A TAPED BASE LINE AND AUTOMATIC METEOROLOGICAL RECORDING INSTRUMENTS

FOR THE CALIBRATION OF ELECTRONIC DISTANCE MEASURING INSTRUMENTS

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Note on the author

Austin C. Poling, General Engineer in the Engineering Division of the U.S. Coast and Geodetic Survey, is presently engaged in the development of improvements in the field of electronic distance measuring instruments, and studies relating to positioning equipment used in hydrographic surveys. He has been with the Bureau since 1930, formerly serving as mathematician and geodesist in the Geodesy Division. He is a graduate of the University of Virginia, majoring in physics. He has contributed several reports on the use of the geodimeter and tellurometer, and is the author of manuals for both instruments. He is a member of the American Congress on Surveying and Mapping, Institute of Electrical and Electronic Engineers, and the Washington Academy of Sciences.

INTRODUCTION

This article summarizes the use of electronic distance measuring instruments by the Coast and Geodetic Survey; discusses the importance of meteorological data for the reduction of measurements to attain high accuracies; and describes the measurement, and the use, of a specially taped base line and newly developed meteorological recording equipment for the calibration and testing of electronic distance measuring instruments.

The Coast and Geodetic Survey uses the Model 2A and Model 4D Geodimeters for the measurement of base lines for triangulation for doing super-accurate traverse for scaling satellite triangulation, and for other special purposes. The Bureau uses micro-wave distance measuring instruments, such as the Tellurometer, the Electro-Tape, and the Electro-Chain for second order traverse.

The Geodimeters have practically superseded tapes for the measurement of base lines and the Model 4D Geodimeter may supersede the Model 2A in the Coast and Geodetic Survey. The accuracy of measurements is about the same with both of these instruments. The Model 4D is, of course, much lighter and easier to handle in the field, though the 2A will measure somewhat longer lines than the 4D.

The micro-wave type of instruments mentioned above have a tremendous advantage over the Geodimeter in that their range is probably three or four times as great and the instruments do not depend on visibility. They can be used even in foggy weather, for example. On the other hand, these instruments cannot attain the accuracy of the Geodimeter. We might say in general terms that the Geodimeter is capable of measuring distances of 10 kilometres or more with an order of accuracy of one part in one million standard error, and that the micro-wave type instruments are capable of measuring lines of this length with an order of accuracy of one part in 300 000 standard error.

The accuracies mentioned above can be attained consistently, however, only when mean atmospheric parameters over the measured line are recorded to provide information to determine the refractive index, and its effect on the velocity of wave propagation, for the reduction of the instrument readings to exact values. The recording of atmospheric temperature, relative humidity, and barometric pressure at the ends of the lines only will suffice for measurements of an order of accuracy of one part in 100 000 to one part in 200 000. Where higher orders of accuracy are required atmospheric parameters must be measured along the line, not only at the ends of the line, to arrive at reliable mean values. This is particulary true in rugged terrain.

The mean temperature along the observed line is the principal atmospheric parameter for the reduction of lengths measured with the Geodimeter. An uncertainty of 1.0 degree centigrade will introduce an uncertainty in the length of one part in one million. If we consider a line across a valley with the two ends elevated some hundreds of feet above the valley floor, we realize that : (1) the temperature along the line will probably vary considerably, and (2) for highly accurate measurements the temperature must be recorded at intervals along the line as well as at the stations at either end. This fact interposes the condition that we must find some means of raising these meteorological recording instruments to line height. Solution of this problem is the one remaining obstacle for Geodimeter measurement of long lines with an order of accuracy of one part in one million standard error.

An uncertainty of 0.1 inch in mean barometric pressure along the line will also introduce an error of one part in one million in the Geodimeter measurement, but this factor is not nearly so critical as the temperature, since the barometric pressure along the line is not so likely to vary to this extent (0.1 inch barometric pressure is roughly equivalent to a pressure-altitude value of 100 feet).

The affect of humidity on light waves (Geodimeter) is very small, a variation in relative humidity over the entire range from 0 % to 100 % will introduce an error in the Geodimeter measurement of but little over one part in one million.

The accuracy of measurement with the micro-wave type instruments, on the other hand, is also affected considerably by reflection and by the mean relative humidity along the line.

Micro-waves are subject to reflections from various objects, which can only approximately be cancelled out by varying the carrier wavelength. The temperature and pressure of the atmosphere have approximately the same effect on measurements with these instruments as on measurements with the Geodimeter. The humidity effect on the refractive index of the radio waves, however, can be a hundred times as great as the effect on light waves. Thus, the important parameters in using these instruments are reflections of micro-waves, temperature, and humidity.

Satisfactory portable field instruments for recording the atmospheric parameters along the line of measurement have not yet been developed, but a considerable amount of research is being done on this matter and it is hoped that these instruments will be available in the relatively near future. The meteorological recording instruments described in the latter part of this article are not for field use, but for testing and calibrating the field instruments when the latter become available. These instruments should have a measuring accuracy of one order of magnitude beyond that necessary to obtain the refractive index to one part in a million. The weather stations should also be self operating, and record temperature, pressure, and relative humidity, automatically.

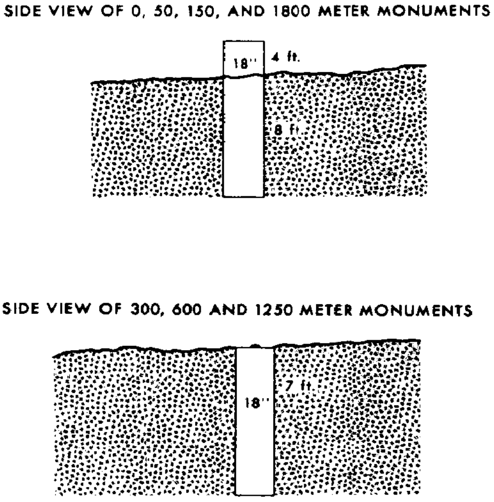
All of these distance measuring instruments must, of course, be serviced, calibrated, and tested from time to time, and our base line at Beltsville, Maryland (near the central office of the Coast and Geodetic Survey) is an essential part of our laboratory for this work. Several base lines are needed for this purpose :

1. A short base, 25 to 35 metres long, marked every 0.8 metres for calibrating and checking the internal constant of the Model 2A Geodimeter.
2. A short base 50 metres long for calibrating and checking the internal constant of the Model 4 Geodimeter.
3. A base about one mile long, with several intervening monumented points, for the overall checking and adjustment of both the Geodimeters and the micro-wave instruments.
4. A base 8 or 10 miles long for checking the performance of the micro-wave type instruments on relatively long lines.

The base listed under Item 3 above is the one described in detail in this article. Fifty-metre stations (Item 2 above) are included in this one-mile base. Field parties, using the Model 2A Geodimeter, measure a short base (Item 1 above), as needed for checking the Model 2A Geodimeter, and a permanently marked base for this purpose has not been required at the central laboratory. An 8-mile base line for the purpose stated in Item 4 has been established by measuring the length several times with two different Geodimeters.

LAYOUT AND MEASUREMENT OF THE ONE MILE BASE LINE

This base line is located on the Agricultural Research Center airport at Beltsville, Maryland. The location is very satisfactory since the base is not likely to be disturbed by land development in this general area and the airport traffic is relatively light and does not disturb our testing. The base was established by permission of the Agriculture Department and the construction work required, such as pouring of concrete, surfacing of the access road, construction of an instrument shelter, provision of electric lines, etc., was done by the U.S. Department of Agriculture.


SIDE VIEW OF 0, 50, 150, AND 1800 METER MONUMENTS

SIDE VIEW OF 300, 600 AND 1250 METER MONUMENTS

FIG. 1

The base line is 1 800 metres long. The 0-, 50-metre, 150-metre, and 1 800-metre points are principal stations on the line. Each of these stations is marked by a concrete monument 18 inches in diameter, set 8 feet underground, and projecting 4 feet above ground so as to serve as an instrument stand (Fig. 1). Each of these monuments is capped with a steel plate (boiler plate steel) welded to the reinforcing rods of the concrete monument. The flat steel plates are 16 inches in diameter. A 14-inch aluminum tribrach with grooves 120 degrees apart, is attached to each of the steel plate caps. Each of these tribrachs has a brass plug screwed in the center and this brass plug has a one-millimetre diameter hole drilled at its center for the mark to which the taping has been referenced (Fig. 2).

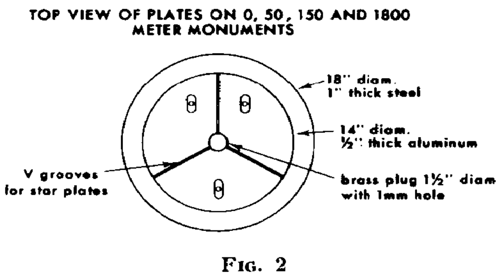

TOP VIEW OF PLATES ON 0, 50, 150 AND 1800 METER MONUMENTS

FIG. 2

The 300-metre, 600-metre, and 1 250-metre stations are also monumented with 18-inch diameter reinforced concrete posts set 7 feet in the ground and with their tops set flush with the ground. A standard Coast and Geodetic Survey brass station mark was set in the top of each of these monuments and, after taping, a one-millimetre hole was drilled to mark the station point. It was not practical to have these monuments extend 4 feet above ground for use as instruments stands because of possible interference with activities at the airport; instrument tripods are used when occupying these stations.

A concrete slab was poured at each remaining 50-metre point along the line that is not one of the monumented stations described above. A screw eye was implanted in the center of each of these slabs for the purpose of attaching taping tripods (Fig. 3). A chain and turnbuckle are used to firmly fasten the taping tripods to the concrete slab when taping.

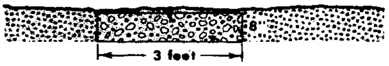

SIDE VIEW OF TAPING TRIPOD CONCRETE SLAB BASE

FIG. 3

The 0- and 50-metre points are visible from the 150-metre point but not from the 1 800-metre point, due to the slope of the terrain. Most electronic distance measurements will be made from the 150-metre point to the 300-, 600-, 1 250-, and 1 800-metre points. A monument was placed at 1 250 metres instead of 1 200 metres because the 1 200-metre point was over an underground power cable.

The preliminary staking of the base line to establish the approximate positions of each 50-metre point was done in May 1963. The total length was measured with an Electrotape and then each 50-metre point was staked out by a 30-metre steel tape. The positions of the 0-, 50-, 150-, 300-, 600-, 1 250- and 1 800-metre stakes were checked with a Model 4D Geodimeter, Tellurometers, and Electrotapes. A Wild T 2 Theodolite was used to keep the preliminary staking on line.

After the concrete monuments were poured and had solidified, a Geodimeter Model 4D was used to measure from the center of each monument to the center of each other monument.

The distances were then adjusted to be approximately an integral number of 50-metre units and the aluminum tribrach plates screwed to the iron top plates so the centers would be nearly an integral 50-metre unit apart. Thus, the 0-, 50-, 150-, and 1 800-metre post tribrachs would be close to the positions to give the proper distances when taped from the center of each post.

The wooden taping tripods were about 30 inches high and the legs were made of 2 × 4″ lumber. A 4 × 6 × 3/4 inch piece of plywood was securely nailed to the top of each tripod. A screw eye was attached to the inner side of the top so that a chain and turn-buckle could be attached.

BASE TAPING

The Beltsville Base was first taped August 16, 17, and 18, 1963 by six members of a geodetic party. The base was again taped in May and November 1964.

It is planned to remeasure this base each spring and each fall to check for any small movement in the stations and also to improve the accuracy of the measurements. The tapes used for measurements will be calibrated prior to each remeasurement of the base line.

A stake-type tape stretcher and spring balance were used for taping. The spring balance was checked before and after each taping with a 15 kilogram weight. This weight was determined at the National Bureau of Standards and found to be one ounce less than the 15 kilograms. This was not considered to be significant so the weight was accepted as 15 kilograms. The tape thermometers were also weighed and found to be within 3 grams of their required weight.

The taping tripods and the concrete monuments had a 10-centimetre boxwood scale attached to the top of each by two screws. Two of the boxwood scales picked at random were checked by a micrometer comparator and found to be accurate to 0.1 mm over the entire 10 cm length.

The taping tripods were then aligned with a Theodolite and a preliminary taping with a 50-metre invar tape was made to position the taping tripods. The tripods were set so that the 5-centimetre mark on the 10-centimetre scale was close to the end of the 50-metre point of the tape. Thus, from the 5-cm mark on one tripod to the 5-cm on the next tripod was almost exactly 50 metres.

A portable astro tripod was used at one 50-metre point which fell upon the east-west airport runway. It was held in position with sand bags.

Standard C & GS procedures were used in stretching the tapes during measurement. One man anchored the tape in the rear, another man attended the middle of the tape, and the front tape stretcher watched the scale and kept the 15 kilogram tension. During actual measurement, the center of the tape was supported by a nail driven in a stake, which was aligned with the end points, vertically and horizontally.

One man read the tape at the rear with a magnifying glass. The tape was brought into coincidence at its 0 mark with the 5-cm point of the boxwood scale on the taping tripod.

Two men read the coincidence of the 50-m mark of the tape with the 10-cm scale on the tripod at the forward end of the tape. First one man took a reading on the scale, estimating to the tenths of a millimetre, then another man repeated this procedure. The readings were only taken when the rear contact man called " MARK " and each front contact man read the scale independently, twice. The readings of both front contact men were then recorded if their readings were within two tenths of a millimeter of each other. Otherwise, the readings were repeated by both men until an agreement within 0.2 mm was obtained.

This method was found to be very satisfactory and time saving over previous conventional base measurement methods.

It was found that the 1 800 metres could generally be taped in one direction in about one hour. One taping of that distance was made in 40 minutes. This included taping through a fence at one place.

Second-order leveling was done over every mark and each 50-metre taping tripod by members of the Geodesy Division.

In January 1964, a metal shelter 5 × 7 × 7 feet was erected over the 150-metre monument. An electric line was run to the shelter to provide 115 volt 60 cycle current to operate electronic instruments.

The shelter has doors which open to the south and windows on the north side. Thus, an instrument placed on the monument can measure to the 0- and 50-metre points in one direction and to the 300-, 600-, 1 250- and 1 800-metre points in the opposite direction.

Beltsville base line

Summary of 1963 and 1964 measurements

From	*To*	*Horizontal Length Metres*	*Diff. In Elevation Metres*	*Slope Length Metres*
0	50	50.0040	+ 1.048	50.0150
50	150	100.0108	+ 0.473	100.0119
150	300	149.9929	— 0.538	149.9939
150	600	449.9983	— 2.354	450.0045
150	1 250	1100.0057	— 2.011	1100.0075
150	1 800	1649.9960	+ 3.076	1649.9989

Probable error of result

$$= 0.6745 \sqrt{\frac{EV^2}{n(n-1)}} = \pm 0.70 \text{ mm}$$

Summary of tape measurements of Beltsville base

Section	*Date 1963*	*Tape*	*Horizontal length Metres*	*Mean Metres*
150-1800	8/16	3870	1649.9917F	
	8/16	3870	.9868B	
	8/17	3611	.9932F	
	8/17	3611	.9946B	
	8/17	739	.9875F	
	8/17	739	.9871B	
	8/18	2219	.9849F	
	8/18	2219	.9876B	1649.9892

Inclination correction + 0.0029 m
Slope length from tops of monuments 1649.9921 m

Section	*Date 1964*	*Tape*	*Horizontal length Metres*	*Mean Metres*
150-1800	5/18	2219	1649.9999B	
	5/18	2219	.9982F	
	5/18	3870	.9934B	
	5/18	3870	.9949F	
	5/18	739	.9984B	
	5/18	739	.9977F	
	5/19	3611	.9980B	
	5/19	3611	.9948F	1649.9969

Inclination correction + 0.0029 m
Slope length from tops of monuments 1649.9998 m

Section	*Date 1964*	*Tape*	*Horizontal length Metres*	*Mean Metres*
150-1800	11/21	3870	1649.9928F	
	11/21	3870	1650.0011B	
	11/21	3611	1649.9991F	
	11/21	3611	1650.0015B	
	11/22	2207	.0056F	
	11/22	2207	.0035B	
	11/23	2219	1649.9932F	
	11/23	2219	.9938B	
	11/23	739	.9969F	
	11/23	739	.9921B	
	11/24	3870	1650.0037F	
	11/24	3870	1649.9988B	
	11/24	2207	1650.0026F	
	11/24	2207	.0050B	1649.9993

Inclination correction + 0.0029 m
Slope length from tops of monuments 1650.0022 m

METEOROLOGICAL INSTRUMENTATION

The portable meteorological recording instrument described in this section is a step towards solving the problem, mentioned earlier, of measuring and recording atmospheric parameters along the line for highly accurate distance measurements with either the Geodimeter or the microwave type instruments. The recorder described here will not serve for the rapid recording of atmospheric parameters in the field; it will, however, be used at the testing station to check and calibrate these latter instruments when they become available.

The recorder has three separate solid state pre-amplifiers. Each of these amplifiers will take a millivolt input of 0-3 to 0-20 millivolts at full scale. Each pen of the recorder has its own pre-amplifier. Thus, the recorder is actually three separate recorders built into one case or box and using the same strip chart to simultaneously record temperature, relative humidity, and barometric pressure (Figure 4).

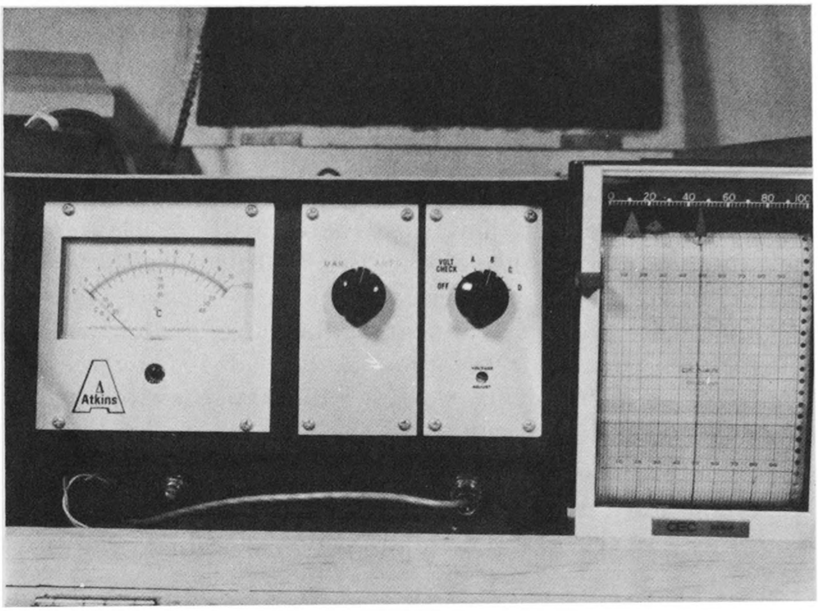


FIG. 4

This recorder works on 115-volt alternating current or 24-volt direct current. The power drain at 24 volts for the complete system is 1.06 amperes or approximately 25 watts.

The power drain is divided as follows :

Recorder 18 watts, temperature transducer 6 watts, pressure and humidity transducers 1 watt total.

The recorder is a DeVar Model R-300, three-pen recorder by Consolidated Electrodynamics. The recorder has the following characteristics :

Strip chart recorder, 4 inch chart width, three pens to record temperature, pressure and relative humidity, simultaneously. Ink colors are red, blue and green respectively, denoting temperature, pressure and humidity.

Input and suppression is adjustable in the field. Chart drive is 12 inches per hour; this should be reduced to 6 inches per hour in future instruments.

The recorder normally operates on a 115-volts alternating current and when operated on 24-volts DC an inverter is used. Maximum power drain when using the inverter is approximately 18 watts.

The strip chart has 50 divisions numbered with 10 major divisions, and can be read to 1 % of full scale.

The maximum sensitivity obtainable from the recorder is 0-1 millivolt full scale. This is sufficient sensitivity for any transducer to be used with it. The temperature transducer was manufactured by Atkins Technical Corp., Gainesville, Florida and has the following characteristics :

Minus 0.5 degree Centigrade to 40.5 degrees Centigrade in four ranges, 11 degrees in each range. It has an automatic range change which is actuated at 0.5 degree below 0 on the lower end of the scale and 10.5 degrees at the top of the scale. Thus, the ranges are — 0.5 to 10.5, 9.5 to 20.5, 19.5 to 30.5, and 29.5 to 40.5 degrees. The temperature on any range of 11 degrees covers 100 divisions on the chart recorder. Thus, a conversion table has been computed for transforming chart readings into temperatures. The temperature will record from — 0.5 to 40.5 degrees Centigrade in four automatic ranges. The overlap of 0.5 degree on each end of the scale is necessary with the automatic range change. If the temperature transducer automatic change device were not constructed with overlapping temperatures, when the temperature was 10 or 20 or 30 degrees there would be a constant changing of the temperature range change device. As an example, when the temperature reaches 10.5 degrees the range switch will automatically switch to the 10 to 20 degree range and read 10.5 degrees. The temperature must drop to 9.5 degrees before the range switch automatically drops into the 0 to 10 degree range.

The temperature transducer with automatic range change has its own metre for temperature readout, and switches for manual or automatic range change as desired. The manual switch provides identification of scales.

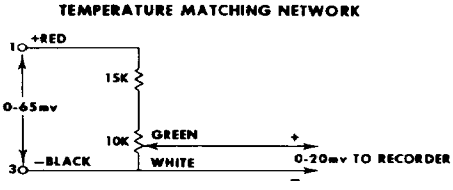


Fig. 5

The output of the temperature transducer is 0 to 65 millivolts into a 50 000 ohm load, full scale. This output of 0 to 65 millivolts must be attenuated to 0 to 20 millivolts for input to recorder. Figure 5 is the schematic of the attenuator. The potentiometer and resistors were precision wire wound as used in the attenuator to maintain stable output conditions. The voltage divider (attenuator) was built into the base of the temperature transducer readout instrument.

When operated in the manual mode, the temperature transducer uses 18 volts from mercury dry batteries contained in the instrument. In the automatic mode, it is operated from 24 volts DC external at 0.25 ampere.

The pressure transducer is an Allegany Instrument Company, Model 151-EBA-28 with a range of 15 PSI. It operates on 24 volts DC or preferably about 16 volts DC, regulated. Power input is less than 1 watt and output to the recorder is 0 to 2 millivolt, approximately. It has a resolution of better than 0.0001 inch of mercury pressure.

It is capable of an output of 2 millivolts for 0.02 inches of mercury, thus full scale on the recorder can represent 0.02 inches of mercury pressure. Voltage input must be regulated for maximum output stability.

For practical use, the transducer is adjusted for 1 inch of mercury for full scale deflection on the chart recorder.

A resistance network is used to couple the pressure transducer to the recorder. This schematic is given in Figure 6. The potentiometer control allows setting an absolute pressure anywhere on the chart scale. Thus, for normal use, the center of the chart is set at 30.0 inches of mercury pressure and the chart reads 29.5 to 30.5 inches of mercury full scale. If desired, the center of the chart can be set to 29, 28, 27, etc., inches for different pressure conditions. A good barometer must be used to set the mid-scale reading on the chart.

PRESSURE OUTPUT NETWORK

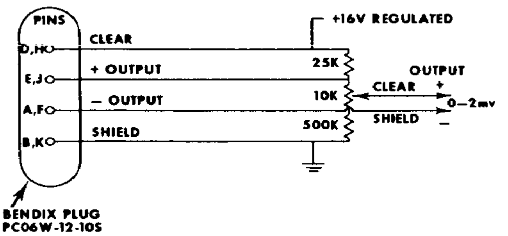


Fig. 6

The voltage regulator used with the pressure transducer is shown in schematic in Figure 7. Precision wire-wound resistors are used in this voltage regulator.

VOLTAGE REGULATOR
5 & 10K RESISTORS ARE PRECISION WIRE WOUND

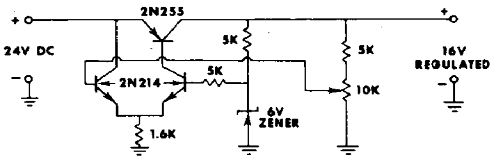


Fig. 7

The humidity transducer was manufactured by Hygrodynamics, Inc., Silver Springs, Md., and operates over a range of 0 to 100 % relative humidity. Eight humidity sensors coated with Lithium Chloride are used to cover the complete range of relative humidity, each sensor covering a small range of humidity.

The humidity sensor requires an input of 24 volts DC and gives an output of 5 volts full scale. The output voltage can be varied ± 1.5 volts.

The humidity sensor is of solid state design and is approximately 2 by 2 by 6 inches in physical size. The claimed accuracy for the sensor is ± 1.5 % relative humidity.

The 0 to 5 volts output must be attenuated to 0-20 millivolts for input to the recorder. Figure 8 is a schematic of the voltage divider for accomplishing this.

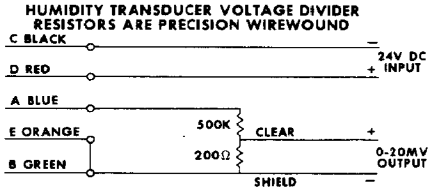


FIG. 8

At the present time, there is only one weather-gathering system built and operating. In order to gather the necessary meteorological data for use on the Beltsville Base Line, at least three complete systems are needed. This would give a fairly accurate indication of weather conditions over the line. In instances where refractive index over the base line were being studied, and integrated temperature, pressure and humidity were needed, it would be desirable to have at least 5 systems. A system of three sets would suffice for use with various electronic distance measuring instruments in the field.

It is believed that this weather-gathering system is the most accurate obtainable at the present state of the art. It should be realized that a limit must be set for the accuracy to which the various weather parameters can be gathered. Thus, 0.1 degree Centigrade temperature, 0.01 inch mercury pressure and 1-1/2 % relative humidity are the maximum practical limits to which each of these parameters can be read. Any accuracies beyond these figures would be difficult to obtain and would not be of any practical value.