(NASA-TM-80641) THE GSFC MARK-2 THREE BAND HAND-HELD RADIOMETER (NASA) 33 p HC A03/MF A01 CSCL 14B

N80-27674

Unclas
G3/35 25193

NASA

Technical Memorandum 80641

The GSFC Mark-II Three Band Hand-Held Radiometer

C. J. Tucker, W. H. Jones, W. A. Kley, and G. J. Sundstrom

JANUARY 1980

National Aeronautics and Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

Page intentionally left blank

TM 80641

THE GSFC MARK-II THREE BAND HAND-HELD RADIOMETER

C. J. Tucker
Earth Resources Branch
Code 923

and

W. H. Jones
W. A. Kley
G. J. Sundstrom
Experiment Engineering Branch
Code 944

January 1980

NASA/GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland 20771

THE GSFC MARK-II THREE BAND HAND-HELD RADIOMETER

C. J. Tucker
Earth Resources Branch
Code 923

and

W. H. Jones
W. A. Kley
G. J. Sundstrom
Experiment Engineering Branch
Code 944

ABSTRACT

A self-contained, portable, hand-held radiometer designed for field useage has been constructed and preliminarily tested. The device, consisting of a hand-held probe containing three sensors and a strap supported electronics module, weighs 4½ kilograms, is powered by flashlight and transistor radio batteries, utilizes two silicon and one lead sulfide detectors, has three liquid crystal displays, sample and hold radiometric sampling, and the spectral configuration of the device corresponds to Landsat-D's thematic mapper bands TM3 (0.63 - 0.69 μm), TM4 (0.76 - 0.90 μm) and TM5 (1.55 - 1.75 μm). The device was designed to support thematic mapper ground-truth data collection efforts and to facilitate *in situ* ground-based remote sensing studies of natural materials. Prototype instruments have been extensively tested under laboratory and field conditions with excellent results obtained.

THE GSFC MARK-II THREE BAND HAND-HELD RADIOMETER

BACKGROUND

The applications of remotely sensed data for environmental monitoring have increased substantially since the launch of Landsat-1 (formerly (ERTS-1) in 1972. The uses of this new technology have extended into many disciplines where the unique features of satellite remote sensing can be employed to address various resource questions. The majority of remote sensing research to date has utilized Landsat data. Several workers have come to realize that ground-based *in situ* remote sensing studies were needed to better understand the basic relationships between natural materials and reflectance or radiance as a function of wavelength. This realization resulted from the apparent fact that Landsat MSS imagery is not an optimum method of conducting more basic remote sensing research of natural materials. The difficulties of concurrently sampling ground experimental areas of ~0.4 ha, quantifying atmospheric variability, compensating for sun angle effects, accounting for instrument responses, etc., and the interaction(s) between these sources of experimental variation are considerable.

Ground-based spectrometers have been utilized by several research groups in an attempt to collect *in situ* spectral reflectance data (Miller et al., 1976; Silva et al., 1971; Leamer et al., 1975; Branch et al., 1978; Zweibaum and Chappelle, 1979). These efforts have largely been successful and, at the same time, have demonstrated the limitations of spectrometers. The limitations include the cumbersomeness of spectrometers, the cost of maintaining and operating of these devices, and the lack of mobility, among other factors. It should be clearly understood that spectrometers do provide basic information about natural materials and their resulting reflectances as a function of wavelength. This is not only important *per se* but has provided the experimental basis for the development of hand-held radiometers.

Hand-held radiometers, as used in this report, refers to a discrete waveband device which can be hand carried and operated. These instruments are spectrally configured by placing a filter in the pathlength of the detector(s) in question. For example, the three-band device described in this report has 2 silicon detectors (sensitivity range ~0.4 – 1.0 μm) and one lead sulfide detector (sensitivity range ~1.0 – 3.0 μm). By placing interference filters of 0.63 – 0.69 μm and 0.76 – 0.90 μm in the pathlength of the silicon channels and a 1.55 – 1.75 μm filter in the pathlength of the lead sulfide channel, the resulting device is configured spectrally to thematic mapper bands TM3, TM4, and TM5. The three band device described in this report was intended primarily to support Landsat-D's thematic mapper by *in situ* data collection.

Previous *in situ* research has reported that spectral regions of at least 0.04 μm bandwidths were sensitive to the same property of vegetated surfaces (Tucker, 1977 and 1978a). Only one report to date has indicated that "fine structure" spectral information may exist for plant canopies (i.e., <0.04 μm). This report (Collins, 1978) used aircraft collected spectra and did not utilize concurrent or detailed ground-truth sampling. Important spectral information may exist as so-called "fine structure" of reflectance spectra but practical application of this information has not been demonstrated for vegetational scenes to date.

The existence of "broad-band" (i.e., 0.04 – 0.20 μm) effects where different properties of vegetated surfaces can be remotely sensed is advantageous for several reasons: it limits the number of spectral regions needed to measured where different biophysical properties of vegetated surfaces can be spectrally sensed; high signal/noise ratios are possible with wider bandwidth systems; radiometric accuracy can be improved with a high signal/noise ratio; the IFOV can be reduced if so-needed without degrading radiometric accuracy; and a manageable number of sensor bands can be used thus minimizing "data rates," data storage, processing time, and the complexity of handling the data in general.

PREVIOUS HAND-HELD RADIOMETER RESEARCH

The first development of hand-held radiometers is attributed to Birth and McVey (1968) who developed a two-filter instrument to measure turf samples. Pearson and Miller (1972) next reported a two-channel digital radiometer which also is further described in Pearson et al. (1976a). A commercial Landsat radiometer was marketed in 1972 (Exotech, 1972).

The Pearson and Miller (1972) two-channel instrument has been widely tested *in situ* since 1972 on a variety of different vegetation types, ranging from Colorado grasslands (Pearson et al., 1976); blue-green algae in Yellowstone National Park, Wyoming, hot springs; Islandic pastures, Arctic tundra and Baltic island alvar vegetation in Sweden; and several sites in England, Scotland, and Wales (Tucker, 1976); on tropical rain forest vegetation in Puerto Rico (Holben and Tucker, 1980); and most recently since 1977 on a variety of agricultural crops at the Beltsville Agricultural Research Center, Maryland (reviewed in Elgin et al., 1979 also see Tucker, 1978b; Tucker et al., 1979a-b; Tucker et al., 1980a-b; and Holben et al., 1980).

Recently, other workers have reported the development and/or application(s) of hand-held radiometers. Methy (1977), Milton (1978), and Robinson et al. (1979) have all developed and used hand-held radiometers for *in situ* data collection. Pinter et al. (1979), Jackson et al. (1979), and Aase and Siddoway (1979) have reported using hand-held radiometers to study grain yield, row effects, and winter kill, respectively, in winter wheat. Holben and Justice (1980) have reported using hand-held radiometers to study topographic effects. It is thus apparent that hand-held radiometers offer definite advantages for *in situ* remote sensing research.

We now report on the continued development of hand-held radiometers which has resulted in a three band device which incorporates several new features.

INSTRUMENT DESCRIPTION

The 3-band unit was designed for extended field use by operators with minimum knowledge of electronics. The radiometer is composed of 2 modules which are connected by an electrical cable (Figure 1). The hand-held portion contains one lead sulfide and two silicon detectors with their respective interference filters placed over the collimation tube of each detector. No optics are involved, other than the collimation tube mechanical layout and the interference filter. The hand-held portion also contains the detector preamplifiers, a "zero" adjustment for the lead-sulfide channel, a "sample and hold" switch, and a sturdy handle for holding the unit or for mounting the unit on an extention device.

The lead sulfide channel is not cooled or chopped and uses paired detectors to form a bridge arrangement to compensate for changes in temperature. A cooled or chopped lead-sulfide channel was found to be incompatible with a reliable, sturdy, and portable instrument coupled with a long battery life for the flashlight and transistor batteries which supply the instrument's power. Field experience has shown that the "drift" which does occur in the lead sulfide channel is slow and easily compensated for by the operator in 5-10 seconds elapsed time (see also Appendix A).

The outer shell of the hand-held portion is light-tight and is held in place by three screws. The collimation tubes have been designed with a threaded portion which holds the interference filter. The initial spectral configuration closely approximates Landsat-D's thematic mapper bands TM3

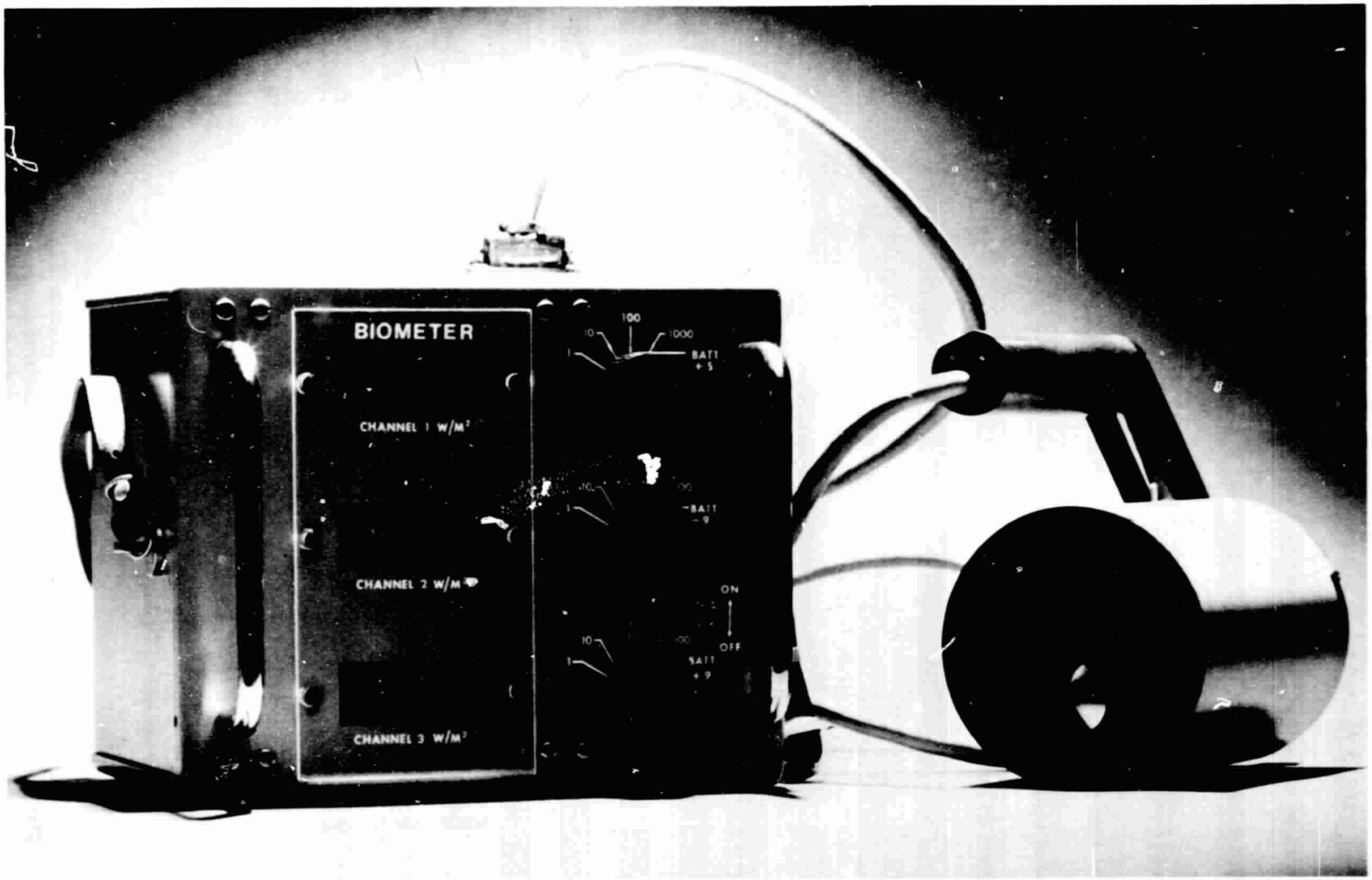


Figure 1. Hand-held 3-band digital radiometer. The instrument consists of a hand-held module which contains the three channels, the readout and control module which contains the electronics, power supply, controls, and displays, and a cable which joins the two modules.

(0.63 - 0.69 μm), TM4 (0.76 - 0.90 μm), and TM5 (1.55 - 1.75 μm) (Figure 2). These three bands were chosen because of their sensitivities to the chlorophyll density, the green leaf density, and the leaf water density, respectively (Tucker, 1978a).

The filters can be changed or removed for cleaning by simply unscrewing the filter-holding apparatus. The field of view of each collimation tube is ~24° full angle and can be reduced mechanically by the attachment of an aperature plate (see Figure A-5, item #11). A cable connects the hand-held portion to the read-out module.

The read-out module contains the power supply, 3 liquid crystal displays, the digitizer and display driver circuits, range controls, battery check, a second "sample and hold" switch, and "off-on" switch. The "sample and hold" function can be operated from either the read-out unit or the hand-held sensor unit. Operating instructions and wiring diagrams are found in Appendix A.

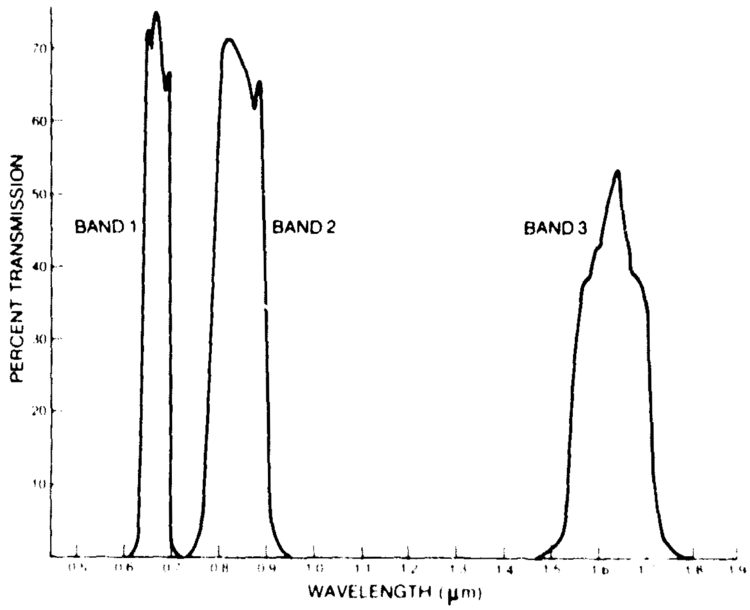


Figure 2. Spectral acceptance of the radiometer probes. Each probe consists of a silicon or lead sulfide detector that views the scene in question through a custom-made interference filter.

There are three liquid crystal displays with digits 1.25 cm high (one display for each channel). When activated, the "sample and hold" switch results in the instantaneous holding of all three channel readings allowing the data to be evaluated and recorded. Liquid crystal displays are advantageous because they appear progressively brighter as the sunlight becomes more intense. Consequently, they are easy to read outside even while wearing sunglasses. Each liquid crystal display provides three digits with decimal points that are displayed in radiometric units.

Radiometric accuracy is 1 part in 1,000 ($\sim$10 bits) with a total range of 1,000,000 (20 bits). This translates into a power range from 1 milliwatt to 1 kilowatt per square meter within the optical bandpass. Radiometric sampling occurs at the rate of 4 times per second.

Power is provided by 4 flashlight batteries for the 5 volt digital logic and display circuits and 2 transistor radio batteries provide ie. ±9 volts to the analog circuits. Total operating time provided by the batteries is on the order of $\sim$100 hours. This long battery life is made possible by the low power drain of the liquid crystal displays. The batteries are available at retail stores everywhere and are easily changed by removing the bottom panel of the read-out unit. In addition, two mercury batteries provide bias for the lead sulfide detector bridge and have a life expectancy of one year. Complete wiring diagrams appear in Appendix A.

Total weight of the instrument is $\sim$1 kg for the hand-held portion and 3½ kg for read-out unit. The read-out unit has been designed with sufficient space so that a 1000-2000 entry digital memory can be added at a later date without any modification to the instrument except minor wiring changes. An uncommitted 50-pin connector is provided on the read-out case which can be used to connect the instrument to external devices. A digital memory is under development with the capability of being retrofitted to existing instruments. Considerable care has been taken to allow for significant modification to the instruments as each investigator may so desire without major changes to the basic mainframe.

In addition to development of the 3-band digital radiometer for hand-held applications, a 4m extension pole has been designed and constructed to enable tall crops and plant canopies to be measured from the ground.* This device is light weight, collapsible, accomodates variable row-widths by having an adjustable cross arm, is counter-weighted and has proven sturdy and stable in field studies on corn (Kimes et al., 1980).

PRELIMINARY TESTING

Three prototype instruments have been field tested during the 1979 growing season with excellent results. Field tests have been conducted on rangelands in West Texas and on alfalfa, corn, soybeans, and winter wheat at the Beltsville Agricultural Research Center, Maryland. An example of some of the collected data appears as Figure 3.

ACKNOWLEDGMENTS

We wish to thank Don Friedman of GSFC Technology Utilization for his support and enthusiasm which made this project possible in the first place. Lee Miller must be acknowledged for his role in overcoming the initial internal inertia and assisting in getting the project under way. We also thank Vince Salomonson, Dean Smith, Lou Walter, Joe Knudson, Tom Ashley, and Ray Gilbert of Technology Utilization of NASA Headquarters.

*Designed by Peter Leone, John Humphreys, and Kenneth Kirks of GSFC.

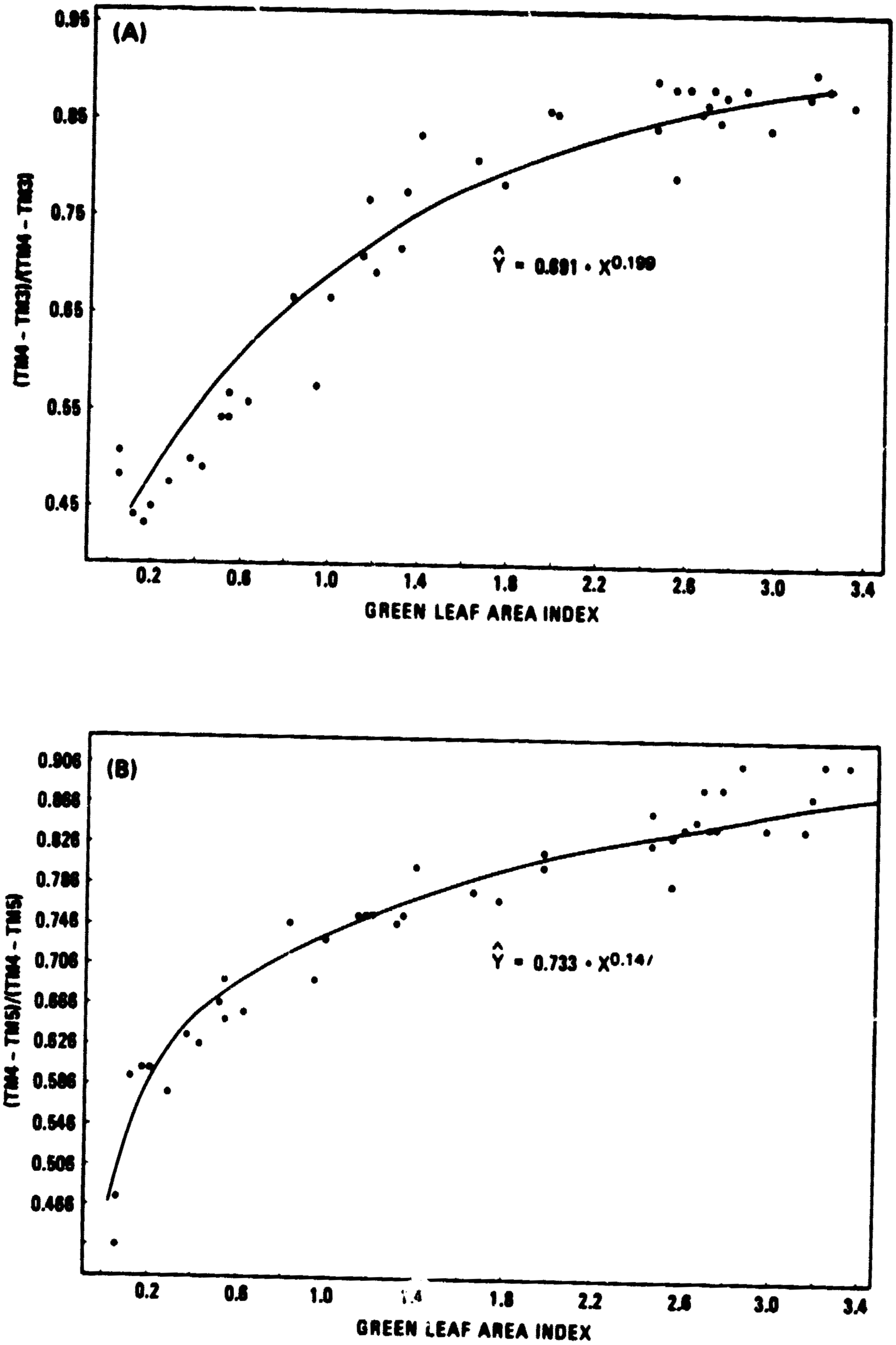


Figure 3. The ratio of (A) TM4/TM3 and (B) TM4/TM5 plotted against corn leaf area index from Kimes et al. (1980).

REFERENCES

Aase, J. K. and F. H. Siddoway. 1979. Relating winter wheat stands (simulated winterkill) to Landsat ground truth radiometer data. Agronomy Abstracts, 71st Annual Meeting, Ft. Collins, Colorado. August 5–10, 1979.

Birth, G. S. and G. R. McVey. 1968. Measuring the color of growing turf with a reflectance spectrophotometer. Agron J. 60:640–643.

Brach, E. J., R. W. Tinker, and G. T. St. Amour. 1977. Improvements in spectral reflectance measurements of field crops. Can. Agr. Engr. 19:78–83.

Collins, W. 1978. Remote sensing of crop type and maturity. Photogram. Engr. and Remote Sensing 44(1): 43–55.

Elgin, J. H., C. J. Tucker, J. E.McMurtrey, and B. N. Holben. 1979. Relationships between ground-collected spectral radiances and crop canopy variables. Agronomy Abstracts, 71st Annual Meeting, Ft. Collins, Colorado. August 5–10, 1979.

Exotech, Inc. 1972. Landsat (ERTS) groundtruth radiometer model 100-A: Description. Exotech, Inc., 1200 Quince Orchard Blvd., Gaithersburg, MD.

Holben, B. N. and C. O. Justice. 1980. Evaluation and modeling of the topographic effect on the spectral response from nadir pointing sensors. Photogram. Engr. and Remote Sens. 46: (in press-also as NASA/GSFC TM-80305 preprint).

Holben, B. N. and C. J. Tucker. 1980. Evaluation of irradiational conditions as they limit spectral estimation of tropical forest leaf area determinations. Photogram. Engr. and Remote Sens. (in press).

Holben, B. N., C. J. Tucker, and C. J. Fan. 1980. Spectral assessment of soybean leaf area and leaf biomass. Photogram. Engr. and Remote Sens. 46(5): 651–656.

Jackson, R. D., P. J. Pinter, Jr., S. B. Idso, and R. J. Reginato. 1979. Wheat spectral reflectance: Interactions between crop configuration and sun elevation and azimuth angle. Applied Optics (in press).

Kimes, D. S., B. R. Markham, C. J. Tucker, and J. E. McMurtrey. 1980. Temporal relationships between spectral response and agronomic variables of a corn canopy. NASA/GSFC TM (in preparation).

Leamer, R. W., V. J. Myers, and L. F. Silva. 1973. A spectrometer for field use. Rev. Sci. Instrum. 44(5): 611–614.

Methy, M. 1977. Estimation quantitative de la biomasse aerienne d'un peuplement de graminees par une methode optique non destructice. Ecologia Plantarum 12(4): 395–401.

Miller L. D., R. L. Pearson, and C. J. Tucker, 1976. A mobile field spectrometer laboratory. Photogram. Engr. and Remote Sensing 42(4): 569–572.

Milton, E. J. 1978. A portable four-band Landsat radiometer for ground data collection in remote sensing. Proc. of the 5th Annual Conf. of the Remote Sensing Society, Durham, England.

Pearson, R. L. and L. D. Miller. 1972. Remote mapping of standing crop biomass for estimation of the productivity of the shortgrass prairie, Paunee National Grasslands, Colorado. *Proc.* of the 8th International Symposium on Remote Sensing of Environment, Univ. of Michigan, Ann Arbor, pp. 1357–1381.

Pearson, R. L., L. D. Miller, and C. J. Tucker. 1976. Hand-held radiometer to estimate gramineous biomass. Appl. Optics 16(3): 416–418.

Pinter, P. J., Jr., R. D. Jackson, S. R. Idso, and R. J. Reginato. 1979. Multidate spectral reflectances as predictors of yield in water stressed small grans. Submitted to Nature.

Robinson, B. F., M. E. Bauer, V. P. de Witt, L. F. Silva, and V. C. Vanderbilt. 1979. A multiband radiometer for field research. In the Proc. of the 23rd Annual Meeting of the Soc. of Photo-optical Instrumentation Engineers, Vol. 196: 8–15.

Silva, L. F., R. Hoffer, and J. Cipra. 1971. Extended wavelength field spectroradiometer. 7th Internat'l. Symp. on Remote Sensing of Environment, Ann Arbor, Michigan, May, 1971, pp. 1509–1518.

Tucker, C. J. 1976. Unpublished research data from Serendipity Meadow, Yellowstone National Park; Keldnaholt, Iceland; Öland, Sweden; Oxfordshire, England; and The Grassland Research Institute, England.

Tucker, C. J. 1977. Spectral estimation of grass canopy variables. Remote Sensing of Environ. 6(1): 11–26.

Tucker, C. J. 1978a. A comparison of satellite sensor bands for vegetation monitoring. Photogram. Engr. and Remote Sensing 44(11): 1369–1380.

Tucker, C. J. 1978b. Hand-held radiometer studies on vegetation *in situ*: a new and promising approach. In Proc. of the International Symposium on Remote Sensing for Observation and Inventory of Earth Resources and the Endangered Environment. Internat'l. Archives of Photogram. Vol XXII-7 (Vol. 1), pp. 667–672.

Tucker, C. J., J. H. Elgin, J. E. McMurtrey, and C. J. Fan. 1979a. Monitoring corn and soybean crop development with hand-held radiometer spectral data. Remote Sens. of Environ. 8:237-248.

Tucker, C. J., J. H. Elgin, and J. E. McMurtrey. 1979b. Temporal spectral measurements of corn and soybean crops. Photogram. Engr. and Remote Sens. 45(5):643-653.

Tucker, C. J., B. N. Holben, J. H. Elgin, and J. E. McMurtrey. 1980a. Relationship of spectral data to grain yield variation. Photogram. Engr. and Remote Sens. 46(5):657-666.

Tucker, C. J., B. N. Holben, J. H. Elgin, and J. E. McMurtrey. 1980b. Remote sensing of total dry matter accumulation in winter wheat. NASA/GSFC TM-80631 (submitted to Remote Sens. of Environ).

Zgeibaum, F. M. and E. W. Chappelle. 1979. Making real-time sun reflectance measurements with a microprocessor-based spectroradiometer. In Proc. of the 23rd Annual Meeting of the Soc. Photo-optical Instrumentation Engineers, Vol. 180:242-255.

APPENDIX A
OPERATING INSTRUCTIONS AND ELECTRICAL LAYOUT

GENERAL OPERATING INSTRUCTIONS

Operation of the 3-band radiometer described in this report is rather straightforward. To facilitate data comparisons, most experimenters have found it necessary to collect spectral data under similar environmental circumstances. This is usually required to minimize irradiational variability which is the principal non-target source of variability.

From the hand-held radiometer experiences of the senior author, covering 8 years of *in situ* data collection from locales ranging from Puerto Rico to the arctic circle, we recommend data collection in direct sunlight near to solar noon for most applications. Investigator experimentation is encouraged to verify the effect(s) of different measurement times of day, solar zenith angles, atmospheric conditions, etc.

When operating the hand-held radiometer, the operator must take care to avoid casting a shadow on the area being measured, must not wear clothing which is spectrally reflective (dark colors are suggested), and must exercise care in holding the hand-held portion in a nadir pointing direction. The "rubber cement" addition of a commercially available circular level device (Sears, Wards, etc.; ~\$5.00) to the hand-held portion is suggested. In addition, users are cautioned that great care must be used when measuring the $BaSO_4$ calibration panels. Not only must the panel be level but the view angle of the hand-held module must be recorded. $BaSO_4$ is not a Lambertian reflector and thus view angles when measuring this target are necessary.

OPERATION OF THE INSTRUMENT

The instrument is turned on or off by the "ON/OFF" switch located on the readout unit. Sampling is provided by triggering either of the "SAMPLE AND HOLD" switches which are located on the readout unit and on the hand-held module. If either switch is in the "HOLD" position, the "SAMPLE AND HOLD" feature is activated. Thus these switches are an "OR" circuit – if either one is on' the circuit is activated and the channel readings when activated are "sampled and held" until both switches are no longer in the "hold" position. The "HOLD" feature is apparent on the display by the presence of an arrow.

A four decode range switch with moving decimal point is provided for each channel. When any channel is over-range, the display for that shows 19:99. Experimenters must gain familiarity with using the range switches to prevent under ranging. This takes a few minutes of field testing to accomplish.

The "BATTERY CHECK" feature is activated by moving each of the range switches to the "BATTERY CHECK" position. If the batteries are seriously depleted, the display for that particular battery circuit will show. If, during field operation any of the three battery circuits drops below specified levels, the display for that circuit will show.

The lead sulfide channel (channel 3) is uncooled and unchopped. This is necessary for a low power consumption and field ruggedness. However, because of thermal induced drift, a manual zero-offset is provided on the top of the hand-held module. It is suggested that instrument operators check for any thermal drift in this channel by blocking the entry of any light into the sensor apertures and simultaneously using the zero adjustment to return the display reading to "zero". It is also suggested that the operator only have the instrument "ON" when data is being collected. This will minimize thermal drift in channel 3 and conserve the batteries. Experiences at Beltsville, Maryland with similar instruments (the prototypes) have shown no difficulty in extended summer field operation of these devices if they are switched "OFF" when not in direct use and the "zero" offset only takes $\leq$10 seconds total elapsed time. There should not be any thermal drift in channels 1 and 2 as they have silicon detectors. The lead sulfide detector used for channel 3 is highly temperature sensitive and a change in temperature of only 1 degree celsius will cause a change in detector resistivity greater than 1%. The incident infrared radiation is also detected by changes in resistivity of this detector. That is, near infrared radiation fa.'ing on the lead sulfide detector reduces its resistance. The minimum target brightness that must be detected by the Mark-II causes a change of less than 1% in detector resistance.

The most common way to overcome this thermal problem is to use a motor driven optical chopper and capacitively decouple the sensor from the instrument. However, we considered a chopper not to be compatible with a hand-held field instrument. Instead careful thermal and electrical design was used to solve the problem. Referring to Figure A.8, the bias circuit is arranged into a bridge to minimize the effects of unbalance in the bias batteries. The left hand side of the bridge contains two lead sulfide detectors. Both of these elements are mounted axially inside of a sealed TO-8 transistor can. One detector is blackened and the other is cemented directly on top of it: the detectors and transistor can are thus in close thermal contact with each other. Only one detector is exposed to the incident radiation. Because the detectors have closely matched electrical characteristics and are in good thermal contact, the detectors change in resistance an almost equal amount. This minimizes the voltage change at their junction point (F) induced by temperature. Since the signal is also picked off by the preamplifier at this point, temperature drift is minimized. The blackened detector is also the load impedance for the detector. The load impedance then is always equal to the detector's internal impedance. This minimizes the change in calibration with temperature. The infrared detectors were specially designed and manufactured for the Mark II.

The zero adjustment has a range of only ±1% to compensate for component mismatch. Should the components age and the mismatch exceed 1% a resistor (R13) can be added between terminals 12 and 13. A 20K thin film low temperature coefficient resistor is recommended. The terminals are not connected to anything so jumpers are needed to put the resistor in the circuit. To shift the zero negatively, move the wire from terminal 7 to 13, and jumper 12 to 7. To shift the zero positively; move the wire from terminal 9 to 13, and jumper 12 to 9 (see Figure A-8).

To gain access to the hand-held units printed circuit board (see Figure A-5):

a. Remove the 3 (4-40) screws on the side of the can near the top.

b. Hold the unit by the handle and slide the can down and off.

c. Remove the 3 (4-40) recessed screws on top of the unit.

d. Remove the top of unit.

There is enough slack in the cable to allow the printed circuit board to be exposed.

The leads from the 3 detectors are soldered to the top side of the board. It is not necessary to remove the board to install R13. Refer to Figure A.8.

BATTERIES

There is a battery access panel on the bottom of the read-out module. Removing a screw at each corner of this panel will allow the batteries to be changed. The service life of the batteries is greater than 100 hours when the instrument is used two hours or less a day. There are three battery sets; +5 volts, plus and minus nine volts, and plus and minus 8.4 volts. The 8.4 volt set will last the shelf life of the batteries.

The five volt set consists of four alkaline size D flashlight batteries. They are used to power the five volt logic circuits and the liquid crystal displays. This set will start out at 6.5 volts with new batteries and should be replaced when they fall below 5 volts. By turning the range switch for channel one to the "BATT" position this voltage can be checked.

The plus and minus 9 volt set consists of two transistor radio batteries. They are used to power the analog circuits in the instrument. A new set will be about 9.6 volts. When they fall below 7.5 volts they should be replaced *as a pair.* In addition, they should be replaced if there is more than a half a volt difference between the two batteries. These voltages can be checked by turning the range switch of channel 2 (-9) and channel 3 (+9) to the respective "BATT" positioning. Also notice that the minus does not indicate for battery checks.

The plus and minus 8.4 set consists of two 8.4 volt mercury batteries. They are Mallory TR146X and are slightly smaller than transistor radio batteries. Accordingly, they have a 1/16 inch spacer at the foot of their holders. The spacer is required to maintain good electrical contact. The mercury batteries are used solely to supply bias to the infrared detector bridge of channel 3. Since the drain on these batteries is low, they should be replaced once a year *as a pair.* This battery set can not be checked from the front panel. Upon replacement of the 8.4 volt batteries, care must be taken to insure that this battery pair is *balanced.* If this set is unbalanced, the operation of the instrument will be compromised.

FIELD OPERATION - READING THE DISPLAYS

LIQUID CRYSTAL DISPLAY

Liquid crystal displays (LCD) were used because they are readable in sunlight and require little power to operate. They are, therefore, ideal for battery powered instruments used in the field. LCD's do have temperature limitation that can occur under extreme field conditions. Below freezing the numbers fade and the display becomes blank. Above 140°F the display turns black and the numbers are no longer visible. Temperatures this high can occur due to the "greenhouse effect". The sun passing through the protective plastic window will heat the display and since the instrument case is sealed, heat is trapped and temperatures rise above ambient. However, in both cases the display can be restored by returning it to normal temperatures. There are no lasting adverse effects to the LCD's should either of these conditions occur.

DIGITIZER

Range: Analog signals are general by the detector circuits in response to stimuii. These signals are converted to digital and formatted for the display by the digitizer. The digit'zer is a 999 count device. That is, it can display positive numbers from 000 to +999. In the negative direction it is a 99 count device and can display numbers from 000 to -999. Polarity is automatically indicated by the display. Negative signals are normally only encountered when balancing the infrared detector bridge of channel three. The magnitude of the number is always indicated by the decimal point and are automatically positioned by the range switches The ranges are labeled by rounding off the maximum value that can be attained on that range. That is, the range switches are labeled 1, 10, 100, and 1000 instead of .999, 9.99, 99.9, and 999.

Positive Over Range (POR): When a signal exceeds a positive count of 999 POR occurs. POR is indicated by a one next to the plus sign, three nines, and a colon all being visible (+19:99). The decimal point is not shown because its position depends on the range switch.

Negative Over Range (NOR): When a negative count exceeds 099 NOR occurs. NOR is indicated by a one next to the minus sign, two nines, and a colon all being visible (-10:99). The decimal point is controlled by the range switch in this mode also.

Sample and Hold Indicator: The Mark-II radiometer samples repetitively all three optical channels within a quarter of a second. To assist the evaluation of the near simultaneous samples, the instrument has a hold circuit. There are two sample and hold switches that operate this circuit. One switch is located under the handle of the hand-held unit and the other is located on the front panel of the display unit. If one or both of these switches are in the hold position, the digitizers hold their last samples. All three channels are held simultaneously. The displays remain fixed with the last sample until the radiometer is returned to the sample mode. To alert the operator that the instrument not sampling a ← is included. When the radiometer is "holding," an arrow located in the upper left hand corner of the display becomes visible (i.e., ↕ 3.21).

MISCELLANEOUS

FILTER SPECIFICATIONS

Optical filters can be ordered from several manufacturers to the specifications supplied by the purchaser. The Mark-II filters were ordered with these mechanical specifications:

1. Silicon channels: Diameter = 1.000 ± 0.010 inches and thickness = 0.375 ± 0.030 inches. (Also blocked to 1 μm.)
2. Lead sulfide channel: Diameter = 1.000 ± 0.010 inches and thickness = 0.125 ± 0.015 inches. (Also blocked for lead sulfide.)

PROBLEMS ENCOUNTERED WITH MARK-II UNITS AND SOLUTIONS TO THESE PROBLEMS

Problem

Channel three can not be zeroed with the potentiometer on the hand-held unit (sensor covered).

Cause A

Some of low serial number (1-5) Mark II's had a 5K or 10K ohm zero adjust potentiometer. This proved to have a limited adjustment range.

Solution A

Replace with 20K ohm potentiometer, supplied on request (see Figures A.2 and A.8).

Cause B

The two bias batteries for the infrared detector bridge could be unbalanced.

Solution B

Remove the battery access panel on the rear of the instrument. With a digital volt meter measure the voltage of the mercury batteries (Malloy TR-146). These batteries are not checked from the front panel and normally are replaced only once a year. These batteries should be greater than 7.8 volts, and within 0.1 volts of each other. Replace as a set.

<u>Cause C</u>

With rough handling, the batteries sometimes come loose.

<u>Solution C</u>

Replace the batteries in their respective battery holders.

Also included in Appendix A are the electrical schematics for the 3-band radiometer display boards (Figure A.1), preamp board (Figure A.2), digitizer board (Figure A.3), and the digitizer box box wiring (Figure A.4). A detailed drawing of the hand-held portion of the 3-band instrument appears as Figure A.5. The assembly drawings for the printed circuit preamp board and digitizer board appear as Figures A.6 and A.7, respectively. An electrical schematic for the lead sulfide circuit appears as Figure A.8.

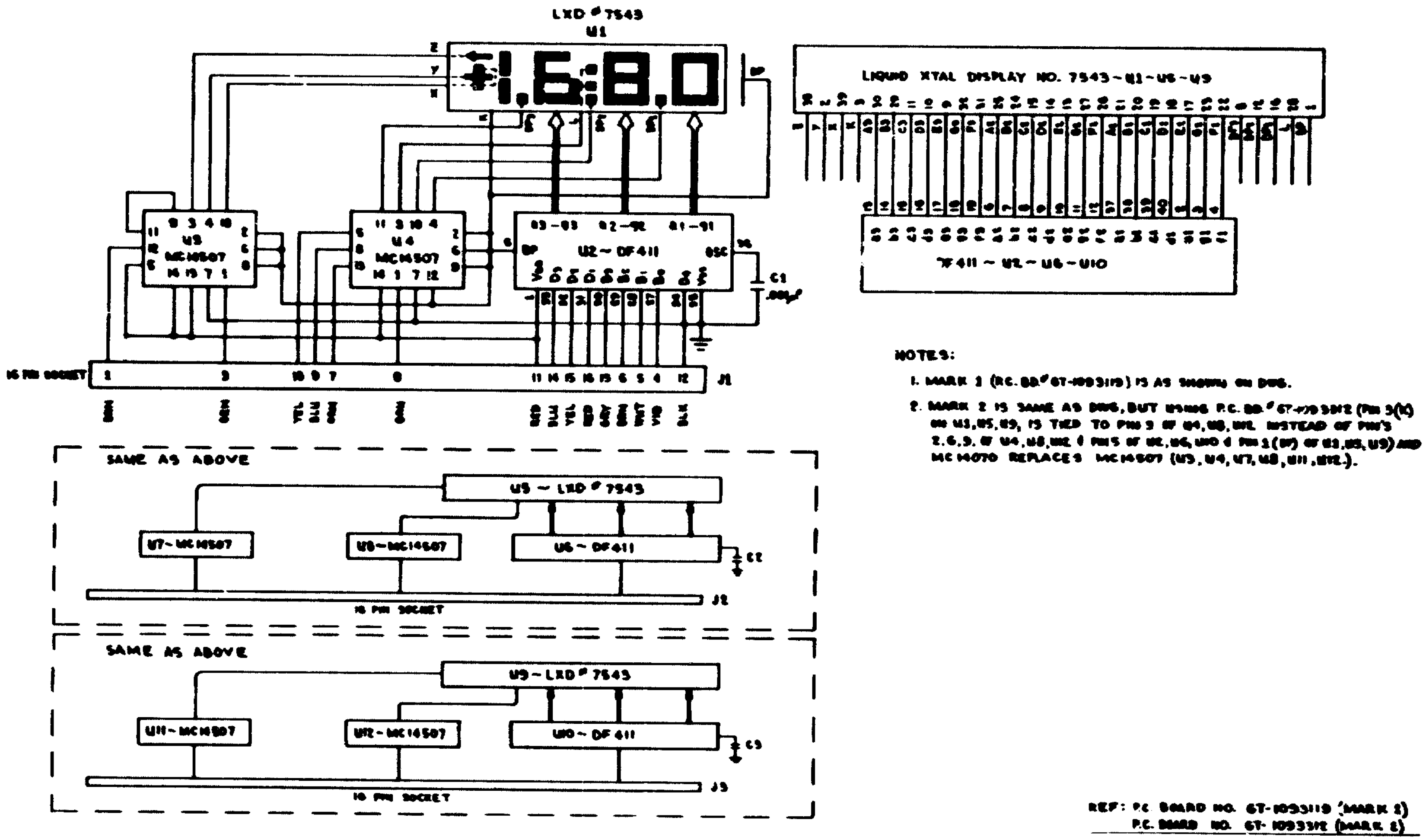


Figure A.1. 3–band radiometer display board schematic.

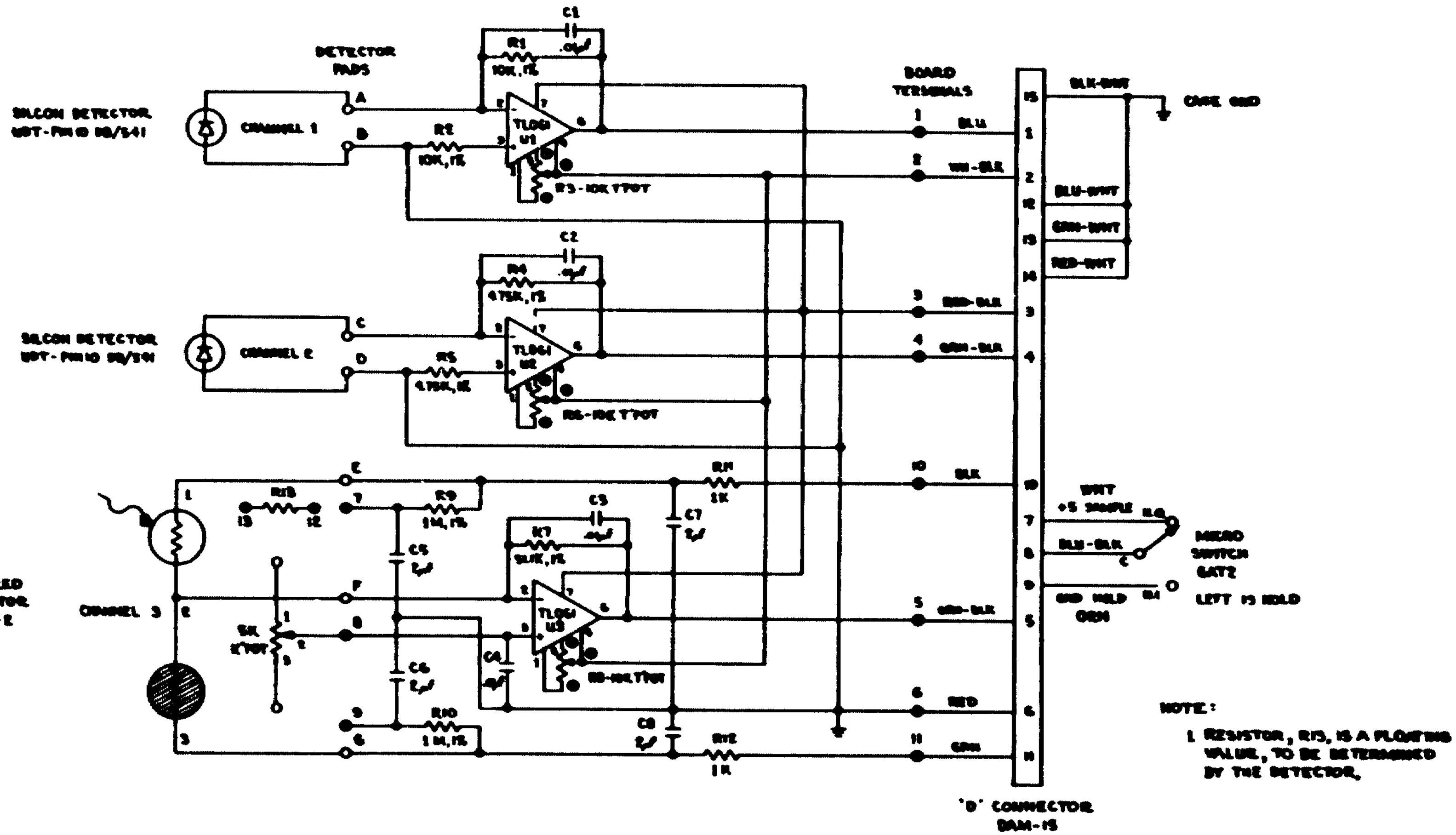
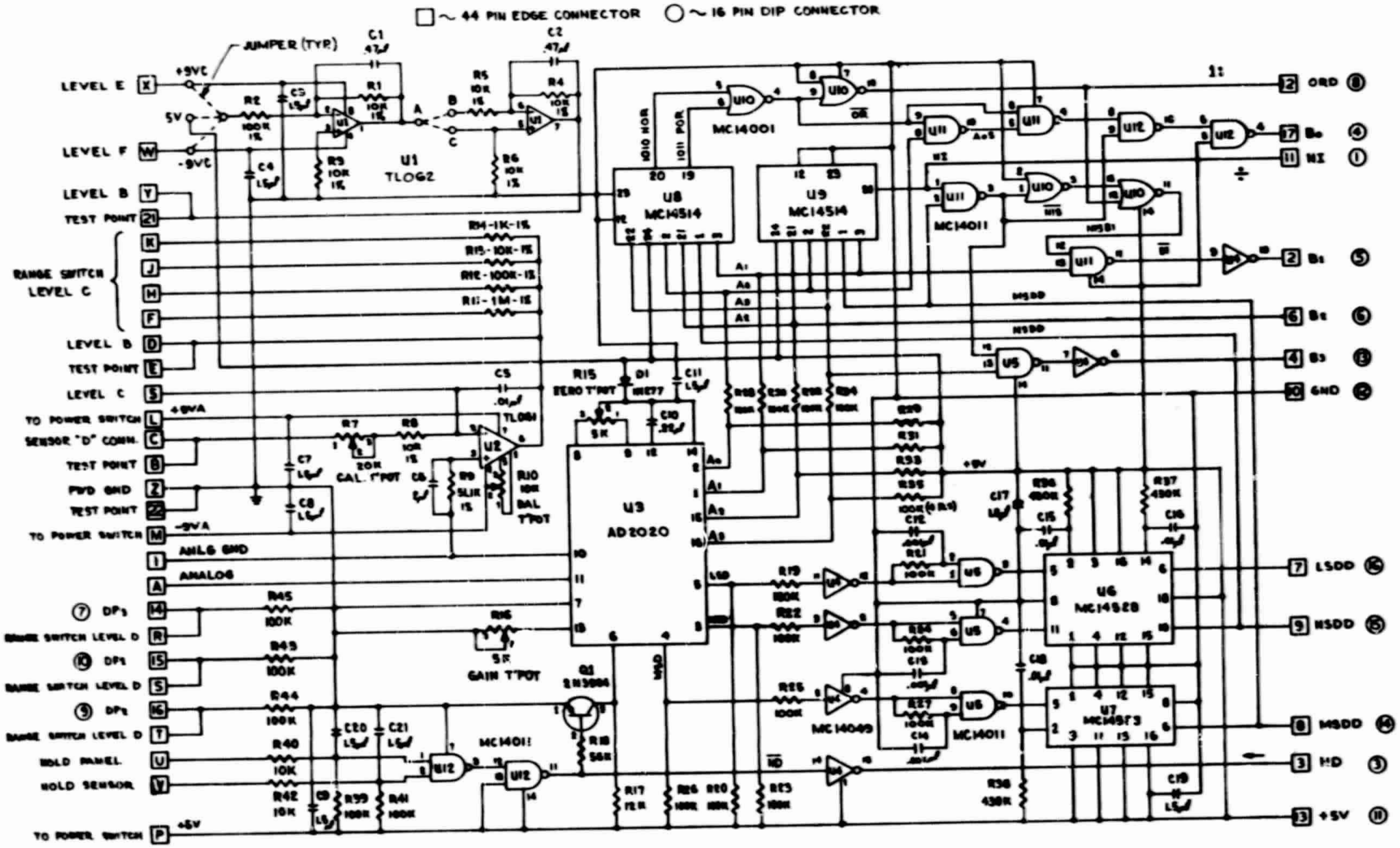


Figure A.2. 3-band radiometer preamp schematic.



NOTE

ORD ~ OVER RANGE DISPLAY
Bo ~ LEAST SIGNIFICANT BIT (BCD)
NI ~ NEGATIVE INDICATOR
B1 ~ BIT ONE (BCD)
B2 ~ BIT TWO (BCD)
B3 ~ MOST SIGNIFICANT BIT (BCD)
LSDD ~ LEAST SIGNIFICANT DIGIT DISPLAY
NSDD ~ NEIGHTER SIGNIFICANT DIGIT DISPLAY
MSDD ~ MOST SIGNIFICANT DIGIT DISPLAY
HD ~ HOLD DISPLAY
DP ~ DECIMAL POINT

Figure A.3. 3-band radiometer digitizer schematic.

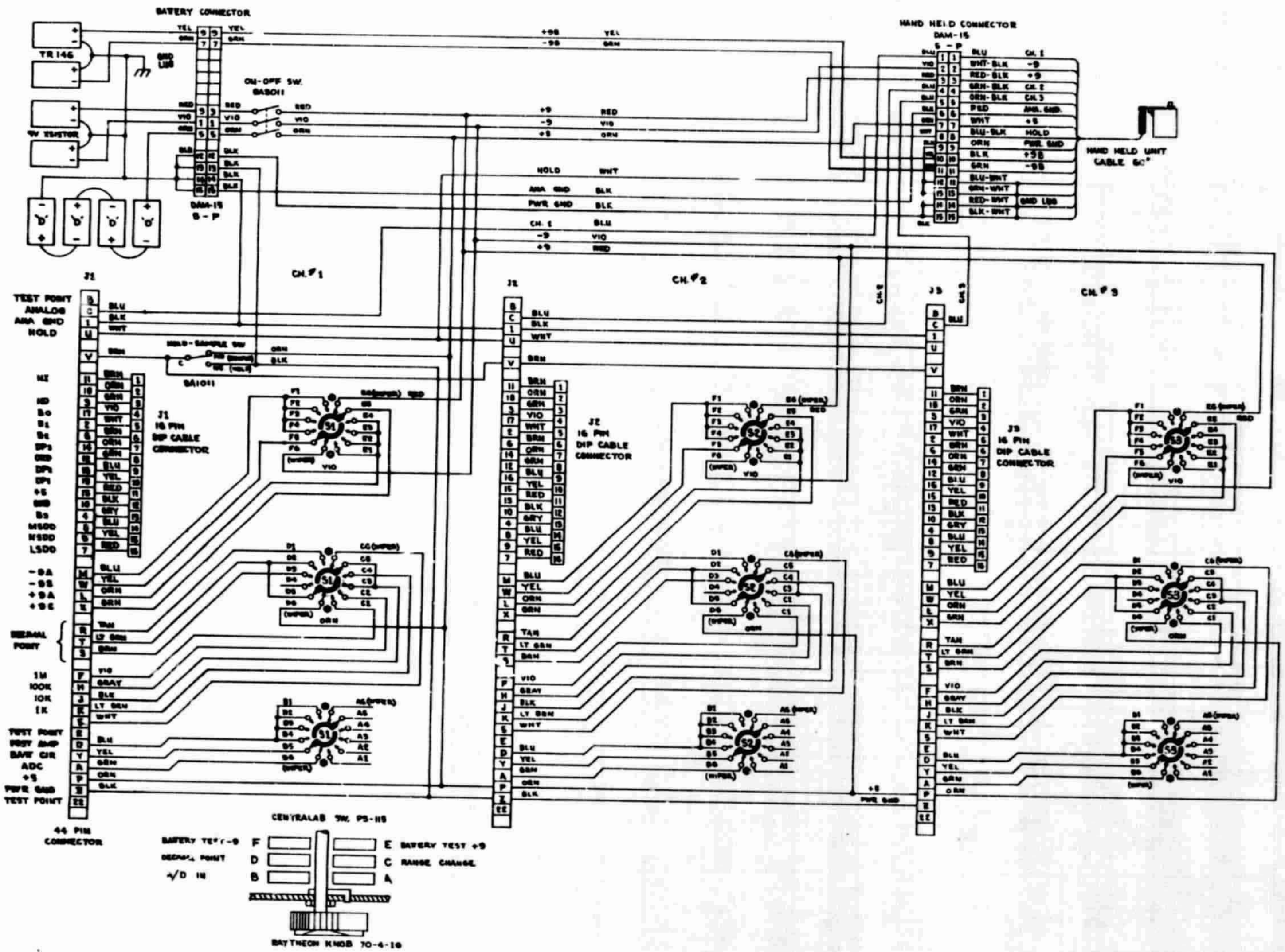
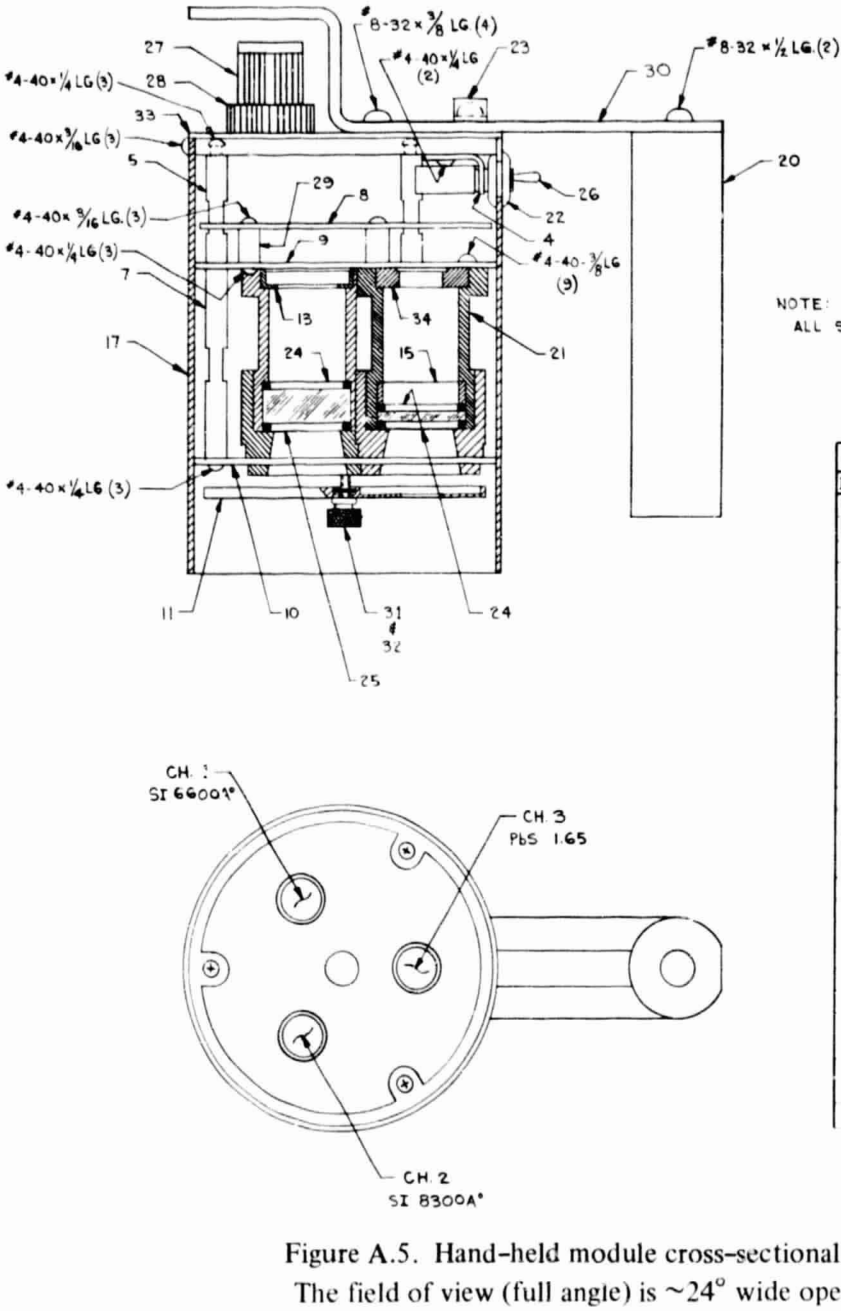


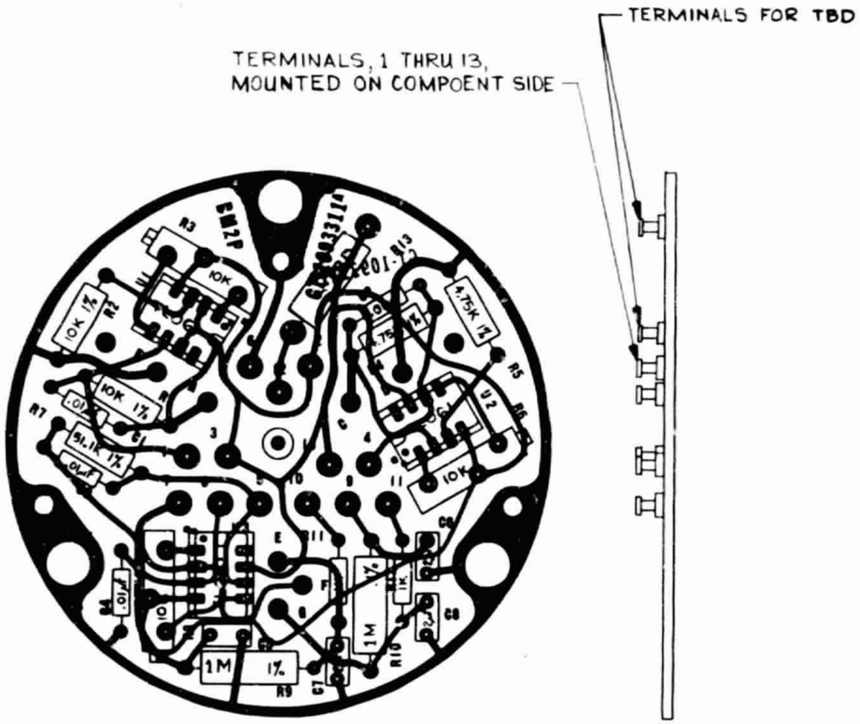
Figure A.4. 3-band radiometer digitizer box wiring.



NOTE:
ALL SCREWS ARE PAN HD. PHILLIPS.

PARTS IDENTIFICATION LISTING	
ITEM NO.	ITEM NAME
4	MOUNTING BRACKET, SWITCH
5	SPACER, UPPER
7	SPACER, MIDDLE
8	BOARD, PC
9	MOUNTING PLATE, DETECTOR
10	PLATE, END
11	PLATE, APERTURE
13	ADAPTER, SI
15	SPACER, FILTER
17	CONTAINER
20	HANDLE
21	HOUSING, SENSOR
22	GROMMET
23	CLAMP, CABLE
24	O' RING, SI • PbS
25	O' RING, SI
26	SWITCH, ON-OFF
27	DIAL, ZERO ADJUST. (CHANNEL 3)
28	DIAL, FRICTION BRAKE
29	SPACER, PC BOARD
30	MOUNTING BAR, HANDLE
31	THUMB SCREW • SNAP RING
32	SNAP RING
33	CAP, CONTAINER
34	ADAPTER, PbS

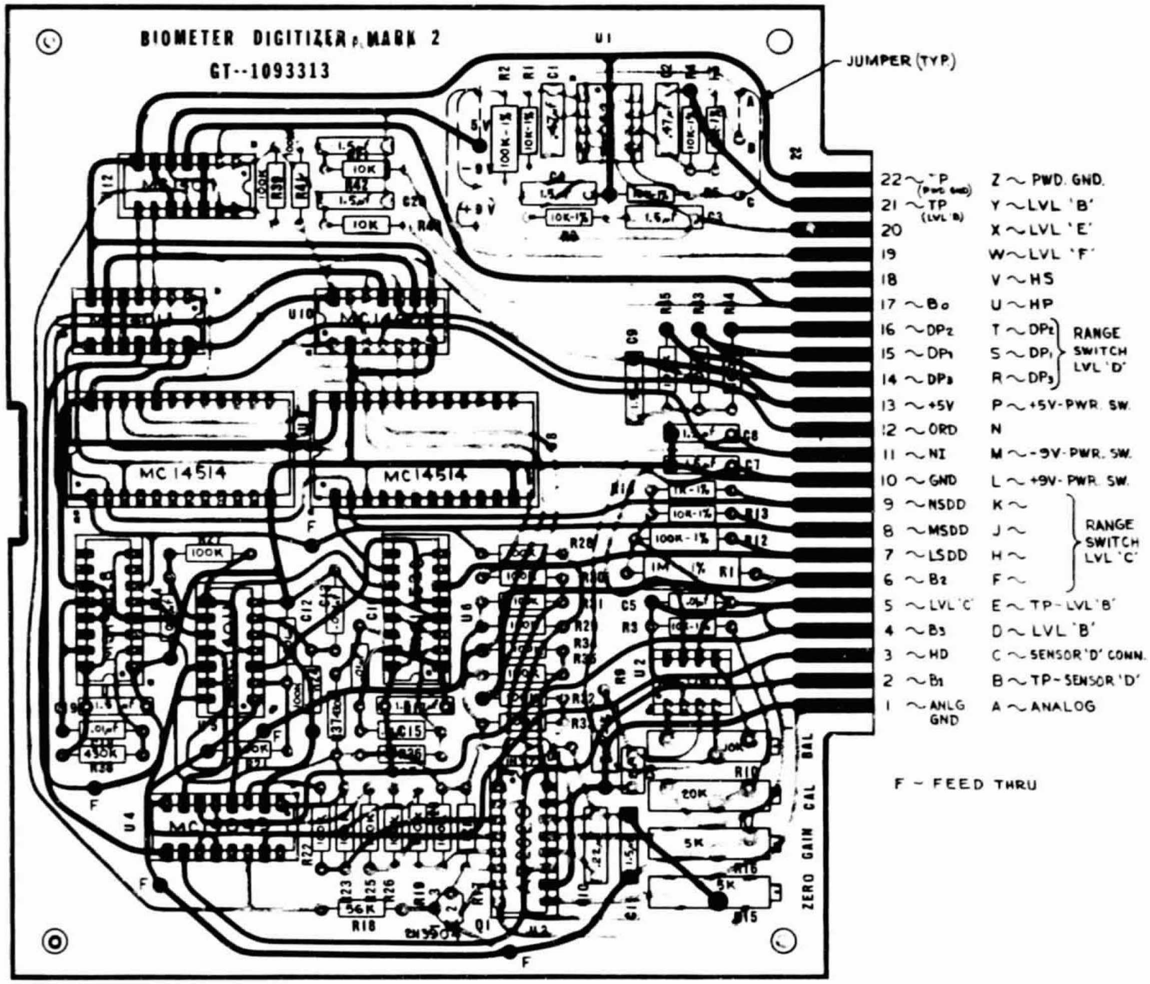
Figure A.5. Hand-held module cross-sectional view. The field of view (full angle) is ~24° wide open or ~24° with the apperature plate attached.



REF. DESIGNATION	DESCRIPTION	PART NO.
R1, R2	RES. 10K, 1%	
R4, R5	RES. 4.75K, 1%	
R7	RES. 51.1K, 1%	
R9, R10	RES. 1M, 1%	
R11, R12	RES. 1K, 5%	
R13	RES. TBD, 1%	
R3, R6, R8	RES. 10K, T'POT	3006P-1-103
C1 THRU C4	CAP. .01μf	
C5 THRU C8	CAP. 2μf	
U1 THRU U3	DUAL-IN-LINE	TL061
U1 THRU U3	SOCKET-8 PIN	TEW-3700-8B
1 THRU 13 & TBD	TERMINAL	2010B

Figure A.6. Preamp printed circuit board assembly (See also Figures A.2 and A.5).

NOTE: ORD ~ OVER RANGE DISPLAY
B_0 ~ LEAST SIGNIFICANT BIT (BCD)
NI ~ NEGATIVE INDICATOR
B_1 ~ BIT ONE (BCD)
B_2 ~ BIT TWO (BCD)
B_3 ~ MOST SIGNIFICANT BIT (BCD)
TP ~ TEST POINT
LSDD ~ LEAST SIGNIFICANT DIGIT DISPLAY
NSDD ~ NEIGHTER SIGNIFICANT DIGIT DISPLAY
MSDD ~ MOST SIGNIFICANT DIGIT DISPLAY
HD ~ HOLD DISPLAY
DP ~ DECIMAL POINT
HP ~ HOLD PANEL
HS ~ HOLD SENSOR



F ~ FEED THRU

DESIGNATION	DESCRIPTION	PART NO.
U1, U2	SOCKET ~ 8PIN	TEW-3700-8B
U5, U10, U11, U12	SOCKET ~ 14 PIN	TEW-3700-14B
U3, U4, U6, U7	SOCKET ~ 16 PIN	TEW-3700-16B
U8, U9	SOCKET ~ 24 PIN	TEW-3700-24B
D1	DIODE	IN277
Q1	TRANSISTOR	2N3904
R1, R3 THRU R6, R8, R13	RES. 10K, 1%	
R2, R12	RES. 100K, 1%	
R7	RES. T'POT. 20K	
R9	RES. 51.1K, 1%	
R10	RES. T'POT. 10K	
R11	RES. 1M, 1%	
R14	RES. 1K, 1%	
R15, R16	RES. T'POT. 5K	
R17	RES. 12K, 5%	
R18	RES. 56K, 5%	
R19 THRU R35, R39, R41, R43, R44, R45	RES. 100K, 5%	
R36, R37, R38	RES. 430K, 5%	
R40, R42	RES. 10K, 5%	
C1, C2	CAP. .47μf	
C3, C4, C7, C8, C9, C11, C17, C19, C20, C21	CAP. 1.5μf	
C5, C15, C16, C18	CAP. .01μf	
C6	CAP. 2μf	
C10	CAP. .22μf	
C12, C13, C14	CAP. .001μf	
U1	DUAL-IN-LINE	TL062
U2		TL061
U3		AD2020
U4		MC14049
U5, U11, U12		MC14011
U6, U7		MC14528
U8, U9		MC14514
U10	DUAL-IN-LINE	MC14001

Figure A.7. Digitizer printed circuit board assembly (See also Figures A.3 and A.4).

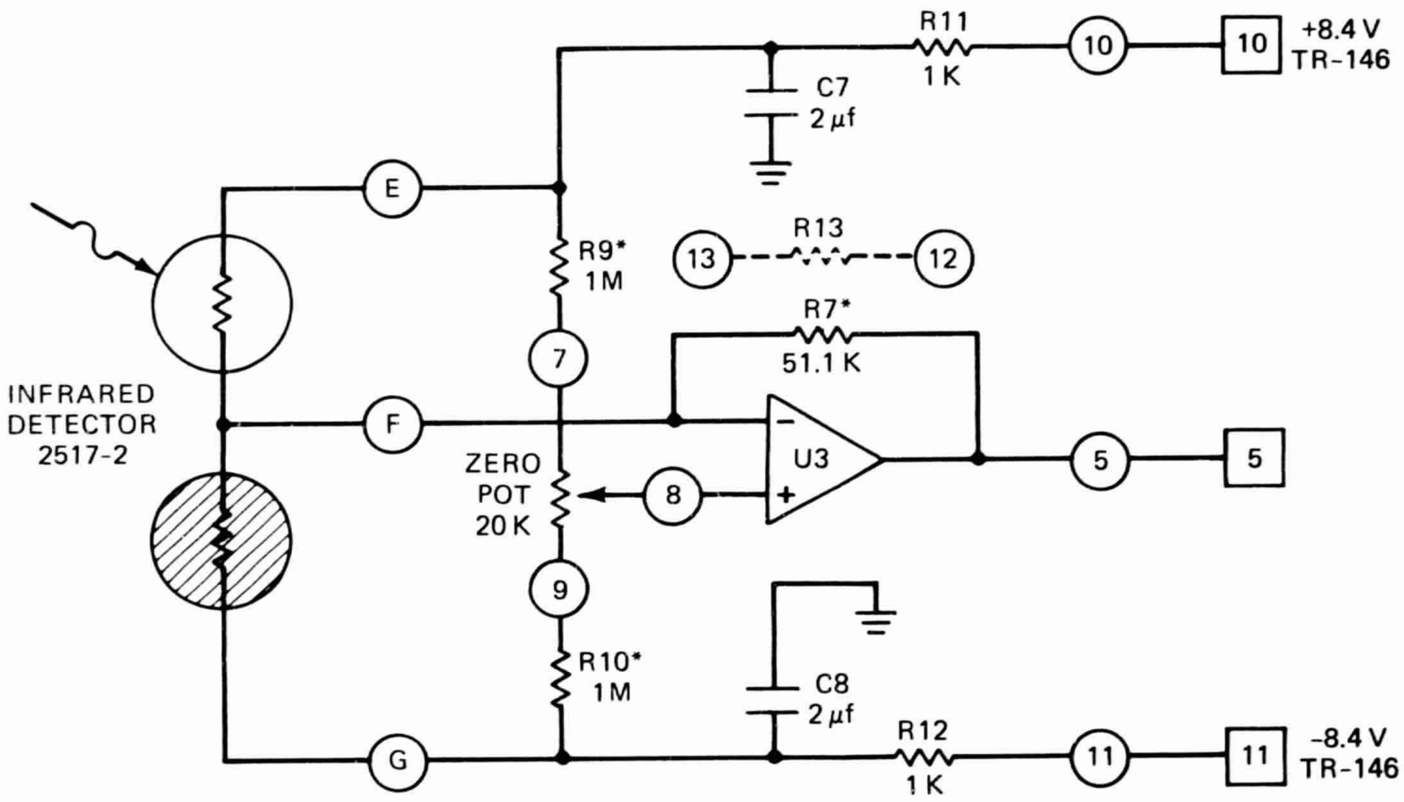


Figure A.8. Infrared detector bridge and preamplifier for Mark-II. ○ denotes terminal identification on printed circuit board, □ denotes connector pin number on hand-held sensor cable, and * denotes 1% precision resistor.