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Design and Operation of a Multispectral Radiometer and Digital Data Acquisition System

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Multispectral Radiometer Model MSR85

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Design and operation of a multispectral radiometer and digital data acquisition system

Introduction

Research and development of methods to utilize remote sensing as a means of monitoring onset and progress of foliar diseases of barley have been progressing since 1975. A low-cost, simple multispectral radiometer was built by which reflected solar radiation could be measured in several narrow band wavelengths from 500 to 850 nm. The radiometer is particularly useful as an objective and efficient means of measuring the progress of diseases for epidemiology studies of foliar diseases of barley. It appears to be a more accurate method of measuring disease severities and for estimating the effect of foliar diseases on yield and quality parameters than the visual assessment method. The instrument may also be useful for evaluating efficacy of foliar fungicides for control of foliar diseases. With the advent of relatively low-cost portable computers, the development of highly sophisticated data acquisition systems is feasible. The new equipment will permit accurate, rapid measurement of reflected solar radiation from field and test plots in several wavelengths.

Materials and Methods

The Multispectral radiometer

Cadmium sulfide and/or cadmium selenide photoconductive cells are used as light transducers in the radiometer. These cells are mounted in a 7 x 7 x 10 cm aluminum housing with 8 of the cells oriented toward incident and eight toward relfected solar radiation. A 12.5 mm dia. interference filter is mounted over each of the cells. The eight filters cover the wavelengths 500 to 850 nm at 50 nm intervals. A plate of flashed opal glass is mounted over the cells oriented upward to diffuse incident solar radiation. A simple convex lens of 18 mm focal length, located in each tube oriented downward, forms an image of the subject on the face of each photocell. The angle of view of these lenses is 28°.

Each of the photoconductive cells is in a voltage divider circuit (Fig. 2). The output voltage of this circuit varies from 0 to 5 volts depending on the intensity of radiation.

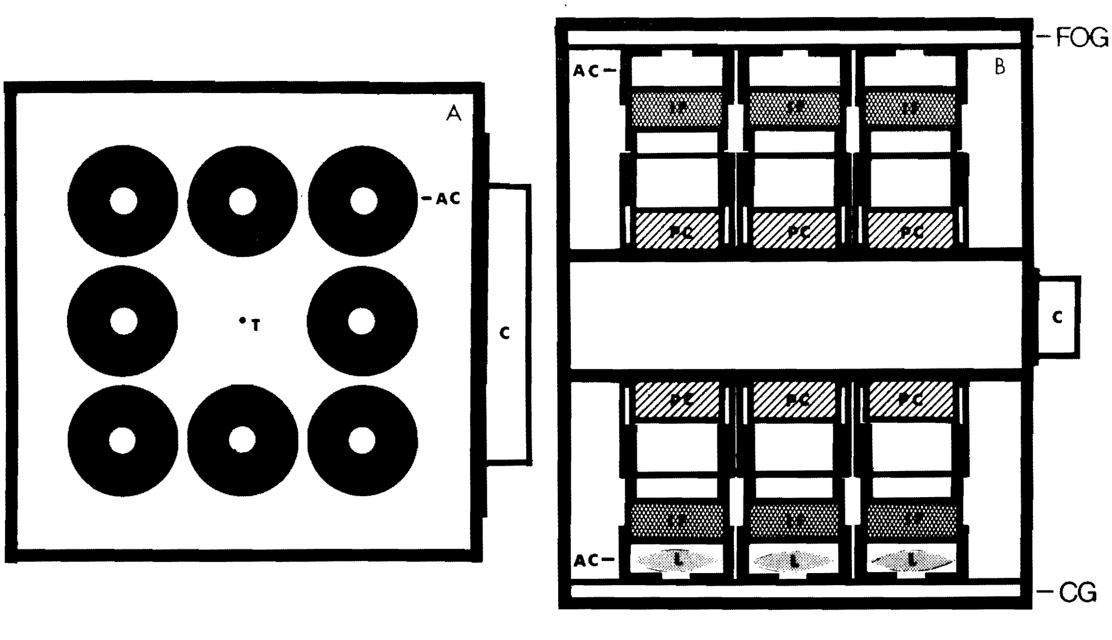

Figure 1. Actual size diagramatic representation of a multispectral radiometer
A. Top view
B. Side view
PC - Cadmium sulfide and/or cadmium selenide photoconducive cells.
IF - 3 cavity interference filter
L - Simple convex lens of 18 mm focal length
T - thermistor
AC - aperature cap
C - 24 pin connector
FOG - Flashed opal glass
CG - clear glass

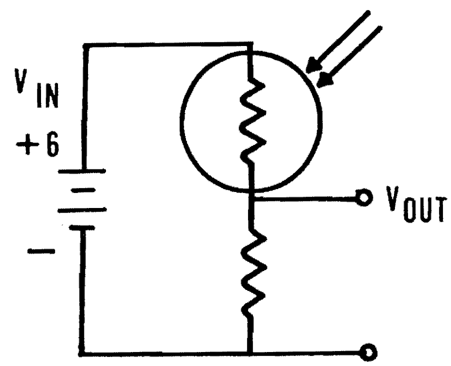

Figure 2. Voltage divider circuit used for each photoconductive cell and thermistor in the multispectral radiometer.

The A/D converter

Theory of operation

A 29 channel, 12 bit analog-to-digital converter was built to interface with a Radio Shack TRS80 model 100 portable microcomputer via the RS232 serial port. The block diagram below shows the major pieces involved in the RS232 analog-to-digital converter. Basic operation of the converter is as follows: when the UART receiver receives a character from the serial input, it outputs it as the channel selection address to the analog multiplexer. After a brief delay to allow the analog voltage to settle at the input of the analog-to-digital converter, the converter is signaled to begin the conversion. When the conversion is complete, the low byte of the conversion is selected via the digital multiplexer, and the UART transmitter is signaled to send a character. After the low byte is transmitted the last nibble is selected via the digital multiplexer and the UART is signaled to transmit it on the serial output. After the last transmission, the logic is reset and ready for another channel selection and conversion.

Circuit diagram description

The following discussion will address, in detail, the operations of each of the blocks previously described. Refer to the attached circuit diagram for this discussion (Fig. 4).

Analog multiplexer

The Analog Multiplexer consists of four CMOS analog multiplexer integrated circuits (IC1-IC4) each

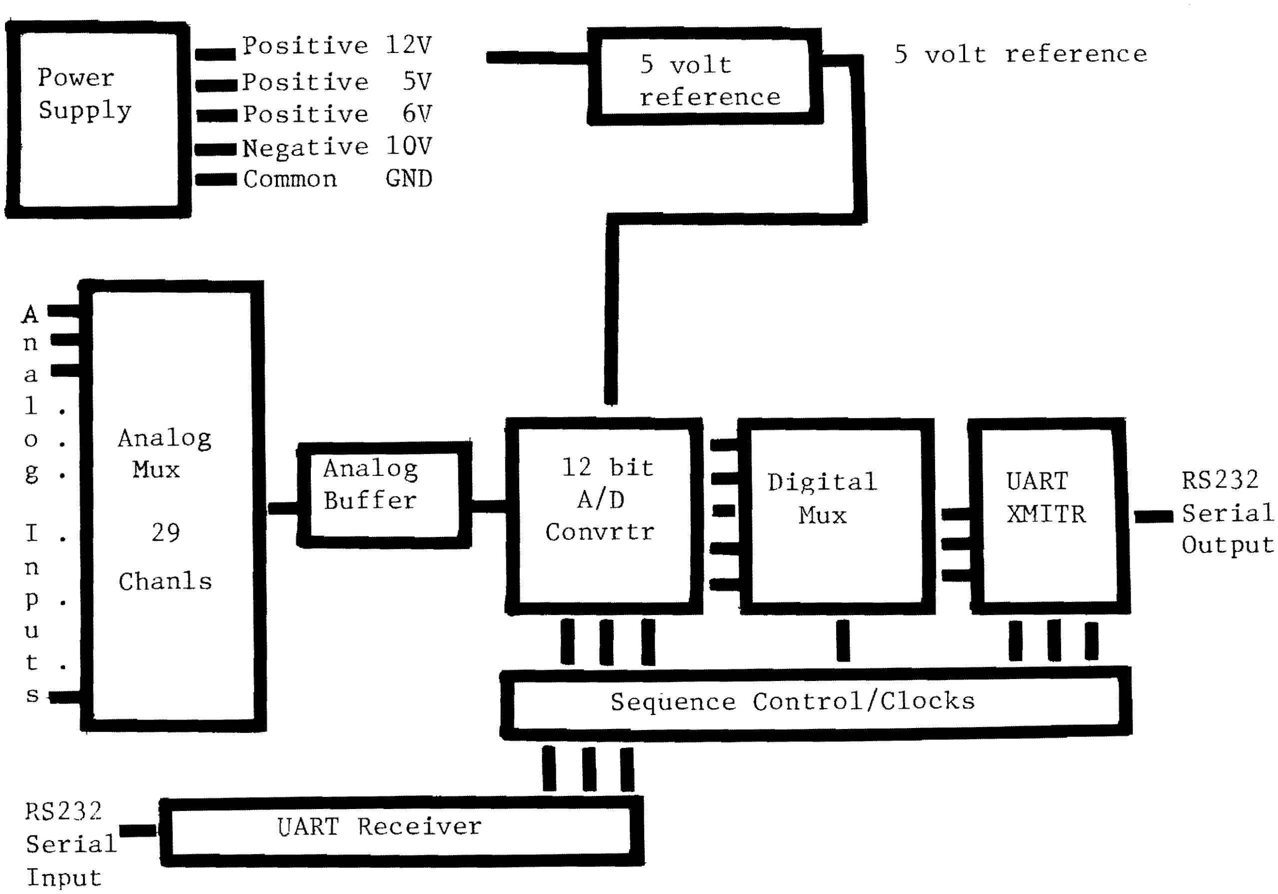

Figure 3. Block diagram of analog-to-digital circuit.

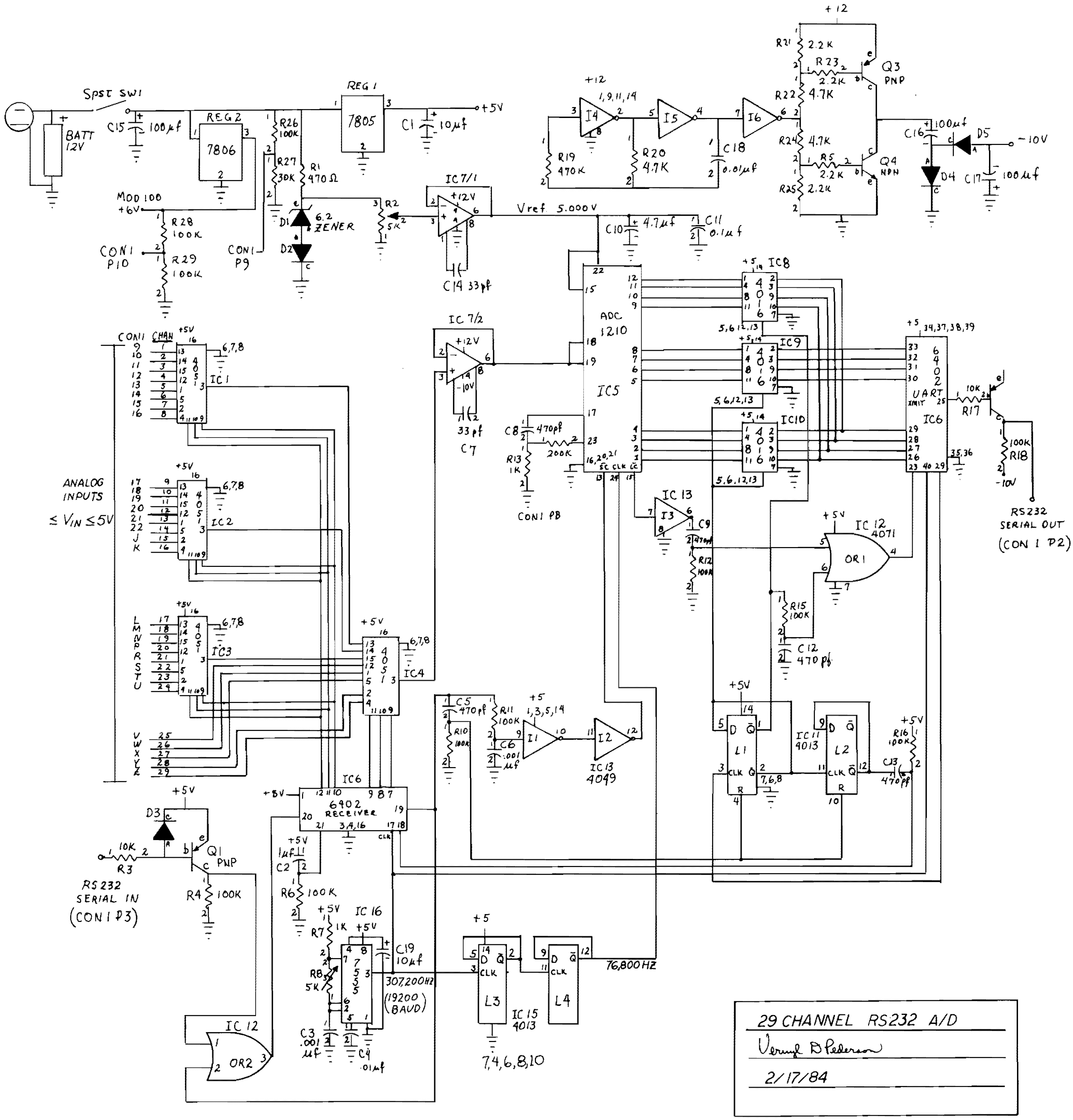
29 CHANNEL RS232 A/D
Verwyl D Pederson
2/17/84
SPST SW1
BATT 12V
REG 1
7805
REG 2
7806
+5V
MOD 100 +6V
6.2 ZENER
IC 7/1
IC 7/2
Vref 5.000V
ADC 1210
IC5
IC8
IC9
IC10
UART
IC6
RS232 SERIAL OUT (CON 1 P2)
ANALOG INPUTS
≤ VIN ≤5V
IC1
IC2
IC3
IC4
IC 12 4071
OR1
IC 13 4049
6402 RECEIVER
RS232 SERIAL IN (CON 1 P3)
Q1 PNP
Q3 PNP
Q4 NPN
IC 16
307,200HZ (19200 BAUD)
IC 15 4013
IC 11 4013
76,800 HZ
OR2
-10V

Figure 4.

with eight inputs. They are arranged in a tree structure allowing for a total of 29 analog inputs. The input voltages may vary from 0 to +5 volts. The channel addressing comes from the low order six bits of the recieved character in the receiver buffer register of the UART.

The output of the Analog Multiplexer stage is input to the Analog Buffer stage.

Analog buffer

The Analog Buffer, OP AMP2, is required to provide a high input impedance (10M ohms) to the analog inputs. The Op Amp is connected in a voltage follower arrangement with unity gain and the output is fed to the analog input of the A/D Converter (IC5).

Analog to Digital Converter

The Analog to Digital Converter (IC5) is a 12 bit successive approximation converter which requires 13 clock periods to complete a conversion (about 170 micro seconds with a clock of 76800 Hz). A conversion is started by the transition from low to high on IC5P13. Conversion complete is indicated by a high to low transition on IC5P14. The 12 bits are then output to the Digital Multiplexer Section.

Digital Multiplexer

IC8-IC10 make up the Digital Multiplexer. IC9 and IC10, when selected by the sequence control logic, will pass the low byte (low 8 bits) of the A/D converter to the UART. IC8, when selected, will pass the high nibble (4 bits) to the UART.

UART Transmitter

The transmitter portion of IC6 will transmit 8 bits of data upon request serially to transistor Q2 which inverts and translates the signal to RS232 compatible levels. After transmitting the data the UART notifies the sequence control logic.

Sequence Control Logic

The Sequence Control Logic is a three state machine consisting of a data received latch (IC6P19), and latchs L1 and L2. When a character has been received, IC6P19 will go high causing a short pulse, generated by C5 and R10, to reset latchs L1 and L2. Latch L1 controls the digital multiplexer. R11 and C6 cause a short delay before activating an A/D conversion. This delay is about 50 micro seconds and is used to allow for the analog voltage to settle at the inputs of the A/D converter before the conversion begins. Inverters I1 and I2 serve merely as buffers.

When the conversion is complete, I3, C9 and R12 generate a short pulse at the input of OR1 which passes it on to the UART transmitter (IC6P23). This initiates the transmission of the low byte of the conversion data. The end of transmission from IC6P24 will clock L1 causing it to select the high nibble of data through the digital multiplexer IC8. R15 and C12 cause a short delay before the L1 transition is transferred via OR1 to the UART transmitter. The UART transmitter will transmit the second byte of data and the transmission complete transition on IC6P24 will clock L1 and L2 causing a reset pulse to be generated by C13 and R16. This reset pulse will reset the data received latch in IC6 and IC6P19 will go low.

That completes a cycle of the RS232 A/D Converter. The time required for a cycle (channel) is:

Receive Time + Settle Time + Conversion Time + Send Time + Send Time

= 521usec+50usec+170usec+521usec+521usec

= 1.78 milli seconds (=560 cycles (channels)/second maximum)

Specifications

Radiometer

Spectral passbands:[1]

Channel	Center Wavelength (nm)	Bandwidth (nm)	Min Peak (%)
1	500	7.4	50
2	550	9.2	50
3	600	10.1	50
4	650	11.4	50
5	700	12.3	45
6	750	13.4	45
7	800	11.3	45
8	850	11.9	45

Radiation transducers

Cadmium sulfide and/or cadmium selenide photoconductive cells.

Field of view

Incident radiation - 180° with flashed opal glass diffuser.

Reflected radiation - 28° - provided by 18 mm focal length convex lens.

Signal conditioner

Input - +6 volt D.C.

Output - 0 to +5 volt D.C.

[1] Optical interference filters, 3-cavity construction. Ditric Optics Inc.

Temperature monitors

One thermistor mounted to measure temperatures among sensors oriented upward, one thermistor to measure temperatures among sensors oriented downward.

The A/D converter and data acquisition system

Analog

29 inputs
0 to +5 volts DC

Digital

12 bit resolution (1 part in 4096)

Battery

1.5 amp, 12 volt gel-cell lead acid rechargeable.

Power requirements

A/D converter, signal conditioner - 40 milliamp
Computer - 60 milliamp

Computer

Radio Shack TRS-80 Model 100 with 27K usable RAM for data storage.

Communications

Serial I/O - RS-232-C
Baud rate - 19,200
Status - 8 bits/character, even parity, 1 stop bit
Speed - 560 channels/sec maximum.

Operation

Microsoft basic with 80C85 machine language subroutines
Manual cycling with space bar triggering
or
Automatic cycling with internal real time clock triggering.

Size

A/D converter and battery housing
21 x 30 x 4.5 cm
Support pole - collapsed - 180 cm
- extended - 275 cm

Weight

Total, including computer - 6 kg.

Calibration Procedure

The size of the aperature in caps for each sensor is experimentally adjusted for near maximum voltage output (4.5 volts) for each of the sensors. Maximum voltage is obtained for the sensors oriented upward by holding the radiometer with the flashed opal cover glass exactly level. Likewise, maximum voltage is obtained for sensors oriented downward by positioning the radiometer over a 2 x 2 ft $BaSO_4$-painted, diffuse, flat panel held exactly horizontal. These adjustments are made on a cloudless day near solar noon.

The output voltage of the signal conditioning circuit is not linear with radiance units (WM^{-2}). Therefore data must be obtained for each sensor to establish the relationship between the digitized output voltage and radiance. In the laboratory, at controlled temperature, each of the eight photocells is calibrated against a LICOR Model LI-185B photometer using the pyranometer sensor transducer LI200SB.

Computer program listing number 1 is used to facilitate calibration data collection.

Regression analysis is used to obtain the intercept and coefficients for a cubic equation. The relationship between radiance and V_{out}/V_{in} is expressed by the equation:

$$Y = a + bx + cx^2 + dx^3$$

where Y is estimated radiance (WM^{-2}),

x is V_{out}/V_{in}

a is 1st order partial regression coefficient

b is 2nd order partial regression coefficient

c is 3rd order partial regression coefficient

A calibration curve for one of the wavelengths, typical of other wavelengths, is shown in Fig. 5.

System operation

In the field, the radiometer is held level, 2 m above the crop canopy. A program written in the BASIC language for the model 100 (Listing 2) facilitates recording of the average of 16 separate digitized voltage values for V_{IN} of the signal conditioner and for V_{OUT} of each of the 16 photocells and two thermistors of the radiometer. The program also allows averaging multiple samples from a plot canopy. The supply battery voltage is monitored and displayed on the LCD but is not recorded. Ancillary data such as plot number, hours, and minutes are also recorded for each cycle.

Each cycle, triggered by pushing the space bar, requires approximately 1 second. The data from each cycle are recorded in a RAM file identified by location, experiment number and Julian day. Sample data is shown in Table 1. This data may be transferred to cassette tape in the field or uploaded to other computer facilities later. Other programs (Listing 3) are used to calculate percent reflection of each wavelength from crop canopies. These BASIC pro-

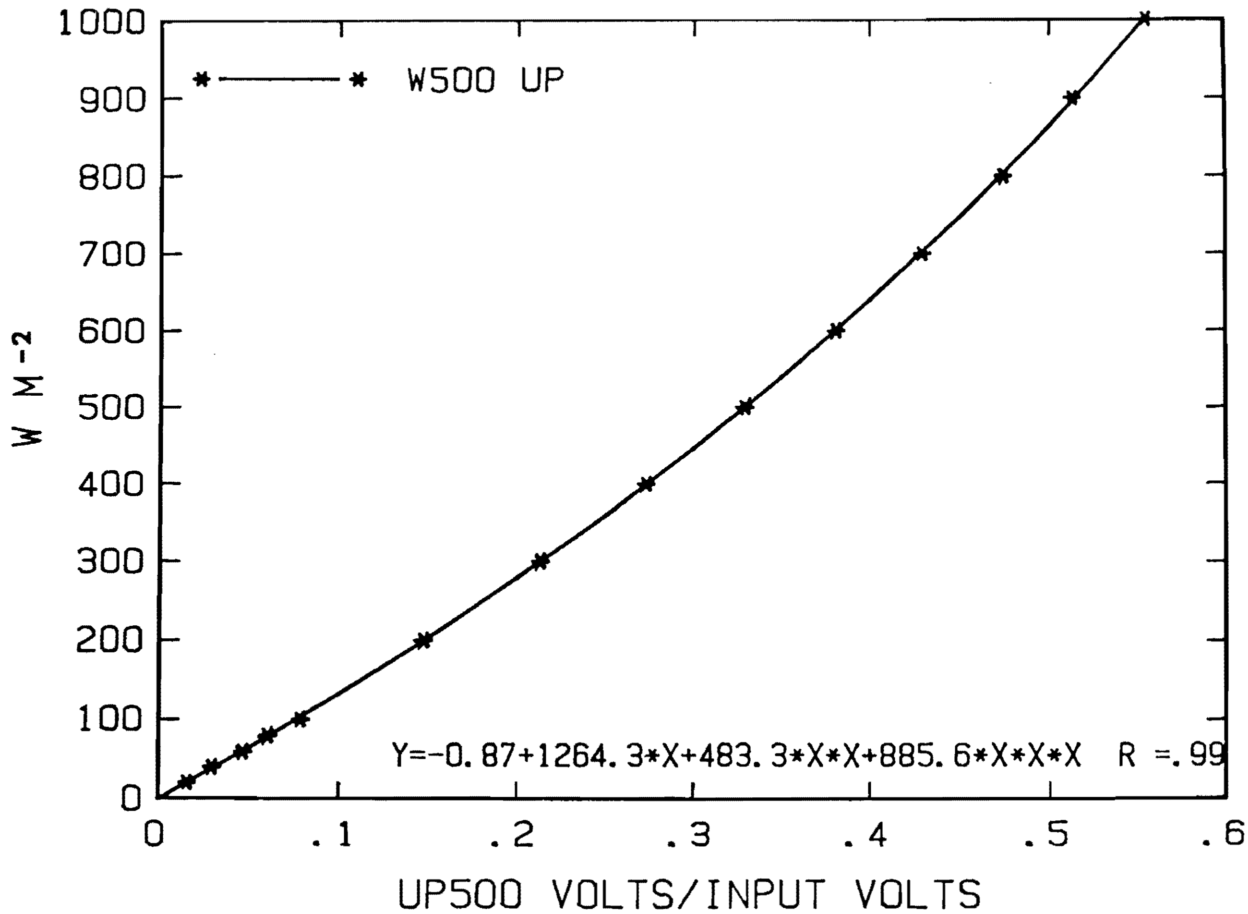

Figure 5. Calibration curve for sensor 500 nm (up) of the multispectral radiometer.

Table 1. Plot number, hour, minute and digitized voltage values of V_{IN} and V_{OUT} from 16 photoconductive cells and 2 thermistors.

Sun. 11/25/84
GROWTH STAGE 75
RADIOMETER SIMULATION

Plot No.	Hour	Minute	SIG. COND.	Wave length (NM) 500 UP	500 DN	550 UP	550 DN	600 UP	600 DN	650 UP	650 DN	700 UP	700 DN	750 UP	750 DN	800 UP	800 DN	850 UP	850 DN	TEMP UP	TEMP DN
1	21	14	2483	168	835	576	918	989	779	726	1462	861	1460	622	965	821	1045	1194	893	2367	1617
2	21	14	2483	168	831	576	919	907	777	725	1462	860	1453	622	965	816	1045	1193	893	2371	1617
3	21	14	2483	168	828	576	918	907	778	725	1462	860	1454	621	965	815	1045	1192	893	2368	1618
4	21	14	2484	168	830	575	918	907	779	726	1461	859	1461	621	968	813	1045	1192	901	2375	1619
5	21	14	2484	168	835	576	924	906	784	728	1468	861	1462	623	971	820	1056	1195	904	2377	1619
6	21	14	2484	168	828	576	917	906	781	725	1461	861	1461	622	971	814	1055	1192	904	2377	1620
7	21	14	2483	168	829	576	917	906	784	725	1463	861	1461	622	970	813	1056	1192	904	2379	1619
8	21	14	2484	168	832	576	921	907	784	726	1467	861	1466	622	976	813	1056	1192	907	2383	1620
9	21	14	2484	168	832	576	925	907	784	727	1468	861	1469	627	976	816	1056	1192	912	2389	1621
10	21	14	2484	168	834	576	928	906	787	727	1473	861	1470	628	980	816	1059	1193	912	2391	1621

grams, written for cassette recording are available from the author. DISK BASIC versions for the Model 100 are also available. Results from a sample experiment are presented in Table 2. The algorithms presented operate satisfactorily with data taken on clear days within ±2 hours of solar noon. Further refinement of calibration algorithms will permit corrections for sensor temperature and/or sun angle and for less than ideal sunlight conditions.

Acknowledgements

I wish to thank Mr. Delmar Nantt for the design and description of the A/D converter circuit and for his help in providing software routines. I also thank Dr. Hans Nialsson, Swedish University of Agricultural Science, Department of Plant and Forest Protection, Uppsala, Sweden for his financial support of the development of the prototype instrument.

Table 2. Plot identification and percent reflection of 8 wavelengths from canopies of barley.

Plot number	Rep	Var	Trt	Hour	Min	Stage of growth	Watt/m²	Percent reflectance at wavelength (nm)								Temp Up	Temp Down
								500	550	600	650	700	750	800	850		
1	1	1	1	13	37	52	913	4.6	8.9	4.8	3.3	3.9	29.3	43.5	43.3	50	46
2	1	1	2	13	37	52	914	5.1	9.5	5.0	3.5	4.0	30.3	44.8	44.2	50	46
3	2	1	2	13	38	52	916	4.7	9.1	4.8	3.4	3.9	31.4	46.8	46.5	50	46
4	2	1	1	13	38	52	915	4.6	9.0	4.8	3.3	4.0	30.4	44.3	43.8	50	46
5	1	2	1	13	38	52	914	4.6	8.6	4.9	3.4	3.9	25.4	36.1	34.9	50	46
6	1	2	2	13	39	52	915	5.2	9.6	5.5	3.8	4.4	26.1	37.7	36.7	50	46
7	2	2	2	13	39	52	915	4.9	8.5	5.1	3.7	4.1	20.8	29.2	29.7	50	46
8	2	2	1	13	39	52	913	4.9	9.1	5.1	3.6	4.1	27.1	39.0	38.0	50	46
9	3	1	1	13	40	52	915	4.2	8.1	4.4	3.3	3.7	29.8	43.1	43.1	50	46
10	3	1	2	13	40	52	911	4.5	8.5	4.6	3.3	3.8	31.3	46.3	46.2	50	46
11	3	2	1	13	41	52	909	4.3	7.7	4.5	3.4	3.8	23.7	33.0	31.8	51	46
12	3	2	2	13	40	52	913	5.0	9.4	5.3	3.7	4.2	25.9	37.7	36.7	51	46

Program listing 1. Data collection program for calibration of each photoconductive cell of the multispectral radiometer (cassette version).

```
10 CLEAR 100,62698:DEFINT I,B:MAXFILES=2:PRINT"RADIOMETER CALIBRATION"
20 PRINT"CALIBRATE:":PRINT"   1. UP SENSORS":PRINT"   2. DOWN SENSORS"INPUTA:INPUT"FILE NAME ";F$
60 DIM R(20),CF(20),CH(20),CD(20),CA(20):FORI=1TO20:CA(I)=I-1:NEXTI
70 A1=62699:A2=62703:AL=62704:AD=62734:FOR I=62792 TO 62959:READ N:POKE I,N:NEXTI:GOTO220
80 POKEA1,16:FOR I=1TO20:POKEAL+I-1,CA(CH(I)):NEXT I:POKEAL+20,255
100 CALL62791:FORI=0TO19:IA=AD+2*I:CD(I+1)=PEEK(IA)+256*PEEK(IA+1):NEXT I
120 IF(PEEK(A2)AND14)=0THENRETURNELSEBEEP:PRINT"OVERRUN, FRAMING OR PARITY ERROR!":PRINT"DATA IS AFFECTED"
125 PRINT"CHECK UART OR CONNECTIONS.":INPUT"PRESS ENTER TO CONTINUE ";Q:RETURN
130 DATA 33,14,245,14,58,54,0,35,13,194,77,245,33,239,244,54,0,33,252,245,54,195,33,195,245,34
140 DATA 253,245,58,235,244,79,33,14,245,235,33,240,244,175,50,238,244,126,254,255,202,149,245
150 DATA 211,200,58,238,244,254,2,194,123,245,235,58,236,244,134,119,35,58,237,244,142,119,35,235
160 DATA 35,195,111,245,13,194,104,245,58,235,244,15,218,183,245,71,14,29,33,72,245,43,175,126,31,119
170 DATA 43,126,31,119,13,194,166,245,120,195,156,245,33,252,245,54,201,33,0,0,34,253,245,201,229,213
180 DATA 197,245,33,247,113,229,58,238,244,254,0,219,200,47,202,224,245,230,15,50,237,244,62,2,195,229
190 DATA 245,50,236,244,62,1,50,238,244,33, 239, 244, 219, 216, 182, 119, 201
220 OPEN"COM:98E1D"FORINPUTAS1:FORI=1TO20:CH(I)=I:NEXT I
230 INPUT"WM^-2:(ENTER 0 TO END) ";B:IFB=0THEN340
240 GOSUB 80
300 OPENF$FORAPPENDAS2:PRINT#2,B;:IFA=1THEN305ELSE310
305 FOR I=3TO17STEP2:GOTO320
310 FOR I=4TO18STEP2
320 PRINT#2,USING"##.###";CD(I)/CD(2);:PRINTCD(I);:NEXT I:PRINT#2,"":PRINT:GOTO 230
340 CLOSE:END
```

Program listing 2. BASIC program which facilitates acquiring and recording digitized voltage values from the multispectral radiometer (cassette version).

```
10 CLEAR 100,62698:DEFINT N,I,B,H,M,J,K,S,C:MAXFILES=2
20 INPUT"FILE NAME ";F$:INPUT"SAVE GROWTH STAGE AND COMMENTS ";CO$:IFCO$="N"THEN30
25 INPUT"GROWTH STAGE";B$:INPUT "COMMENTS ";C$
30 INPUT"MANUAL PLOT INPUT (Y/N) ";A$:IF A$="Y" THEN 50
40 INPUT"BEGINING PLOT NUMBER: ";B:INPUT"END PLOT NUMBER ";P
50 INPUT"NUMBER OF SAMPLES PER PLOT: ";S
60 DIM R(20),CF(20),CH(20),CD(20),CA(20):FORI=1TO20:CA(I)=I-1:NEXTI
70 A1=62699:A2=62703:AL=62704:AD=62734:FOR I=62792 TO 62959:READ N:POKE I,N:NEXTI:J=1:GOTO220
80 PRINT"PLOT ";J;"SAMPLE ";K:POKEA1,16:FOR I=1TO20:POKEAL+I-1,CA(CH(I)):NEXT I:POKEAL+20,255
90 I$=INKEY$:IFI$<>CHR$(32)THEN 90
100  CALL62791:FORI=0TO19:IA=AD+2*I:CD(I+1)=PEEK(IA)+256*PEEK(IA+1):NEXT I
120 IF(PEEK(A2)AND14)=0THENRETURNELSEBEEP:PRINT"OVERRUN,FRAMING OR PARITY ERROR !": PRINT"DATA IS AFFECTED."
125 PRINT"CHECK UART, CLOCK OR CONNECTIONS.":INPUT"PRESS ENTER IF YOU WISH TO CONTINUE ";Q:RETURN
130 DATA 33,14,245,14,58,54,0,35,13,194,77,245,33,239,244,54,0,33,252,245,54,195,33,195,245,34
140 DATA 253,245,58,235,244,79,33,14,245,235,33,240,244,175,50,238,244,126,254,255,202,149,245
150 DATA 211,200,58,238,244,254,2,194,123,245,235,58,236,244,134,119,35,58,237,244,142,119,35,235
160 DATA 35,195,111,245,13,194,104,245,58,235,244,15,218,183,245,71,14,29,33,72,245,43,175,126,31,119
170 DATA 43,126,31,119,13,194,166,245,120,195,156,245,33,252,245,54,201,33,0,0,34,253,245,201,229,213
180 DATA 197,245,33,247,113,229,58,238,244,254,0,219,200,47,202,224,245,230,15,50,237,244,62,2,195,229
190 DATA 245,50,236,244,62,1,50,238,244,33,239,244,219,216,182,119,201
220 OPEN"COM:98E1D"FORINPUTAS1:FORI=1TO20:CH(I)=I:NEXT I:IFCO$="N"THEN230
225 OPEN F$ FOR APPEND AS 2:PRINT#2,F$;" ";DAY$;" "DATE$:PRINT#2,"GROWTH STAGE ";B$:PRINT#2,C$:CLOSE2
230 IF A$="N"THEN 240
235 INPUT"PLOT NUMBER (ENTER 0 TO END PLOT INPUT) ";B:IF B=0 THEN 330
240 FOR J=B TO P:FOR K=1 TO S:GOSUB 80
250 FOR I=2TO20:CF(I)=CF(I)+CD(I):NEXTI:NEXTK:FOR I=2TO20:CD(I)=CF(I)/S:NEXTI
270 H=VAL(LEFT$(TIME$,2)):M=VAL(MID$(TIME$,4,2)):PRINT"BATT. :";CD(1)
280 IF CD(1)<1650 THEN PRINT"WARNING -- LOW BATTERY!!"
300 OPENF$FORAPPENDAS2:PRINT#2,USING"###";J;H;M;
310 FOR I=2TO20:PRINT#2,USING"#####";CD(I);:NEXTI:PRINT#2,"":CLOSE2:FOR I=1TO20:CF(I)=0:NEXTI:IF A$="Y" THEN 235
320 NEXT J
330 END
```

Program listing 3. BASIC program that facilitates operation on digitized voltage values, records plot identification and percent reflection of 8 wavelengths and 2 temperatures.

```
10 MAXFILES=2:DIM CD(22),R(22):INPUT"NAME OF FILE ";F$
20 E1=VAL(MID$(F$,2,2):IFE1=9THENGOSUB800
170 OPENF$FORINPUTAS1:INPUP#1,A$,B$,C$:LPRINT#2,A$:LPRINT#2,B$:LPRINT#2,C$:CLOSE#2
200 IF EOF(1) THEN CLOSE#2:END
210 INPUT#1, J,H,M,SC:FORI=1TO18:INPUT#1,CD(I):NEXTI:FORI=1TO18:CD(I)=CD(I)/SC:NEXTI
270 R5=INT(P(J)/10000):V5=INT(P(J)/100)-R5#100:T5=P(J)-INT(P(J)/100)#100
280 RESTORE360:FORI=1TO18:READD0,D1,D2,D3
290 R(I)=D0+D1#CD(I)+D2#CD(I)#CD(I)+D3#CD(I)#CD(I)#CD(I):NEXTI
300 OPEN"F$FORAPPENDAS2:LPRINT#2,USING"###";J;R5;V5;T5;H;M;
310 FORI=2TO16STEP2:PRINT#2,USING"###.#";R(I)/R(I-1)#100;:NEXTI
320 LPRINT#2,USING"###";R(17);R(18):CLOSE#2:GOTO 200
350 'THE FOLLOWING ARE COEFFICIENTS FOR SENSORS 1984.
360 DATA 5.22,1440.47,497.09,614.13,-12.71,278.27,-474.64,340.28
370 DATA .312,513.92,-185.06,485.95,-16.93,308.51,-529.96,336.44
380 DATA -5.45,385.91,-380.92,496.66,-14.42,282.6,-485.51,344.34
390 DATA 2.07,440.35,-242.04,512.51,-15.43,299.8,-543.26,350.13
400 DATA 1.81,398.72,-295.7,517.46,-15.28,300.56,-561.85,356.33
410 DATA 3.62,470.35,-203.64,562.62,-4.28,239.92,-269.33,336.33
420 DATA -1.13,393.78,-284.85,545.48,-7.29,236.86,-349.91,319.44
430 DATA -7.49,386.17,-551.19,558.17,-5.26,221.11,-286.63,330.39
440 DATA 73.07,-278.32,358.37,-120.85,38.62,-208.81,416.34,-193.42
800 'RVT NUMBERS FOR EXPERIMENT 09. (AN EXAMPLE)
810 DIM P(144):RESTORE830:FORN1=1TO144:READP(N1):NEXTN1:RETURN
830 DATA 11101,10403,10301,10802,10103,10701,10202,10601,10901,11203,10502,11003
840 DATA 11001,10501,11202,10903,10602,10203,10702,10102,10803,10302,10402,11103
850 DATA 11102,10401,10303,10801,10101,10703,10201,10603,10902,11201,10503,11002
860 DATA 20702,20601,21001,20301,20101,20903,21203,21102,20503,20202,20802,20402
870 DATA 20403,20803,20201,20502,21101,21202,20902,20103,20302,21003,20602,20703
880 DATA 20701,20603,21002,20303,20102,20901,21201,21103,20501,20203,20801,20401
890 DATA 31203,30602,30202,30402,30102,31003,31101,30502,30801,30703,30303,30902
900 DATA 30903,30301,30702,30802,30503,31103,31002,30101,30403,30201,30603,31202
910 DATA 31201,30601,30203,30401,30103,31001,31102,30501,30803,30701,30302,30901
920 DATA 40401,40202,40301,40703,40601,41203,41102,40501,40802,41001,40102,40901
930 DATA 40903,40101,41002,40803,40503,41103,41202,40602,40702,40302,40201,40403
940 DATA 40402,40203,40303,40701,40603,41201,41101,40502,40801,41003,40103,40902
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References:

1. Pederson, V.D. and C. Fiechtner. 1980. A low-cost, compact data acquisition system for recording visible and infrared reflection from barley crop canopies. In: Crop Loss Assessment Proc. of E.C. Stakman Commemorative Symposium. Misc. Publication 7, Agri. Exp. Sta., Univ. of Minn. pp. 71-75.

2. Pederson, V.D. and F.W. Nutter, Jr. 1982. A low-cost, portable multispectral radiometer for assessment of onset and severity of foliar disease of barley. Proc. of International Society for Optical Engineering 356: 126-130.

APPENDIX A. Parts list for analog-to-digital converter circuit.

Batt1	6 Volt Lead Acid Battery
Batt2	6 Volt Lead Acid Battery
Con1	44 pin connector
Con2	2 terminal charger connector
C1	10uf electrolytic
C2	.01uf ceramic
C3	.001uf ceramic
C4	.01uf ceramic
C5	470pf ceramic
C6	.001uf ceramic
C7	33pf ceramic
C8	470pf ceramic
C9	470pf ceramic
C10	4.7uf tantulum
C11	.1uf ceramic
C12	470pf ceramic
C13	470pf ceramic
C14	33 pf ceramic
C15	100uf electrolytic
C16	100uf electrolytic
C17	100uf electrolytic
C18	.01uf ceramic
C19	10uf electrolytic
D1	6.2 volt zener diode
D2	silicon diode
D3	silicon diode
D4	silicon diode
D5	silicon diode
IC1	4051 Octal Analog Switch CMOS
IC2	4051 Octal Analog Switch CMOS
IC3	4051 Octal Analog Switch CMOS
IC4	4051 Octal Analog Switch CMOS
IC5	ADC1210 A/D Converter CMOS
IC6	IM6402 UART CMOS
IC7/1	LM308 OP AMP
IC7/2	LM308 OP AMP
IC8	4016 Quad Switch CMOS
IC9	4016 Quad Switch CMOS
IC10	4016 Quad Switch CMOS
IC11	4013 Dual D Latch CMOS
IC12	4071 Quad 2-In OR CMOS
IC13	4049 Hex Inverter CMOS
IC14	4049 Hex Inverter CMOS
IC15	Dual D Latch CMOS
IC16	7555 Timer CMOS
Q1	PNP Transistor
Q2	PNP Transistor
Q3	PNP Transistor (power)
Q4	NPN Transistor (power)
R1	470 ohm resistor
R2	5K ohm 15 turn pot
R3	10K ohm resistor
R4	10K ohm resistor
R5	2.2K ohm resistor
R6	100K ohm resistor
R7	1K ohm resistor
R8	2K ohm 15 turn pot
R10	100K ohm resistor
R11	100K ohm resistor
R12	100K ohm resistor
R13	1K ohm resistor
R14	200K ohm resistor
R15	100K ohm resistor
R15	100K ohm resistor
R17	10K ohm resistor
R18	100K ohm resistor
R19	470K ohm resistor
R20	4.7 ohm resistor
R21	2.2K ohm resistor
R22	4.7K ohm resistor
R23	2.2K ohm resistor
R24	4.7K ohm resistor
R25	2.2K ohm resistor
R26	100K ohm resistor
R27	30K ohm resistor
R28	100K ohm resistor
R29	100K ohm resistor
REG1	+5 Volt Regulator
REG2	+6 Volt Regulator

APPENDIX B. Part Quantities.

Description	Quantity
6 Volt Lead Acid Battery	2
44 pin wire wrap connector	1
3 terminal charger connector	1
33pf ceramic	2
470pf ceramic	5
.001uf ceramic	2
.01uf ceramic	3
.1uf ceramic	1
4.7uf tantulum	1
10uf electrolytic	2
100uf electrolytic	3
6.2 volt zener diode (1N4735)	1
Silicon diode (1N4148)	4
4051 Octal Analog Switch CMOS	4
ADC1210 A/D Converter CMOS	1
IM6402 UART CMOS	1
LM308 OP AMP	2
4016 Quad Switch CMOS	3
4013 Dual D Latch CMOS	2
4071 Quad Dual In OR CMOS	1
4049 Hex Inverter CMOS	2
7555 Timer CMOS	1
2N3906 PNP Transistor	2
MJE-712 Transistor (power)	1
MJE-344 NPN Transistor (power)	1
470 ohm resistor	1
1K ohm resistor	3
2.2K ohm resistor	4
4.7K ohm resistor	3
6.8K ohm resistor	1
10K ohm resistor	3
30K ohm resistor	1
100K ohm resistor	10
200K ohm resistor	1
2K 15 turn pot	1
5K 15 turn pot	1
+5 Volt regulator	1
+6 Volt regulator	1

APPENDIX C. Wire connections for radiometer 20 conductor cable and Con. 1.

RADIOMETER CABLE	CON1 PINS	COMMENTS
	01	12 VOLT SUPPLY
	02	RS232TRX (TO MOD100 RS232 RCV-P3-BLUE)
	03	RS232 RCV (FROM MOD100 RS232 TRX-P2-RED)
	09	12 VOLT MEASURE
	10	SIGNAL CONDITIONER 6 VOLT MEASURE
1 500 UP	11	RED-GREEN
2 500 DN	12	LIGHT BROWN
3 550 UP	13	RED-YELLOW
4 550 DN	14	GREEN
5 600 UP	15	PINK
6 600 DN	16	GREY
7 650 UP	17	VIOLET
8 650 DN	18	YELLOW
9 700 UP	19	WHITE-BLUE
10 700 DN	20	WHITE-YELLOW
11 750 UP	21	RED-BLACK
12 750 DN	22	WHITE-BLACK
13 800 UP	J	WHITE-RED
14 800 DN	K	WHITE
15 850 UP	L	ORANGE
16 850 DN	M	BLUE
17 TEMP UP	N	DARK BROWN
18 TEMP DN	P	WHITE-GREEN
19 NC		
20 NC		
21 NC		
22 ND		
23 PHOTO CELL COM.	5	MOD100 +6, RED
24 GND-RESISTOR COM.	B	RS232GND-P7-BLACK