwise with respect to the slit. It is a problem that may be encountered in setting up any autocollimator.

12.1.1 By successive small rotations of the autocollimator barrel in its mount, an orientation will be found where the cross-coupling is minimized. The minimum will usually be less than 1%.

13.0 STARTING POINT FOR MEASUREMENTS

13.1 Any arbitrary initial alignment, as in Figs. 2a, 2c, or 2e, may be used as the starting point for measurements.

13.2 The dial is convenient for the last seconds of adjustment needed to establish alignment; much easier than trying to budge the autocollimator stand or the mirror stand.

14.0 THREE USES FOR THE ELECTRONIC AUTOCOLLIMATOR: DIAL MEASUREMENTS, ANALOG MEASUREMENTS (TRACKING), AND ERROR SIGNALS

14.1 Dial Measurements: If the mirror rotates after an initial alignment has been established, the amount of rotation may be accurately measured by using the dial to re-establish null and taking the difference between the initial and final dial readings. Going from null to null is the most accurate way to use an electronic autocollimator because the full accuracy of the lead screw is obtained.

14.1.1 Even though an anti-backlash feature is built in, it is possible that backlash may amount to one or two tenths of a second. Approach null from the same direction when readings are to be made to 0.1 second.

14.2 Analog Measurements and Tracking: Mirror rotation may be closely measured by meter readings and/or analog output. Analog tracking is used for convenience or whenever the mirror rotation is too rapid or too prolonged to follow with the dial. The analog output may be recorded (See

2.1.2.1). The calibration is easily determined as in 16.0; accuracy is discussed in 17.0.

14.2.1 The analog output is a DC voltage. Its value drops to zero at null, and its polarity reverses after crossing through null. Saturation levels are approximately ±10 volts.

14.3 Error Signals: The autocollimator may be used as the error signal generator in angle-holding, or null-seeking, closed-loop servo systems. The error signal is essentially the analog output, with the distinction that the servo is concerned with the slope of the output while analog measurements relate to the magnitude of the output.

14.3.1 Calibration of the error signal usually amounts to taking one point (See 15.3).

15.0 GAIN, SCALE FACTOR AND SLOPE

15.1 The gain control is located on the panel of the electronic unit.

15.2 The scale factor (volts/second) of the analog (or error) signal is adjustable by means of the gain. For example, after a null has been established, if the dial is turned 50 seconds and the gain is adjusted to bring the analog output to 10 volts, you have a ±50 second analog readout (See also 29.5).

15.3 The slope established by a one-point calibration, as easily as the example in 15.2, is usually adequate for servos.

16.0 CALIBRATION

16.1 Calibrating the analog means making a plot of output voltage vs. seconds, and is readily done for a particular set-up by turning the dial in increments and noting the output voltage, or the meter reading, for each dial setting. A plot of this type is included in this manual. The analog calibration is based on the fact that turning the dial through a given number of seconds while looking at a fixed mirror is exactly equivalent to turning the mirror through the same number of seconds while the dial is fixed. The more points on the calibration plot, the greater the accuracy, but after the shape of the voltage-angle relationship has been determined once, fewer points should suffice for new set-ups. An appreciable change in mirror distance, mirror size, or gain constitutes a new set-up.

17.0 ACCURACY AND LINEARITY

17.1 Dial: 0.1 second over any 5 seconds
1.0 second over an 100 seconds

17.1.1 The dial calibration is traceable to the U.S. Bureau of Standards.

17.1.2 Autocollimators of identical mechanical design and construction date back to 1968, and there has been no case of an instrument going out of calibration.

17.2 Analog Linearity: normally ±0.2 sec over ±10 sec at full gain. At lower gain, to cover a wider analog range, it is advisable to obtain a calibration curve as in 16.0. Linearity can be adjusted to be best at one particular gain, usually chosen to be full gain.

17.2.1 Analog Accuracy: as good as the calibration (see 16.0).

17.3 Error Signals: null repeatability = ±0.1 sec or less. For slope accuracy in servo nulling, see 15.3.

18.0 DYNAMIC RESPONSE

18.1 The data bandwidth, or the maximum frequency at which the analog output voltage will track an oscillating mirror, is, by Nyquist's criterion, equal to 0.5f, where f is the frequency at which the light sources are modulated. However, Micro-Radian sets the bandwidth equal to 0.1f.

18.2 All electronic units contain oscillators powered by regulated D.C. to drive the light sources at approximately 300 Hz, unless a higher bandwidth is ordered. Therefore, the standard bandwidth is 30 Hz (See 21.1.2).

18.2.2 Bandwidths to 1000 Hz may be ordered.

19.0 ACQUIRE

19.1 When a reflection falls on the detector and causes a reading on the digital display, the autocollimator is said to have acquired the reflection.

19.2 For seeking a reflection, the light sources are large enough so that the acquire range extends over ±15 minutes of arc.

19.3 Acquire indication is a standard feature on all Micro-Radian electronic autocollimators. The digital display will only light up when the autocollimator has acquired its own light.

19.3.1 If the digital display goes out near null, stays on when the objective lens is covered, or stays on when the mirror is too far away from null to return any of the autocollimator's own light, the acquire may need adjusting.

19.3.2 Cover the objective lens with a dark, non-reflective mask and adjust pot no. R-39 inside the electronic unit until the display goes out when the mask is in place and stays on when the mask is removed. Only a slight adjustment should be necessary.

20.0 NOISE

20.1 Noise, as seen on the meter and on the output, originates both internally and externally.

20.1.2 Internal noise has three sources:

20.1.2.1 Photodetector and circuit noise.

20.1.2.2 Refractive variations due to air convection in the internal light path (almost non-existent inside the small Micro-Radian barrel).

20.1.2.3 Ripple from the demodulator, at twice the modulation frequency, amounting to a few millivolts.

20.1.3 External noise has three sources:

20.1.3.1 Refraction due to air temperature variations in the optical path between the autocollimator and the mirror. This can easily cause fluctuations of a second in a few inches of path, and several seconds in a path of several feet, especially if there are drafts, or air currents from heaters or air conditioners.

20.1.3.2 Vibration: Even though the autocollimator and the mirror might be clamped to a heavy base, the whole structure will seldom vibrate as a unit without flexure. Vibration may come from machinery in the next room or from traffic. Place a dish of water on the base and look at the reflection of a ceiling light in the surface. Ripples signify a problem.

20.1.3.3 Pick-up from 60 Hz wiring, fluorescent fixtures, and equipment; not normally encountered unless fluorescent light enters nearly along the axis. Avoid shiny metal parts adjacent to the mirror.

20.2 Remedies: Air noise and vibration noise contain low frequencies that may fall within the signal bandwidth. To that extent they cannot be filtered out, but must be avoided.

20.2.1 Air turbulence may be diminished by enclosing the optical path in a

cardboard tube. Of course, there may be convection within the tube, so elevation measurements may be accompanied by more air noise than azimuth measurements.

20.2.2 The remedy for vibration is isolation.

20.3 Noise limitation: the unavoidable noise puts a limitation on the minimum readable angular change (see 21.1.1). As with any signal containing noise, the limit is dependent on the allowable time for obtaining a mean reading.

20.3.1 Sometimes the user may wish to integrate, or smooth, the noise at the signal output, such as by adding an RC time constant to the output.

20.3.2 The signal plus noise may be recorded for a time, and a mean drawn through the noise.

21.0 TRADE-OFFS

21.1 The most important trade-off is sensitivity vs. bandwidth. As bandwidth increases toward 1000 Hz, more of the internal noise spectrum rides through, and sub-second signals get buried. On the other hand, if bandwidth is filtered down to the order of 0.1 Hz, the sensitivity approaches 0.001 sec.

21.1.1 Sensitivity is defined here as the minimum detectable signal and is set equal to the RMS noise voltage.

21.1.2 Bandwidth is defined as the frequency at which the low-pass characteristic of a 3rd-order Chebyshev filter is down 3db. The ripple factor of the filter is 0.1.

21.1.3 The following table gives reasonable expectations:

Bandwidth	RMS Noise-equivalent angle	
	Micro-radians	Seconds
0.1 Hz or less	0.005	0.001
1.0 Hz	0.05	0.01
5 Hz	0.1	0.02
30 Hz	0.5	0.1
100 Hz	1.2	0.25
300 Hz	3	0.6
1000 Hz	5	1.0

21.2 Another Trade-Off is Mirror Distance vs. Analog Range. The following table summarizes the calculated relationship as modified by practical experience:

Max. Total Analog Range		Corresponding Max. Mirror Distance	
Milliradians	Seconds	Meters	Feet
6.0	1200	1.3	4
3.0	600	2.8	9
2.0	400	4.8	16
1.0	200	8.5	28
0.5	100	15	50
0.1	20	30	100

22.0 MAXIMUM ANALOG SIGNAL

22.1 The Analog Signal is limited by either electronic saturation (see 14.2.1), or by the slit becoming full of reflected light (in which case further rotation of the mirror cannot put more light on the photo-detector). The latter condition is called geometrical saturation.

22.2 The standard slit saturates for changes in the direction of the reflection of about ±150 sec. (0.75 millirad). Wider slits, saturating at various ranges up to ±600 sec. (±3 mr), are optional, but that seems to be the widest for which the output can be reasonably linearized.

23.0 TEMPERATURE AND HUMIDITY

23.1 Operating temperature: Maximum 52°C/125°F
Minimum -18°C/0°F or the dew point, whichever is higher.

23.2 Storage temperature: Maximum 65°C/150°F
Minimum -30°C/-20°F or the dew point, whichever is higher.

23.3 Humidity: the relative humidity is not important provided condensation does not occur. The optical elements cannot function properly if coated with moisture droplets, frost, or ice. If a drop of condensation is collected between some of the optical elements and then frozen, the force exerted could cause a permanent displacement that might impair operation.

23.4 Temperature Coefficient: the null may shift a maximum of 0.2 arc second per degree C in the range from 15°C/60°F to 32°C/90°F. Beyond these temperatures, the coefficient has not been measured.

24.0 DIGITAL DISPLAY

24.1 The standard digital panel meter is a 3½ digit solid state voltmeter which samples and displays the analog output voltage at a 3 Hz rate.

25.0 OUTPUT CONNECTOR

25.1 A BNC connector on the front panel supplies an analog output for interfacing the autocollimator with oscilloscopes, computers and recorders.

25.2 Short circuiting the output to ground will do no harm to the electronics.

25.3 The output will source or sink 5 milliamps.

26.0 DUAL-AXIS SYSTEMS

26.1 Dual-axis systems consist of 2 optical heads and a single cabinet dual electronic unit. Separate electronic units for each axis are optional. Also optional as an accessory is the MR-40 dual stand which mounts two MRA-150 or MRA-145 series optical heads side-by-side on a center-to-center distance of 57.2mm (2.25 inches). Operation of dual-axis systems is the same as for the single axis units.

27.0 MIRRORS AND PRISMS

27.1 Mirrors for use in making measurements to 0.1 sec. should be of the front-surface type, and be flat to about 1/10 wave. The best material is fused quartz, but pyrex is satisfactory in a laboratory environment. The thickness should be 15 to 20% of the diameter so that the mounting clamps will not cause appreciable bending.

27.2 Prisms such as pentas and porros must be free of strains and striae, and have deviation errors of no more than a few arc seconds.

28.0 USE OF THE MR-20 STAND (See Figure 3)

28.1 Open the circumferential clamp on the stand by tightening the clamp knob. Insert the optical head, sliding it forward until the index pin mates with one of the two index holes in the clamp. Indexing the autocollimator so that the scale window is up places the optical head in position to measure azimuth angles. Rotating the optical head 90° to the second index position sets the instrument for elevation angles (scale window facing sideways).

29.0 OPERATING INSTRUCTIONS. This section will refer frequently to the plot of output vs. angle (Fig. 4).

29.1 Mount the optical head and aim it at the mirror (see 3.1.1, 6.2, 7.0, and 28.0).

29.2 Connect the cable between the optical head and the electronic unit.

29.3 Plug the power cable into a 3-wire outlet of the proper voltage and frequency.

29.4 Turn the electronic unit on and set the gain control at position 2. The power switch will be illuminated green and a rectangle of red light should be seen when looking into the barrel of the optical head. This red light is harmless to the eye. The digital panel meter may or may not be lit up (see section 19.3).

29.5 Gain Control: Start with the gain low while acquiring a reflection. As the alignment gets better, the gain can be increased. The final gain setting will depend on what analog working range you want, such as ±10 seconds, ±25 seconds, ±50 seconds or some other range (see 15.2, 21.2 and 22.0).

29.6 The first indication on the digital panel meter will be a voltage located somewhere on the curve defined by DCAOA'C'D'(fig. 4). The object of initial alignment is to get the output to go to point O (center zero, or null) by moving the autocollimator or the mirror. In the plot shown, the horizontal (or X) axis may be either the azimuth or elevation axis depending on the rotational orientation of the optical head in the stand.

29.7 A few definitions may be of assistance (See fig. 4).

29.7.1 The distance from D to D' along the X-axis is the total acquire range, usually expressed in arc minutes. The acquire range will be greatest (typically ±15 - 20 arc minutes) when the mirror is close (within 12 inches)

to the optical head. The digital display will be on when you are between D and D' and off if you are to the left of D or to the right of D'.

29.7.2 The distance AA' usually expressed in arc seconds, is the total analog measuring range (low gain), shown in this example to be ±100 arc seconds. The slope of the plot from A to A' can be adjusted with the gain control: plot BB' represents high gain.

29.7.3 The plots CAB and B'A'C' are the saturation levels, typically ±10 to 11 volts.

29.7.4 Null, the center 0 position, is where the output changes from + to - (or vice-versa).

29.8 Let's assume that you have obtained an initial minus reading on the digital panel meter. You are somewhere on the plot DCA0. We will further assume that only the mirror will be adjusted, and only in the measuring direction.

29.8.1 If you are between C and A (position 1), the output will be -10 to -11 volts and will not change noticeably with small adjustments of the mirror.

29.8.1.1 Adjust the mirror carefully until the output starts to change.

29.8.1.2 If the output rapidly goes to zero and the display goes out, you have gone the wrong way (towards D).

29.8.1.3 If the output gets less negative and the display goes out no matter which way you turn the mirror, the acquire level may need adjusting (see sections 19.3.1 and 19.3.2).

29.8.2 If you are between D and C (position 2) small adjustments of the mirror will cause the output to:

29.8.2.1 Raise quickly to zero and turn off the display (wrong way) or

29.8.2.2 Drop to the negative saturation level (keep turning the mirror in the same direction).

29.8.3 If you are between A and 0 (position 3), careful mirror adjustments will:

29.8.3.1 Cause the output to drop to the negative saturation level (wrong way) or

29.8.3.2 Cause the output to pass through 0 and on to increasing positive readings. If you're not careful here, the output may jump to the positive saturation level A' to C'.

29.8.4 Alignment, or null, has been achieved when you are at position 0. At this point, the output will rapidly change sign. This sign change must be clearly evident to prove you are at null.

29.9 If you will be measuring azimuth angles, first rotate the optical head

in the stand to the "elevation" position (window sideways) and adjust the autocollimator stand (or the mirror, if it is adjustable) in elevation until an approximate null is achieved. You may have to move the mirror or autocollimator manually in the azimuth direction while making this elevation adjustment. After acquiring a signal, continue with small elevation adjustments until the digital display is reading near null. At this point, the system is sufficiently well aligned in elevation.

29.9.1 Rotate the optical head to use "azimuth" position (window up) and adjust the optical head, or the mirror, in azimuth only, until null is again obtained. Turn the gain up to the desired level. The knob at the back of the optical head may be used for any small adjustments that may be necessary. The autocollimator is now "nulled" on the mirror.

30.0 RANGE AND BANDWIDTH SELECTION

30.1 Model MRA-150C autocollimators have front panel switches for selecting different analog measuring ranges and bandwidths.

30.1.1 Range selection switch:

30.1.1.1 The lower, or smaller, the analog measuring range, the higher the sensitivity.

30.1.1.2 The greatest sensitivity (about .1 arc-second or .5 micro-radian) can be realized by setting the Range to ±10, the Bandwidth to 30, and the Gain to 10.

30.1.1.3 Please note that at the higher analog measuring ranges, the maximum mirror distance is reduced (see the Trade-Off Table, section 21.0).

30.1.1.4 A null shift may be noticed when selecting different analog measuring ranges.

30.1.2 Bandwidth selection switch:

30.1.2.1 The lower the data bandwidth, the higher the sensitivity (see the Trade-Off Table, section 21.0).

30.1.2.2 Changing to different bandwidths will not cause an appreciable null shift.

31.0 RADIANS VS. DEGREES

1 radian = $\frac{360}{2\pi}$	=	57.29578 degrees
1 milliradian	=	0.05729578 degrees
	=	3.4377468 minutes
	=	206.2648 seconds
1 microradian	=	0.2062648 seconds
1 degree	=	0.01745329 radians
	=	17.45329 milliradians
1 minute	=	0.00029088 radians
	=	0.29088 milliradians
	=	290.88 microradians
1 second	=	0.0000048481 radians
	=	0.0048481 milliradians
	=	4.8481 microradians

ALL SOLID STATE ELECTRONIC AUTOCOLLIMATOR

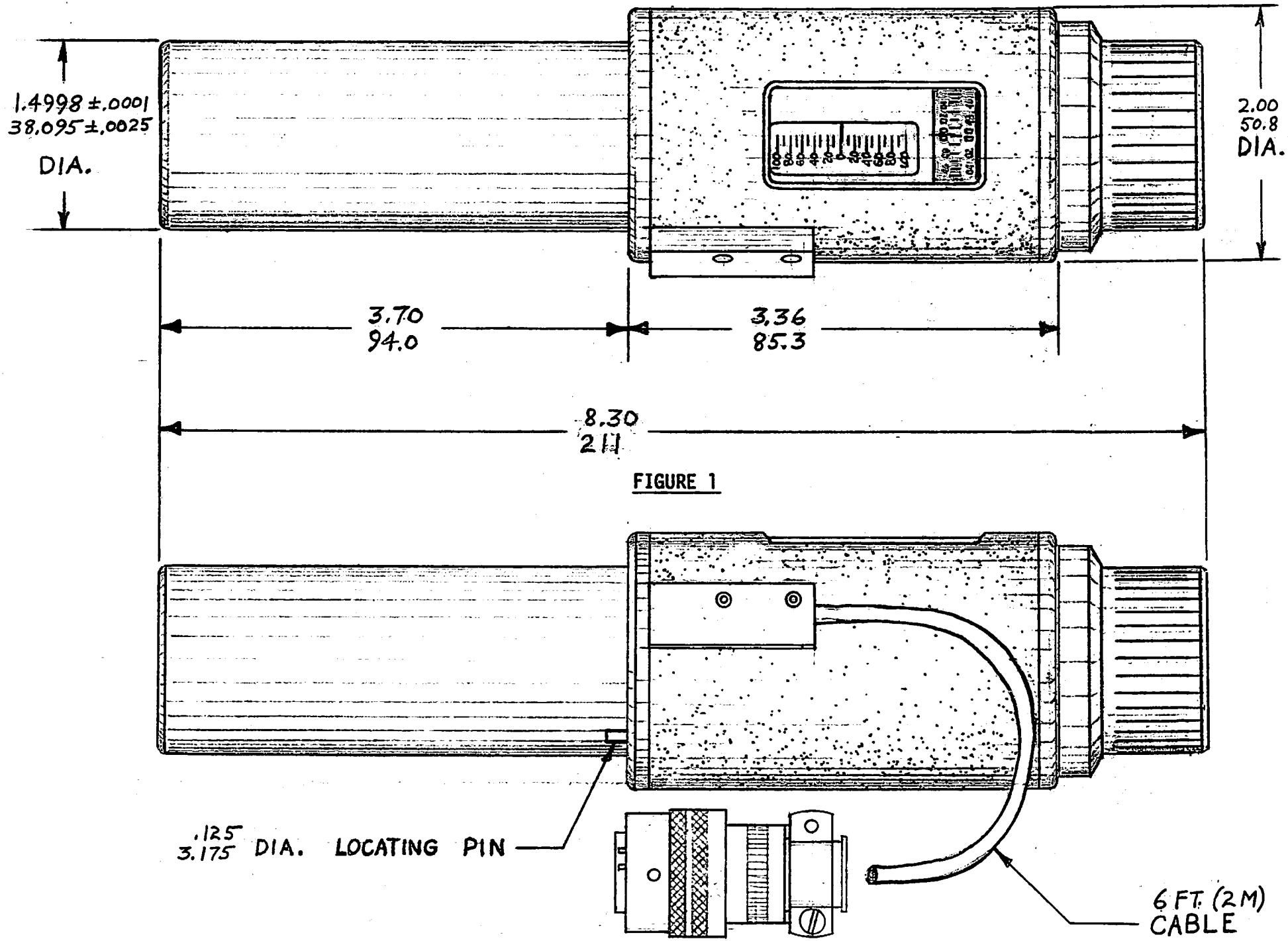


FIGURE 1

MICRO-RADIAN INSTRUMENTS 350 MULBERRY DR. SAN MARCOS, CALIFORNIA 92069

Figure 2 Optical Schematic

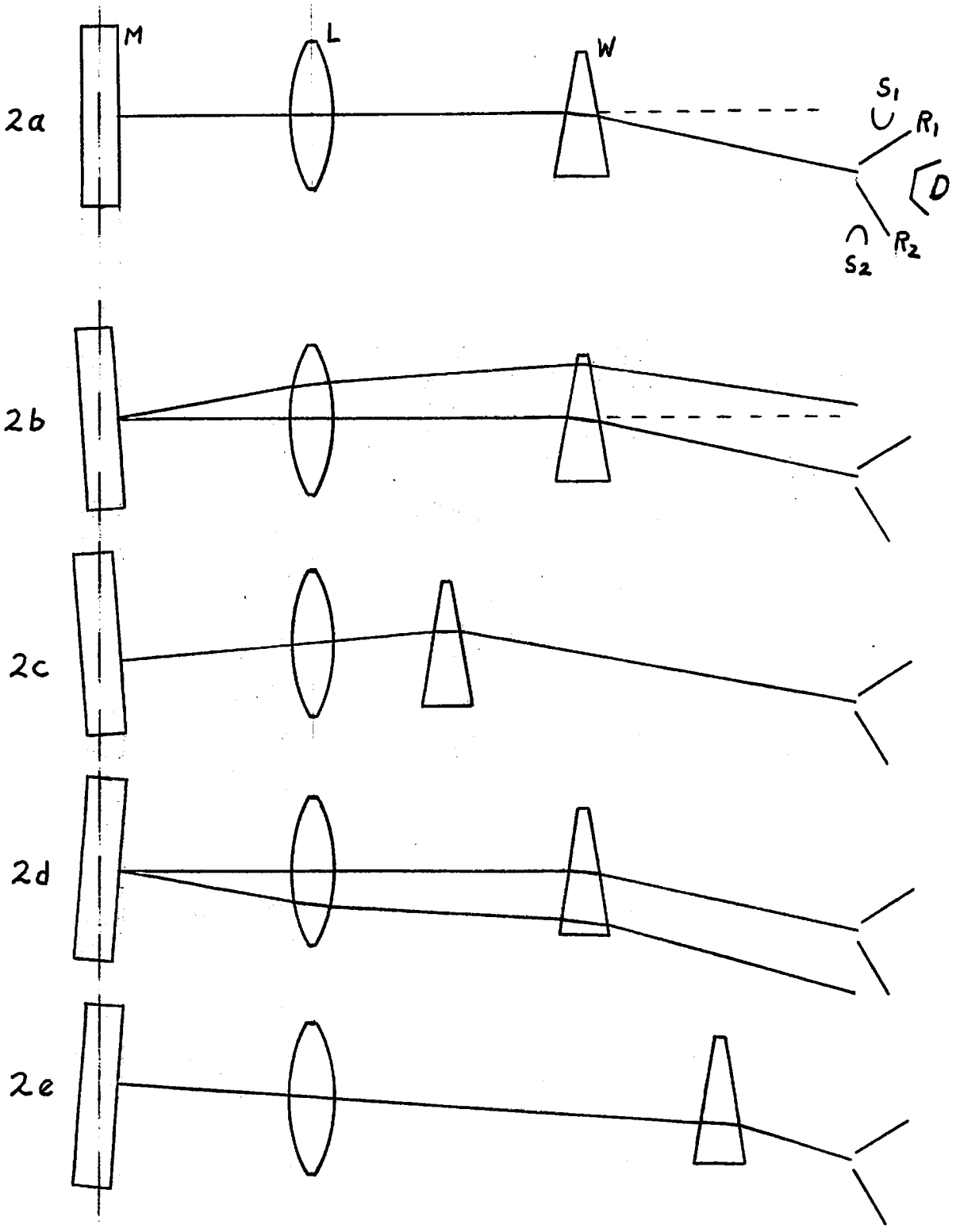
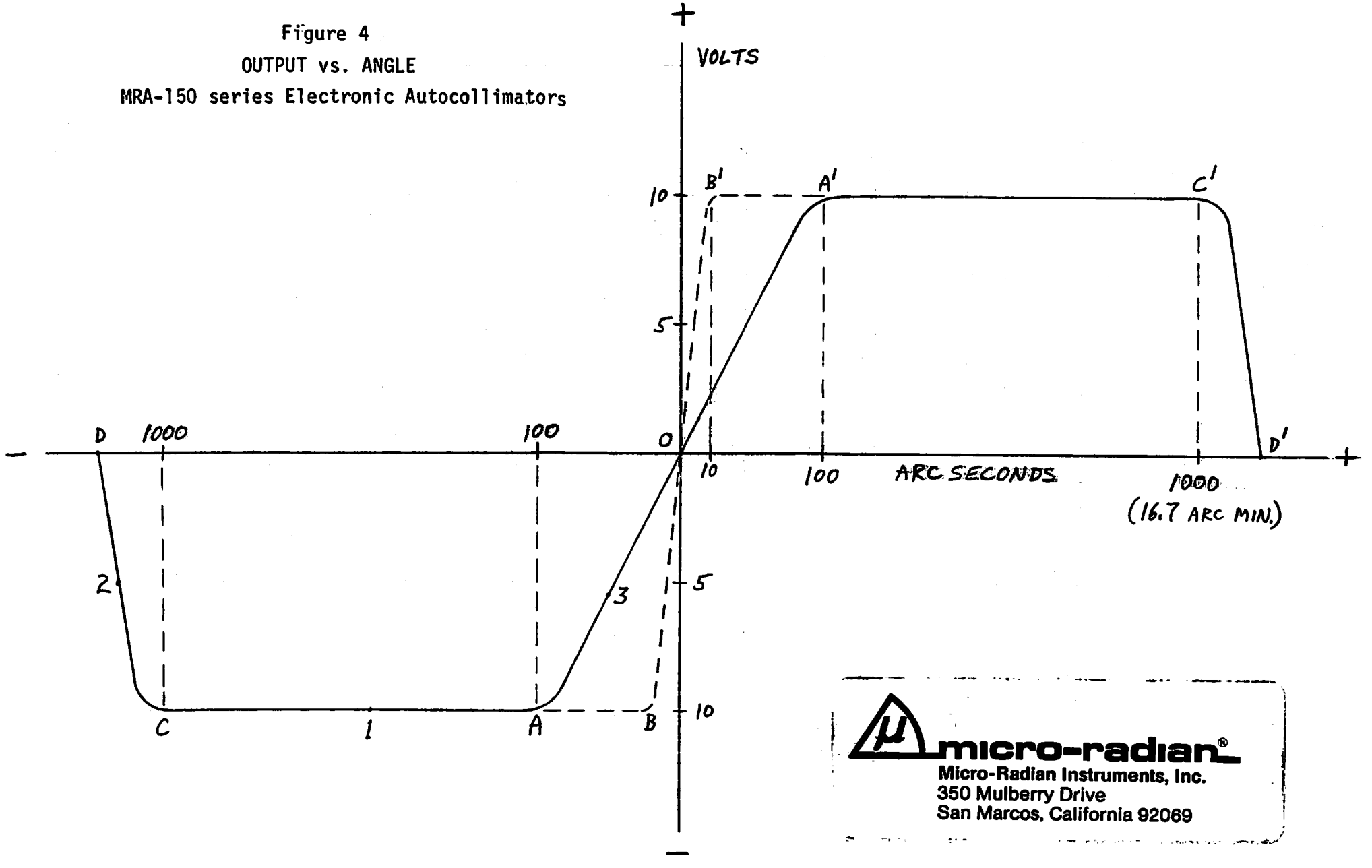


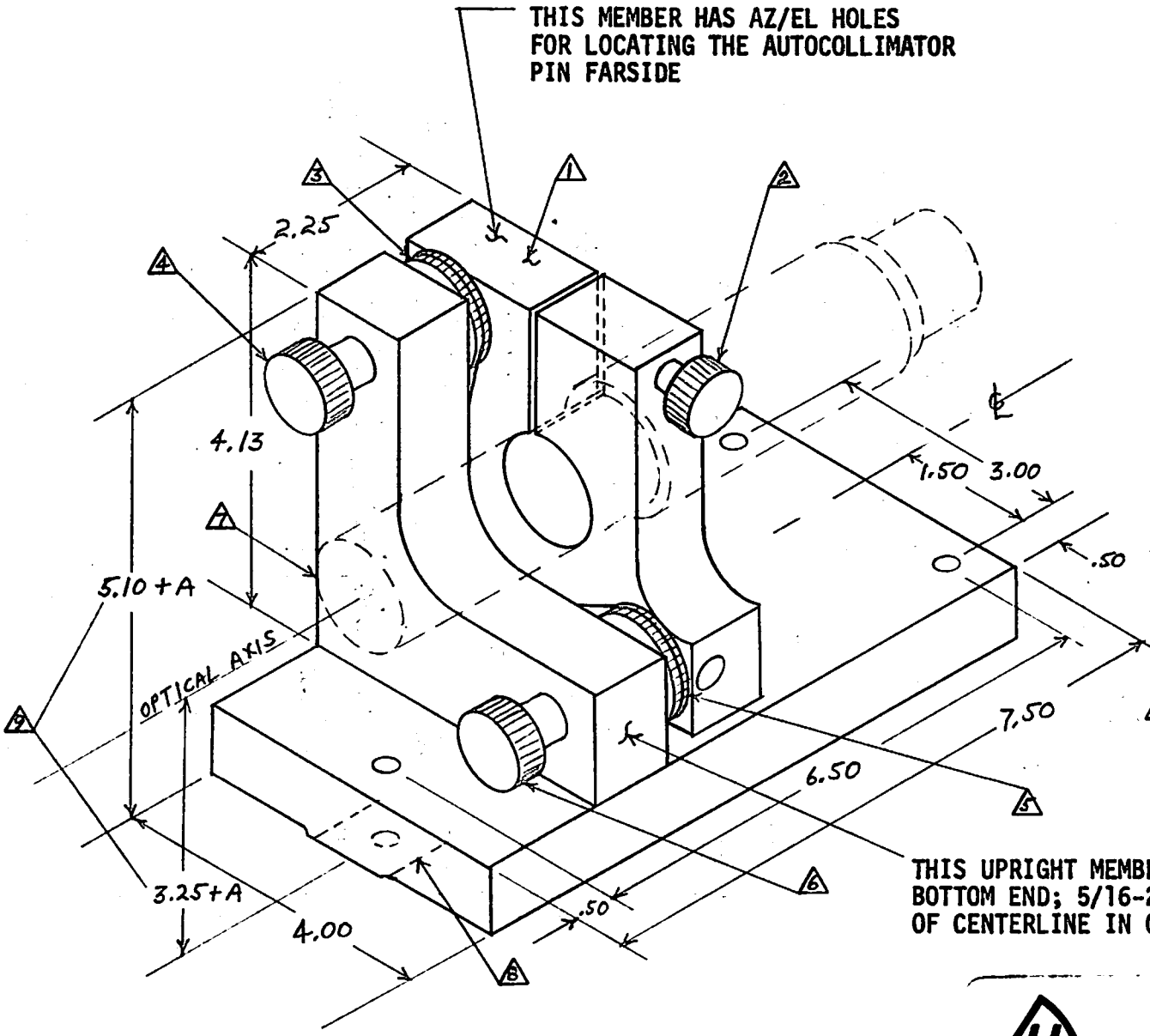
Figure 4

OUTPUT vs. ANGLE

MRA-150 series Electronic Autocollimators



micro-radian®
Micro-Radian Instruments, Inc.
350 Mulberry Drive
San Marcos, California 92069



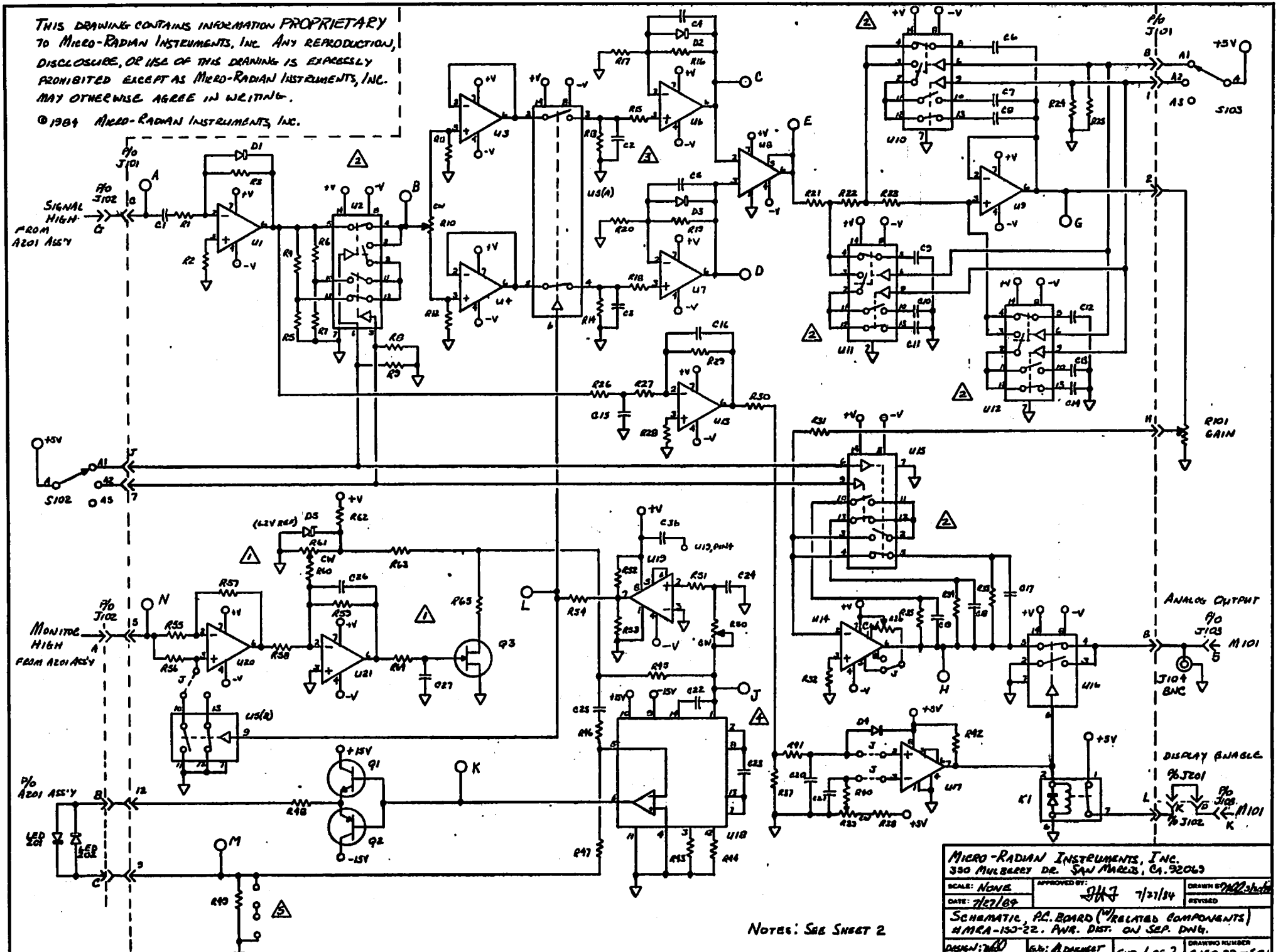
1. KINEMATICALLY MOUNTED AUTOCOLLIMATOR CLAMP
2. CLAMP RELEASE
3. ELEVATION COARSE ADJ THUMBWHEEL
4. ELEVATION FINE ADJ
5. AZIMUTH COARSE ADJ THUMBWHEEL
6. AZIMUTH FINE ADJ
7. FRONT OF BARREL APPROX. FLUSH WITH FRONT OF STAND
8. .250 DIA HOLE THRU 1 INCH SQ PAD TYP 3 PLACES. PAD LAPPED
9. "A" DIM. ON SPECIAL ORDER
10. EDGES CHAMFERED

Figure 3 MR-20 STAND

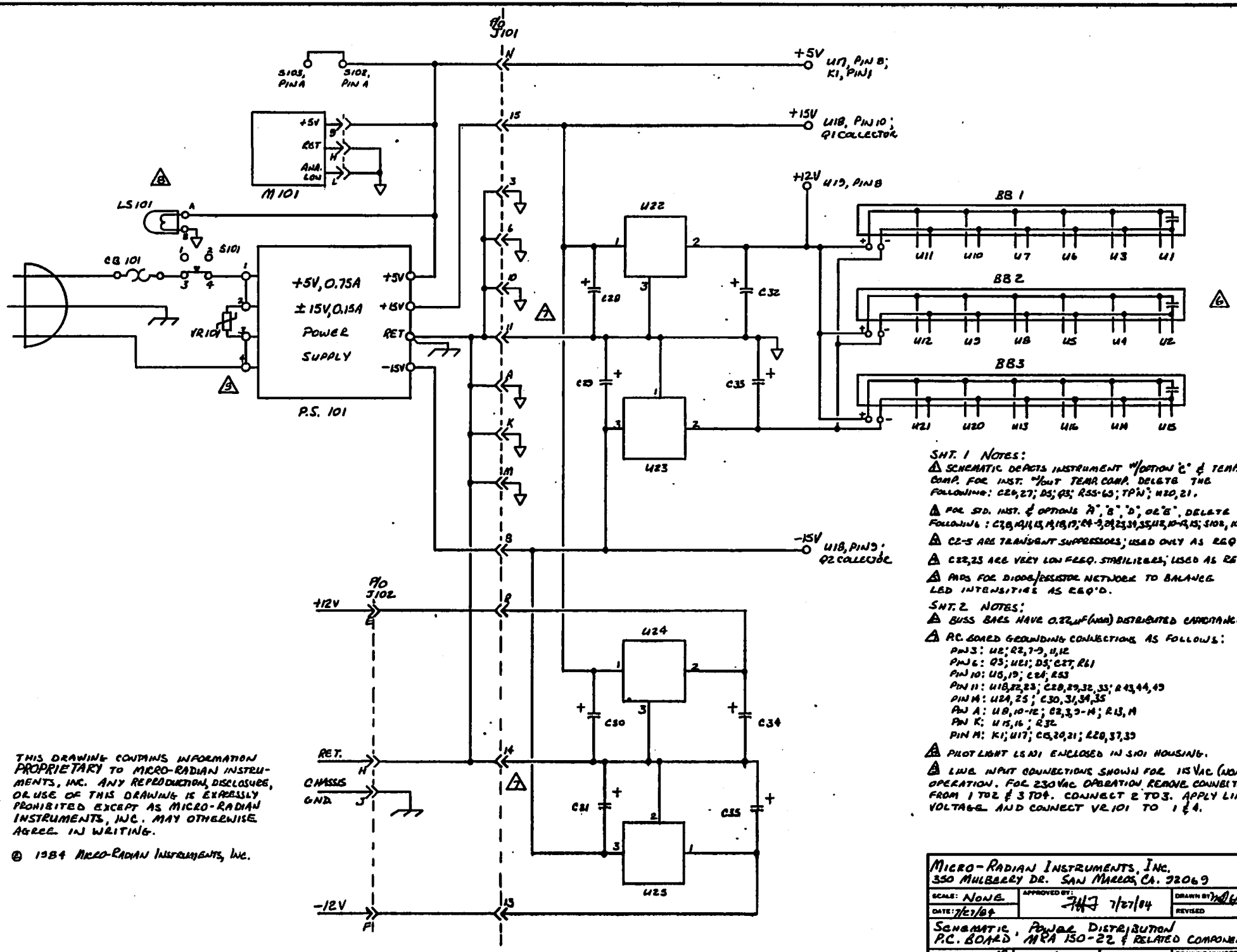
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SCALE: NONE	APPROVED BY: 7/27/84	DRAWN BY: 7/27/84
DATE: 7/27/84		REVISED
SCHEMATIC, P.C. BOARD (W/RELATED COMPONENTS) HMRA-130-22. PWR. DIST. ON SEP. DWG.		
DESIGN: 6/1/84	CHK: APPARENT 6/11/84	SHT. 1 OF 2
DRAWING NUMBER C130-22-501		



SHT. 1 NOTES:

1. SCHEMATIC DEPICTS INSTRUMENT W/OPTION "C" & TEMP. COMP. FOR INST. W/OUT TEMP. COMP. DELETE THE FOLLOWING: C26,27; D5; Q3; R55-63; TP4; U20,21.
2. FOR STD. INST. & OPTIONS "A", "B", "D", OR "E", DELETE THE FOLLOWING: C28,29,31,33,36,37; C4-5,24,25,34,35,38,39-42,45; S102, 103
3. C2-5 ARE TRANSIENT SUPPRESSORS; USED ONLY AS REQ'D.
4. C22,23 ARE VERY LOW FREQ. STABILIZERS; USED AS REQ'D.
5. PADS FOR DIODE/RESISTOR NETWORK TO BALANCE LED INTENSITIES AS REQ'D.

SHT. 2 NOTES:

1. BUSS BARS HAVE 0.22 μF (NOM.) DISTRIBUTED CAPACITANCE.
2. P.C. BOARD GROUNDING CONNECTIONS AS FOLLOWS:
   - PIN 3: U2; R2,7-9, 11,12
   - PIN 6: Q3; U21; D5; C27; R61
   - PIN 10: U6,19; C24; R53
   - PIN 11: U18,22,23; C28,29,32,33; R43,44,49
   - PIN M: U24,25; C30,31,34,35
   - PIN A: U8,10-12; C2,3,9-M; R13,M
   - PIN K: U15,16; C32
   - PIN M: K1; U17; C6,20,21; R28,37,39
3. PILOT LIGHT LS101 ENCLOSED IN S101 HOUSING.
4. LINE INPUT CONNECTIONS SHOWN FOR 115 VAC (NOM.) OPERATION. FOR 230 VAC OPERATION REMOVE CONNECTIONS FROM 1 TO 2 & 3 TO 4. CONNECT 2 TO 3. APPLY LINE VOLTAGE AND CONNECT VR101 TO 1 & 4.

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DATE: 7/27/84	DRAWN BY:
	REVISED
SCHEMATIC, POWER DISTRIBUTION P.C. BOARD, MRA 150-22 & RELATED COMPONENTS	
DESIGN: 5/20/84	ENG. M. DONNER 8/1/84
SHT 2 OF 2	DRAWING NUMBER C150-22-502

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