To the Graduate Council:

I am submitting herewith a thesis written by Fred Henry Moody III entitled "Development and Evaluation of a Real-Time Cotton Flow Rate Sensor." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Engineering.

John B. Wilkerson, Major Professor

We have read this thesis and recommend its acceptance:

Accepted for the Council:

Associate Vice Chancellor and
Dean of the Graduate School

Development and Evaluation of a Real-Time Cotton Flow Rate Sensor

A Thesis
Presented for the
Master of Science
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Abstract

Cotton producers are interested in quantifying yields site-specifically within large fields. In order to measure yield site-specifically during harvest, cotton flow rate into the harvester must be sensed. A system has been developed to measure cotton flow rates on a spindle-type cotton picker. It uses a non-intrusive optical technique to estimate flow rate as the cotton passes through harvester conveyer pipes. Discrete beams of light are projected across the conveyer pipes, and beam intensities are measured by individual photo-detectors mounted opposite the light emitters. As cotton passes between emitters and detectors, light beams are deflected, thus reducing the amount of light energy reaching detectors. The photo-detectors give an integrated measure of light energy attenuation over time. This measurement is related to the amount of cotton that travels between emitters and detectors during the time interval. Since the time interval is typically short (measured in ms), measurement of the amount of cotton that passes through the system during one time interval approximates an instantaneous flow rate measurement.

The system was prototyped and tested in both the laboratory and field. Test results show that the system is capable of measuring cotton flow rate with some degree of accuracy. Accuracy measurements were based on predicted load weight totals with load weights ranging between 275 and 1361 lb. Seventy-five out of 79 loads harvested were measured with errors less than +/-10 percent with an average absolute error for the 79 loads of 4.7 percent. Accuracy was independent of flow rate over the range tested.

Refinements are needed in the data transmission circuitry to eliminate signal noise that may have reduced measurement accuracy in the data set. Future test efforts should concentrate on high cotton flow rates to determine the maximum range of system operation.

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Nomenclature

A_j	sensing unit output from the j^{th} sensing unit
b_{ij}	baseline output level for the i^{th} emitter-detector pair in the j^{th} sensing unit
C_i	weighting coefficient for the i^{th} emitter-detector pair
Δ_{ij}	baseline offset for the i^{th} emitter-detector pair in the j^{th} sensing unit
E	error expressed as a percentage of total load weight
G	gin turn-out ratio
K	constant
m	number of emitter-detector pairs in a sensing unit
n	number of sensing units in a system
p_{ij}	raw counter output for the i^{th} emitter-detector pair in the j^{th} sensing unit
PW	predicted load weight
Q	average seed cotton flow rate during an integration interval
Q_{cot}	seed cotton flow rate
Q_{grain}	grain mass flow rate
ρ_{grain}	grain density
S	swath width
V	ground speed
x_{ij}	normalized difference for the i^{th} emitter-detector pair in the j^{th} sensing unit
Y	crop yield

Chapter 1--Introduction

Justification for Research

Since the dawn of civilization, man has sought out ways to increase the efficiency of agricultural practices, thus allowing fewer and fewer farmers to provide food and fiber for more and more people. During the twentieth century, the advent of large farm machinery has tremendously increased the amount of crop land a single farmer can manage. The efficiency gained by using large machinery coupled with dwindling profit margins for farm products has increased the average farm size in the United States from 215 acres in 1950 to 469 acres in 1995 (USDA, 1960, 1996). As farm size has increased, so has field size. Today, fields containing 100 acres or more are common throughout the major crop producing parts of the country. In general, these large fields are managed as units, and treated with uniform field operations and input applications.

During the last ten years, members of the agricultural community have questioned the practice of treating large fields as homogeneous units. The idea of site-specific crop management, or breaking a field into small management units, measuring plant growth parameters present in these units, and treating each unit accordingly has received a lot of attention. There are many variables that can affect plant growth including soil type, soil fertility, pest pressure, and moisture availability. According to Stafford et al. (1991), crop yield provides an integrated measurement of a number of these factors, and is a valuable piece of information to have when making management decisions on a site-specific basis.

As interest in site-specific crop management has grown, techniques for measuring grain yield during harvest have been developed. Grain yield monitors have been marketed in the United States for several years, and are gaining acceptance. The success of attempts to measure grain yields has led to a demand for site-specific yield measurement equipment for other crops including cotton.

Researchers at several locations in the southern United States have attempted to develop equipment for site-specific cotton yield measurement. Recent publications document progress made by engineers at Texas A&M University and the USDA U.S. Cotton Ginning Laboratory in their cotton yield measurement projects (Searcy, et al., 1997a, and Thomasson, et al., 1997). Although some success has been documented by these researchers, problems with the systems limit their practical application.

In 1994, a paper was published by agricultural engineers at The University of Tennessee describing a real-time cotton flow sensor (Wilkerson, et al., 1994). The sensor was successfully tested in the laboratory, and provided accurate measurement of cotton flow rate. However, when the device was mounted on a harvester and tested in the field, signal noise and other problems rendered the test data useless. This thesis is based on further modification, development, and testing of the device first described by Wilkerson, et al.

Objectives

The overall objective of this research effort is to develop a sensing system capable of measuring the flow rate of cotton as it is collected by a spindle-type harvester,

so that the sensor can be used as part of a site-specific yield mapping system. To reach this goal, several intermediate objectives were identified. These included (1) the design and construction of a sensor for non-intrusively measuring the flow rate of pneumatically conveyed cotton in a duct, (2) development of a data acquisition and processing system for use with the sensing system, (3) construction of a stationary test apparatus for laboratory sensor evaluation, and (4) application of the sensing system to a modern spindle-type cotton picker for field evaluation.

Chapter 2--Review of Literature

Background

Since the mid-1980s, interest in site-specific crop management has increased. Many researchers believe yield is one of the most useful pieces of information available to farmers making decisions about how to treat each management unit in a field (Pringle, et al., 1993, Vanden Heuvel, 1996). The reason yield is such a valuable measurement is that it provides an integrated indication of how factors in the above and below ground environment influence crop growth (Stafford, et al., 1991).

Grain Yield Measurement

Grain yield monitors have been under development for some time. To document grain yield during harvest, several pieces of information are necessary. Instantaneous grain yield in bushels per acre (bu/a) is determined by the following equation.

$$Y = K\frac{Q_{grain}}{S\rho_{grain}V} \qquad \text{Equation I}$$

where Y=yield (bu/a)

K=unit conversion constant $\left(29{,}700\frac{s \cdot mi \cdot ft}{hr \cdot ac}\right)$

Q_{grain}=grain flow rate into the combine (lb/s)

S=swath width being harvested by the combine (ft)

ρ_{grain}=grain density (lb/bu)

V=combine ground speed (mph)

The swath width (S) is typically estimated and held constant. Grain density (ρ) depends mostly on the grain type and its moisture content which can either be measured in real time or estimated and held constant. Ground speed (V) is measured with radar or transmission speed sensors on most modern combines. Grain mass flow rate (Q_{grain}) is the remaining variable that must be sensed during harvest.

Many grain flow rate measurement techniques have been studied. Bae, et al. (1987) used a volumetric paddle wheel sensor in their yield measurement work. The paddle wheel sensor counts individual paddle-loads of grain. Because of the discrete nature of the sensor output, the accuracy of instantaneous flow rate prediction is limited. Pfeiffer, et al. (1993), and Strubbs, et al. (1996), both used optical emitters and detectors to estimate clean grain elevator paddle contents during combine operation. These optical sensors tend to be influenced by parameters such as slope, machine vibration, and grain properties that may vary during normal harvester operation. Sadjadi (1996) describes an alternate optical technique that consists of light projected onto grain on a horizontal conveyer belt, a camera that takes a picture of the surface of the grain on the belt, and a processor that digitizes the image into a three-dimensional coordinate system and compares the image's coordinates with reference coordinates to obtain an estimate of the volume of grain on the conveyer. Image digitization and processing is generally computationally intensive and requires expensive equipment. Pang and Zoerb (1990) measured grain impacts on piezo film strips to estimate grain flow. Whether piezo film

strips are durable enough for use in a combine is questionable. Howard, et al. (1993) describe a method of weighing one end of a pivoting auger to continuously estimate its contents. The pivoting auger requires a moderate amount of modification to a combine, and is highly sensitive to variation in installation and maintenance of its mechanical components. Stafford, et al. (1991) and Borgelt and Sudduth (1992) discuss radiometric grain flow sensors used in Europe. While radiometric sensors generally give good results, existing regulations make their use impractical in the United States.

Research has culminated in the commercial release of several types of grain yield monitors. The most popular yield monitors in the United States use a grain flow sensor that measures momentum of flowing grain to determine flow rate. The first description of this type of sensor was given by DeBaerdemaeker, et al. (1985). They describe a sensor that works by measuring the forces necessary to make flowing grain abruptly change direction in a curved conduit. Momentum sensors popular today use a curved impact plate to abruptly change grain direction, and a force transducer to measure the resulting force. Grain yield monitors have rapidly gained popularity. Successful Farming magazine (Mangold, 1998) estimates the number being used in the United States to be approximately 17,000.

Cotton Yield Measurement

United States cotton growers who produced about 17,971,200 bales worth over $6,550,680,000 in 1995 (USDA, 1996) are eager to gain access to site-specific yield sensing technology. Searcy, et al. (1997a) reports that "Cotton producers interested in

precision management need to have yield mapping capabilities." Until the limited releases of cotton yield monitors by Zycom Corp. and Microtrak Systems, Inc. in 1997 (Sray, 1997 and Laws, 1997), cotton yield measurement equipment was not commercially available.

The information needed for measuring cotton yield site-specifically is similar to that needed for grain. Instantaneous cotton yield in bales per acre (ba/a) can be calculated using the following equation.

$$Y = KG\frac{Q_{cot}}{SV} \qquad \text{Equation II}$$

where Y=yield (ba/a)

K=unit correction constant $\left(59.4\frac{s \cdot mi \cdot ft \cdot ba}{hr \cdot ac \cdot lb}\right)$

G=average gin turn-out ratio $=\frac{\text{Lint Weight After Ginning}}{\text{Seed Cotton Weight}}$

Q_{cot}=seed cotton flow rate into the picker (lb/s)

S=swath width being harvested by the picker (ft)

V=picker ground speed (mph)

Gin turn-out ratio (G) is the fraction of seed cotton (by weight) that will end up in useable lint form after ginning and can be estimated from variety information and field condition. The swath width (S) depends on the number or rows being harvested and the row spacing which is constant. Machine ground speed (V) is typically measured by a transmission speed sensor. Cotton mass flow rate (Q_{cot}) is the most important variable to be sensed during harvest. Technology developed for grain flow rate measurement has

not been adapted for use with cotton because the physical properties and harvester conveying systems for cotton are much different than those for grain.

To fill this technological void, researchers have investigated several cotton flow rate measurement techniques. To understand these approaches, it is necessary to have some knowledge of how cotton pickers work.

Refer to Figure 1 for the following description of picker operation. Cotton plants enter the machine's picking units and come in contact with the picking drums. Cotton is drawn away from the plants by spindles and deposited near the conveyer pipe intakes. Air from conveyer fans is blown through conveyer jets, thus creating the low pressure necessary to draw cotton away from the picking drums and into the air stream. Once entrained in the air stream, cotton is propelled up through the conveyer pipes and finally into the cotton picker's basket.

Research at Texas A&M University has focused on a direct mass flow rate measurement technique. Searcy, et al. (1997b) developed a system for measuring the rate of change of the weight of cotton as it accumulates in the basket during harvest. The basket is isolated on load cells and continuously weighed during picker operation. While test results indicate that this system shows promise, there are problems. Cotton's low density limits the resolution of the site-specific yield data. The harvester must travel a relatively long distance before enough cotton accumulates in the basket to be weighed with acceptable accuracy. System accuracy is also limited by the impact of dynamic forces on weight measurements and difficulty with basket isolation.

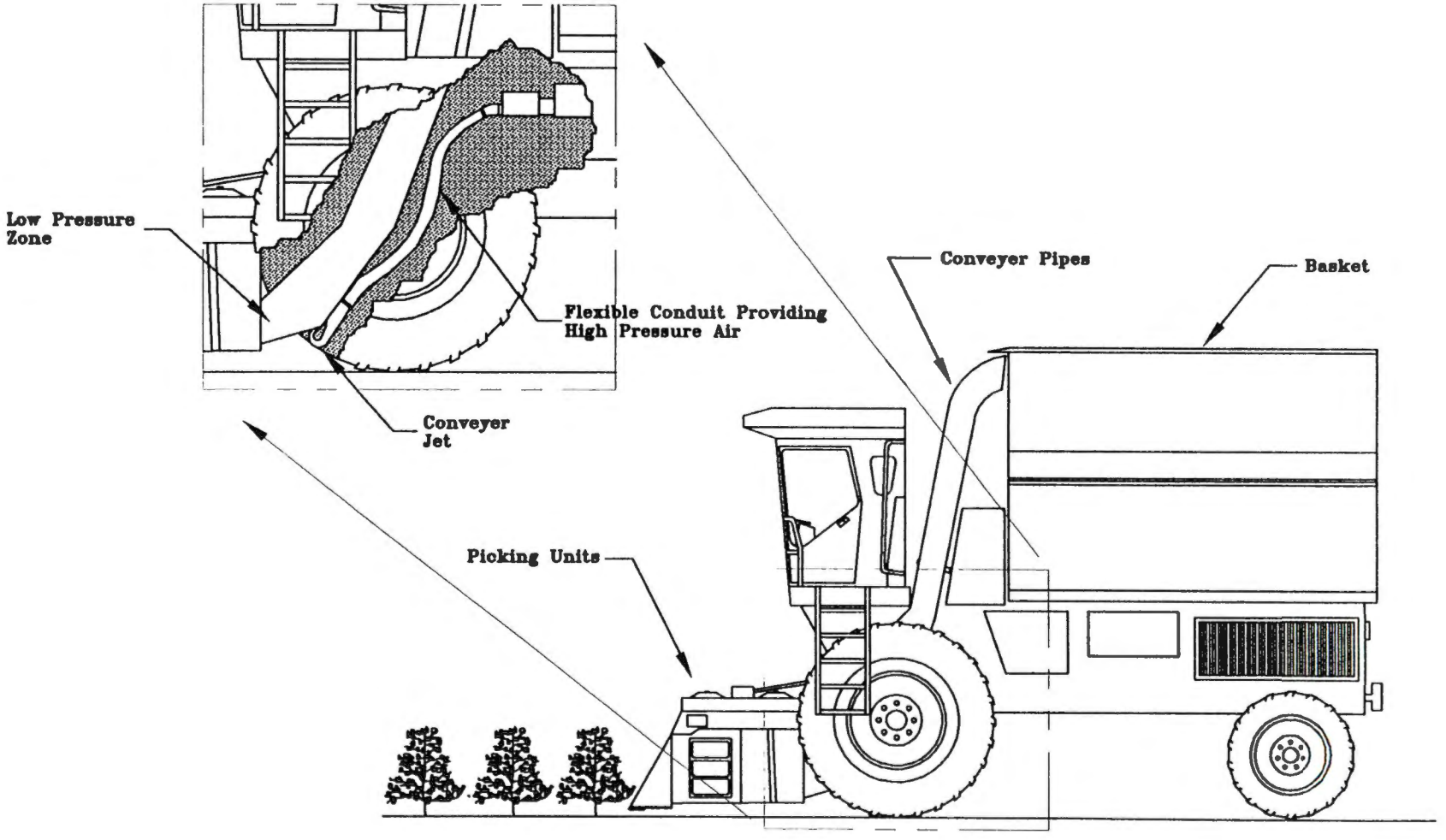


Figure 1. Cut-away view of a cotton picker showing conveying system details.

Other research has concentrated on indirect mass flow rate measurement techniques. The most popular indirect approach is to non-intrusively measure the cotton flow rate as it passes through the conveyer pipes. Researchers at Louisiana State University have investigated a technique in which changing air pressure in the conveyer pipes is measured and correlated with cotton flow rate. The LSU team reports some success, but to this date, no results have been published (Moriasi, 1997). Another method attempted by engineers working for Case Corporation involves measuring the magnitude of sound produced when seed-laden cotton impacts the conveyer pipe wall. Sound measurements are correlated with cotton flow rate (Ovsborn, 1990). Since this system was developed only to give an indication of whether or not cotton flow is present in the conveyer pipe, it is questionable whether it can generate flow rate measurements of acceptable accuracy.

The indirect flow rate measurement technique that has received the most attention from researchers and industry is an optical technique pioneered by Dean Pennington in Mississippi (Kepple, 1988). The idea is to project light through the conveyer pipes in a direction normal to cotton flow, and measure the intensity of light striking a photo-detector mounted on the conveyer pipe wall opposite the source. As cotton flows through the pipe, it deflects the light beams, thus reducing the intensity of the light measured by the detection unit. The cotton flow rate is correlated with the reduction of light intensity.

Pennington's work on an optically based system that correlates an integration of light energy attenuation to cotton flow rate has continued, and in 1997 a progress report

was given at the Beltwide Cotton Conferences (Thomasson, et al., 1997). Thomasson, et al. reported mounting a light sensing bar on the rear wall of a conveyer pipe of a one-row cotton picker and a transparent window opposite the detector. The sun provides the light source, as sunlight is projected through the transparent window and across the pipe. The system was tested by integrating sensor output over the time it took to harvest a 30-ft row, and the linear correlation between the integrated sensor output and the weight of cotton harvested was measured. The correlation was strong with coefficient of determination (r^2) values ranging from 0.89 to 0.98. In the same report, Thomasson, et al. also discuss the application of optical sensing to measuring cotton flow rates in ducts in the gin.

Another attempt to use an optically based system to sense cotton flow rate was described by Wilkerson, et al. (1994). The Wilkerson, et al. device consists of a light source that projects a linear plane of light across the conveyer pipe cross section normal to the direction of cotton flow. A detector array is mounted opposite the light source. The detector array and associated circuitry provides an output that is correlated with cotton flow rate. Wilkerson, et al. mounted the device on a cotton feed duct in the laboratory and tested it by running five loads of cotton with different total weights through the sensor at three feed rates and three air flow rates. Both seed cotton and processed cotton puffs were used in tests. All trials were replicated four times. Sensor output was processed to give a measure of integrated light attenuation and those values were correlated with cotton weight. Ninety-three percent of the variability in integrated sensor output was due to variability in cotton load weights.

Wilkerson, et al. also mounted the device on a John Deere 9930 cotton picker for field testing, but problems with ambient light striking detector arrays caused test results to be unacceptable. The report indicates that plans to re-design sensor electronics and reposition the sensor on the conveyer pipe were made.

Similar technology has been used in other applications, primarily to count individual objects such as seeds (Steffens, 1981, and Friend, 1987) or drops of liquid (Paolini, 1997). Application of this object counting technique to measuring cotton flow rate introduces special challenges. Counting individual pieces of cotton is difficult because of the large cross-sectional area of the conveyer pipe, variations in cotton flow patterns, and the high velocity of cotton flow. Even if pieces of cotton are counted accurately, variation in clump size and geometry limits the correlation between the number of pieces of cotton counted and cotton flow rate.

The device described by Wilkerson, et al. is not based on a counting technique. Instead, it operates by integrating the amount of light attenuation measured by the photo-detector array and using the integrated signal to predict mass flow rate. This is the basic difference between the Wilkerson, et al. design and previously patented technology.

Chapter 3--Methods and Materials

Sensing Unit Design

Design Overview

A modern spindle-type cotton picker is likely to have a number of conveyer pipes with one or more cross-sectional geometries fixed in several different mounting configurations. For each conveyer pipe on the picker, there is a sensing unit that consists of one light emitter array and one photo-detector array mounted opposite each other as shown in Figure 2a. The emitter array projects a number (depending on pipe width) of discrete light beams across the conveyer pipe. Note that this is a change from the device originally used by Wilkerson, et al. (1994) which is shown in Figure 2b. The original device projects a continuous curtain of light across the pipe as opposed to a number of discrete beams. The change to discrete beams allows some correction for variation in the cotton flow pattern in the x-direction that is caused by differences in conveyer pipe mounting and geometry. The correction technique is described in more detail below. Each light emitter is paired with a photo-detector that has a limited field-of-view and only receives light energy from the corresponding emitter. Detectors used are integrated circuits that have a frequency-based digital output that is linearly proportional to the intensity of light energy received by the sensor active area. Output from each individual emitter is transmitted via cable to a digital counter in a data acquisition and processing system. The counter sums pulses produced by the detector over some integration interval. The resulting sum represents the total amount of light energy received by the

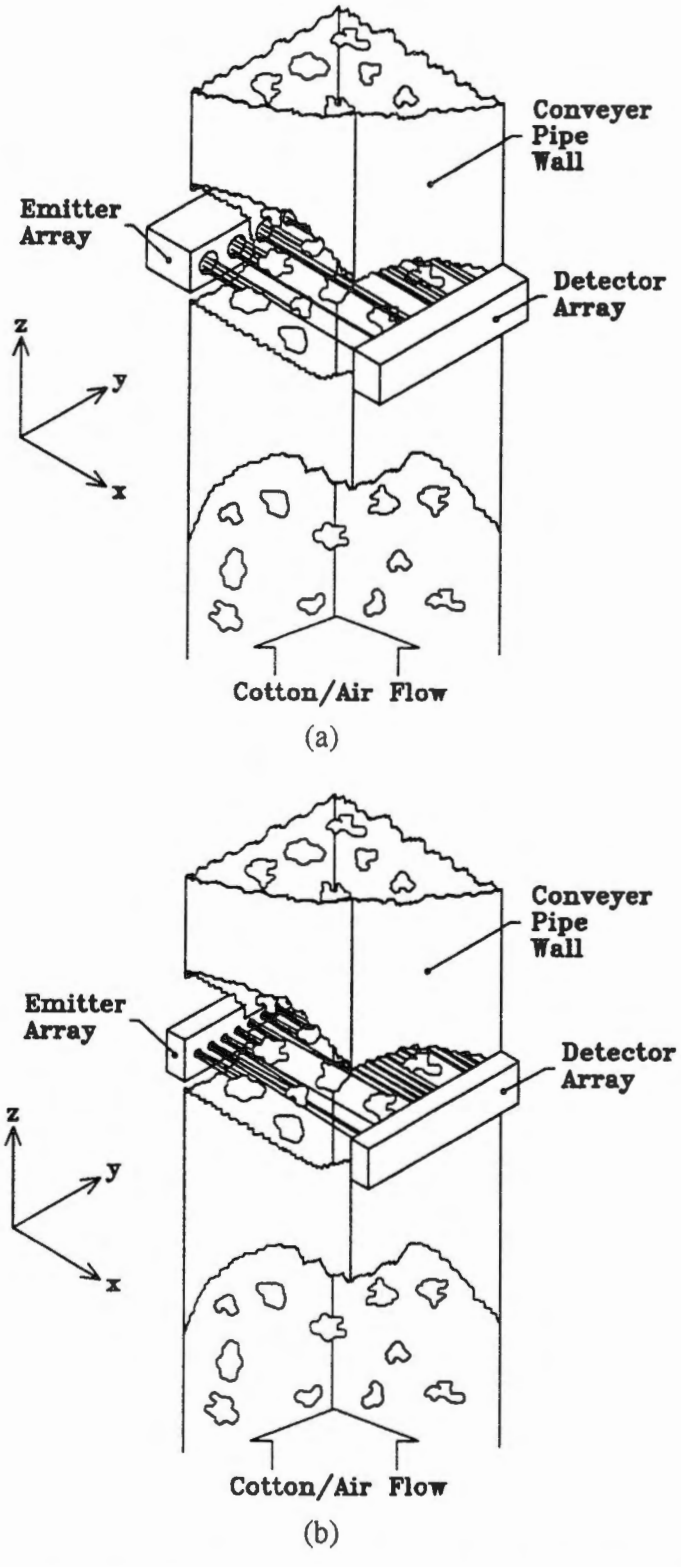


Figure 2. Cut-away views of conveyer pipes showing mounted sensing units. (a) The sensing unit developed in this research effort, and (b) the original device described by Wilkerson, et al. (1994).

detector during the interval. This integrated measure of light energy is correlated to the amount of cotton that passed between the emitter and detector during the integration period. A graph illustrating typical counter output over time is shown in Figure 3a.

Initial Processing

The following discussion assumes that the sensing system includes j sensing units mounted on j conveyer pipes, and that each sensing unit contains i emitter-detector pairs. To convert the raw data shown in Figure 3a into predicted cotton flow rate, several calculations are necessary. The general idea is to establish a baseline output level (b_{ij}) that represents no cotton flow, and measure the difference between the baseline (b_{ij}) and each counter output observation (p_{ij}). This difference is then multiplied by the appropriate weighting coefficient which depends on emitter-detector pair position in the pipe. These weighting coefficients (C_i) are included to account for some of the variation in flow pattern depth and velocity. Finally, the result is summed with similar values from the other emitter-detector pairs to obtain a measure of how much cotton flowed through the system during the sampling interval.

Baseline Drift

One result from the preliminary field tests conducted in 1996 was the recognition of significant baseline drift. Before the 1996 tests, plans were made to accept and compensate for changes in baseline (b_{ij}) due to gradual temperature shifts and fouling of sensing unit optics by foreign material. This compensation was designed to take place when a no cotton flow situation existed for a relatively long period of time (turning around at the end of a field, unloading the picker, etc.). However, the baseline

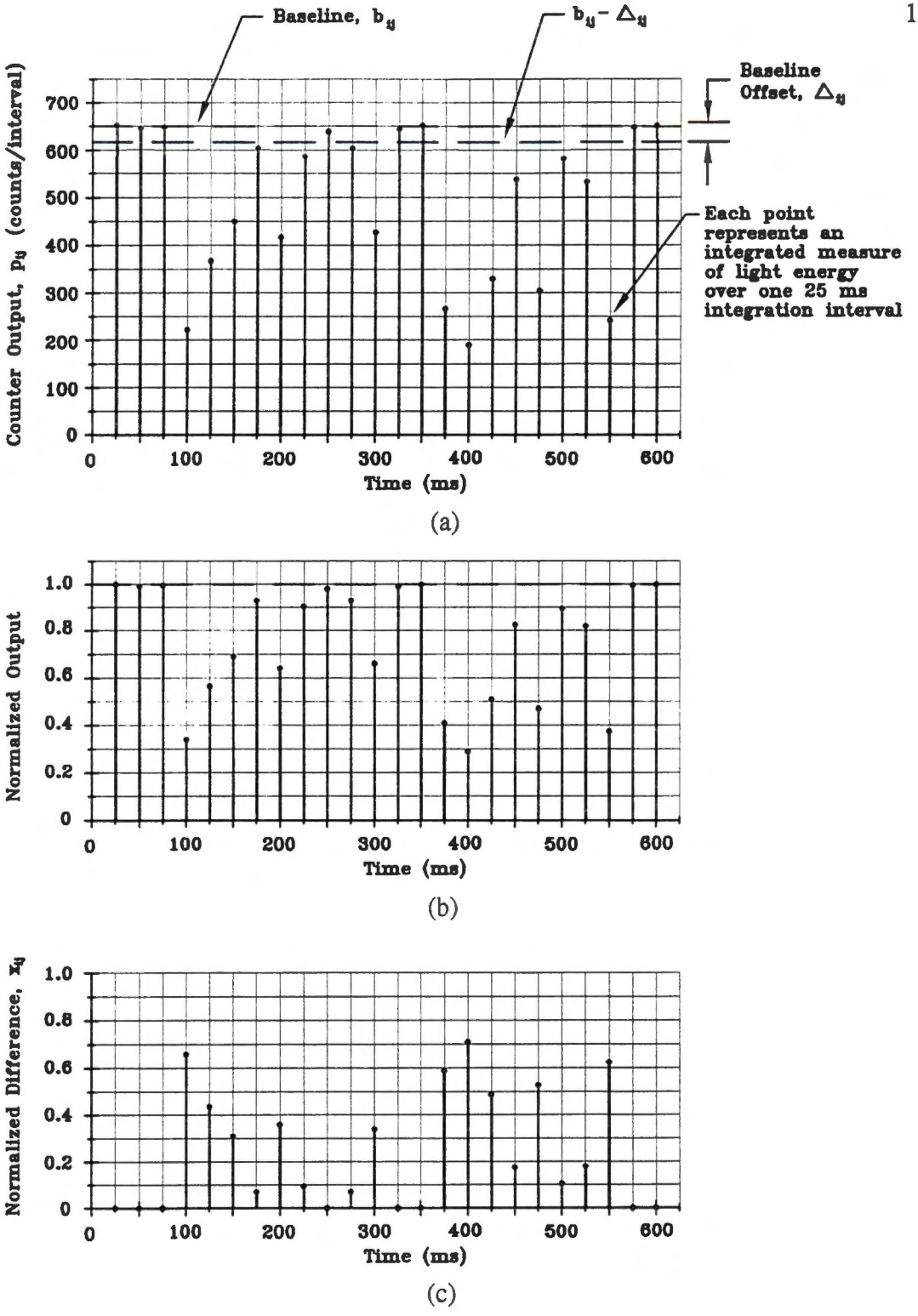


Figure 3. Graphs illustrating data processing steps. (a) Raw counter output, (b) normalized counter output, and (c) normalized difference.

fluctuation was more rapid and unpredictable than expected. Changes were made to allow the system to compensate for baseline drift as often as possible during operation.

Two different baseline adjustment techniques can be used. In the first method, a number of raw counter outputs (p_{ij}) are collected. The difference between the largest and smallest p_{ij} in the group is calculated. If the difference is less than some pre-defined value, the baseline (b_{ij}) is reset to equal the average of the group of p_{ij} values. The advantage of this technique is that it provides some degree of assurance that the baseline (b_{ij}) will only be reset to true no cotton flow p_{ij} levels. Disadvantages of this technique are that it is computationally intensive and it limits the opportunities for baseline (b_{ij}) reset to those times when a no cotton flow situation exists for several integration intervals.

The second baseline determination technique is less computationally intensive and only requires that a no cotton flow situation be present for one integration interval. The baseline (b_{ij}) is reset by collecting a number of p_{ij} values and setting b_{ij} equal to the second largest p_{ij} value in the lot. Use of the second largest p_{ij} reduces the chance of setting b_{ij} equal to an abnormally large p_{ij} value. Abnormally large p_{ij} values have been observed periodically in field test data. One disadvantage to this technique is that it depends on the assumption that there are at least two integration intervals that represent no cotton flow present in each lot tested. Because of the advantages, this technique was used in all of the work described below. It proved adequate for use in the laboratory and field tests conducted, but may not be sufficient when cotton flow rates are very large in high-yielding areas.

Low-Level Noise Elimination

To limit the accumulation of error due to low level noise, any p_{ij} values that are greater than a threshold level determined by subtracting the baseline offset (Δ_{ij}) from the baseline (b_{ij}) are assumed to represent no cotton flow (see Figure 3a).

Data Normalization

Because of variations present in many factors such as light source output, lens imperfections and mounting, and sensing unit mounting, baseline (b_{ij}) values are likely to be unique to each emitter-detector pair. In order to convert the data from each emitter-detector pair to the same scale, each p_{ij} value is normalized by dividing it by b_{ij}. Normalized data is shown in Figure 3b. Finally, the normalized difference (x_{ij}), which is shown in Figure 3c, is found by subtracting the normalized data point from 1.0 for every p_{ij} less than b_{ij}-Δ_{ij}. For all p_{ij} greater than b_{ij}-Δ_{ij}, x_{ij} is set to zero.

The initial processing described above is represented by the following expressions.

If $p_{ij} < b_{ij}$-Δ_{ij}, then x_{ij} is calculated using the following equation.

$$x_{ij}=\frac{b_{ij}-p_{ij}}{b_{ij}} \qquad \text{Equation III}$$

where p_{ij}=total number of pulses produced by the i^{th} detector in the j^{th} sensing unit during the integration interval

b_{ij}=baseline value for the i^{th} emitter-detector pair in the j^{th} sensing unit

Δ_{ij}=baseline offset for the i^{th} emitter-detector pair in the j^{th} sensing unit

x_{ij}=normalized difference for the i^{th} emitter-detector pair in the j^{th} sensing unit

Otherwise, if $p_{ij} > b_{ij}-\Delta_{ij}$ then x_{ij} is set to zero.

Intermediate Processing

Weighting Coefficient Application

The next step in data processing is to multiply each normalized difference (x_{ij}) by its weighting coefficient (C_i). As mentioned briefly above, the purpose of the C_i coefficients is to account for some of the variation in the depth (x-direction in Figure 2) and velocity of cotton flow. Variation in the cotton flow profile results from differences in conveyer pipe mounting configuration and conveyer jet geometry in each conveyer pipe.

During the early phases of system development, C_i values were assigned through an iterative calibration process. After some preliminary field testing, this iterative technique was compared to another method involving systematic assignment of C_i values. Since there was no statistically significant difference between the two techniques, the latter was chosen because of its simplicity.

C_i values are systematically assigned such that C_1=1.0, C_2=0.8, C_3=0.6, C_4=0.4, and C_5=0.2. Note that the subscript i is not arbitrarily assigned to an emitter-detector pair, but is the pair's rank in terms of relative cotton flow rate within the conveyer pipe. For each emitter-detector pair, i is determined by summing x_{ij} values over some time period and ranking the emitter-detector pairs from greatest (i=1) to least (i=m where m is the number of emitter-detector pairs in the sensing unit). Figure 4 shows a bar graph

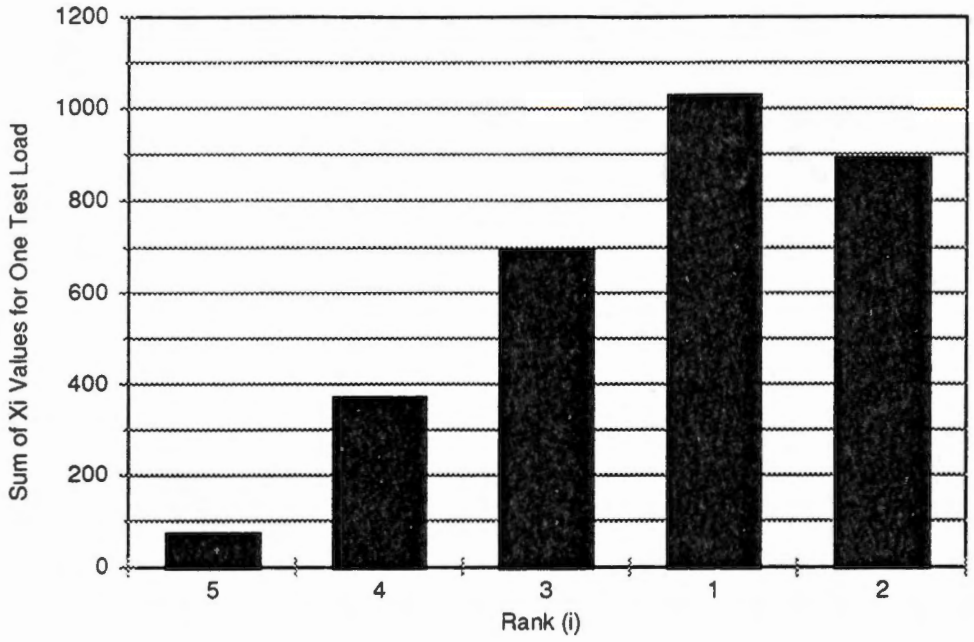


Figure 4. Sums of normalized differences (x_{ij}) over one harvested load for each emitter-detector pair in a sensing unit. The sums represent relative cotton flow rates within the conveyer pipe, and are ranked from greatest to least to determine the i values for the emitter-detector pairs.

that illustrates the ranking process for a typical sensing unit (recall that there is one sensing unit per conveyer pipe). Each bar represents the sum of x_{ij} collected during a field test run in which approximately 95 lb of seed cotton traveled through the conveyer pipe of interest.

Once the C_i coefficients have been applied, the resulting values are summed for each sensing unit (recall that there is one sensing unit per conveyer pipe).

The intermediate processing described above is summarized by the following expression.

$$A_j = \sum_{i=1}^{m} C_i x_{ij} \qquad \text{Equation IV}$$

where A_j=sensing unit output from the j^{th} sensing unit

m=number of emitter-detector pairs in the j^{th} sensing unit

C_i=weighting coefficient for the i^{th} emitter-detector pair

x_{ij}=normalized difference for the i^{th} emitter-detector pair in the j^{th} sensing unit

Final Processing

Finally, sensing unit outputs (A_j) from all of the conveyer pipes are summed and multiplied by a scaler to obtain an estimate of the average flow rate of cotton through the sensing system during the integration period. The scalar is a value that must be determined through a calibration process for each system installation. This final processing is represented by the following equation.

$$Q = K \sum_{j=1}^{n} A_j \qquad \text{Equation V}$$

where Q=average cotton flow rate during the integration interval

K=scaler (determined by calibration)

n=number of sensing units in the sensing system

A_j=sensing unit output from the j^{th} sensing unit

Emitter Design

Infra-red light emitting diodes (LEDs) are used as emitters. An assembly drawing of an emitter array is shown in Figure 5. The emitter array consists of a housing, plano-convex lenses, lens cover, printed circuit board, and rear cover. The housing is machined from polyvinyl chloride (PVC) material. Lenses are plastic plano-convex lenses (U.S. Precision Lens, Inc., part no. 7350-1), and are included to focus light into individual beams. The lens cover is pressed from poly-carbonate sheet that has a nominal thickness of 0.025 in. Lens cover protrusions are slightly deeper than the thickness of the mounting plate so that there is no recess at the lens cover apertures when the device is assembled. This is important to limit the accumulation of foreign materials on the lens cover. The lens cover is bonded to the housing with silicone sealant. The mounting plate is designed so that the top flange slides up into a rectangular cut-out in the conveyer pipe wall and the bottom holes accommodate studs that are welded into the conveyer pipe wall below the rectangular cut-out. The printed circuit board fits inside the rear slot of the housing and a layer of silicone seals it to the housing. After circuit board installation, the rear slot of the housing is filled with a two-part epoxy material and the rear cover is attached with adhesive (See Appendix A for mechanical drawings and circuit board layouts).

A schematic of the circuit contained on the printed circuit board is shown in Figure 6. The light source is an infra-red LED (American Bright Optoelectronics Corp., part no. BIR-BL734; see Appendix B for full specifications). The LM317LZ adjustable regulator is used in conjunction with a fixed resistor and a trim pot to provide adjustable

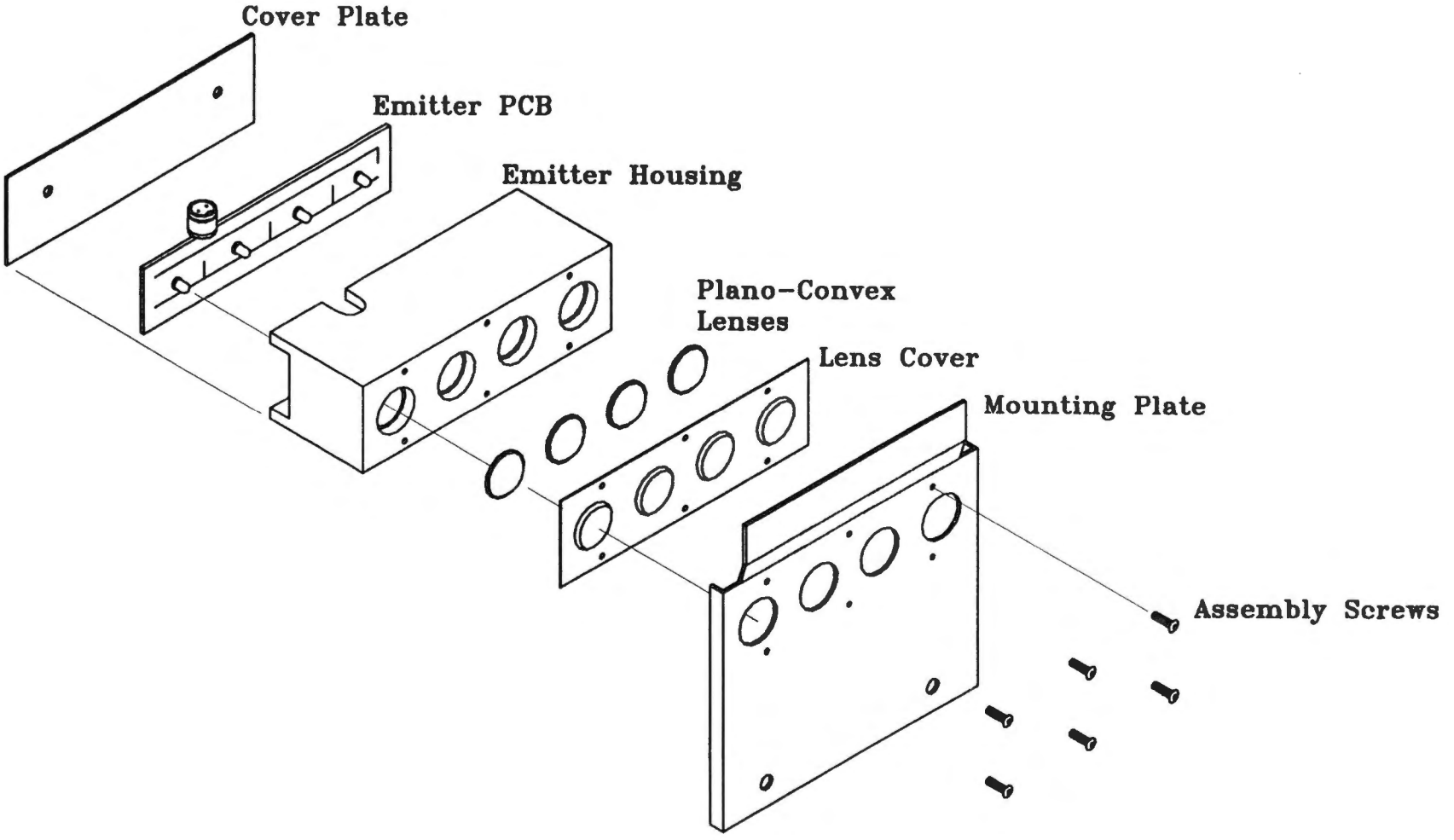
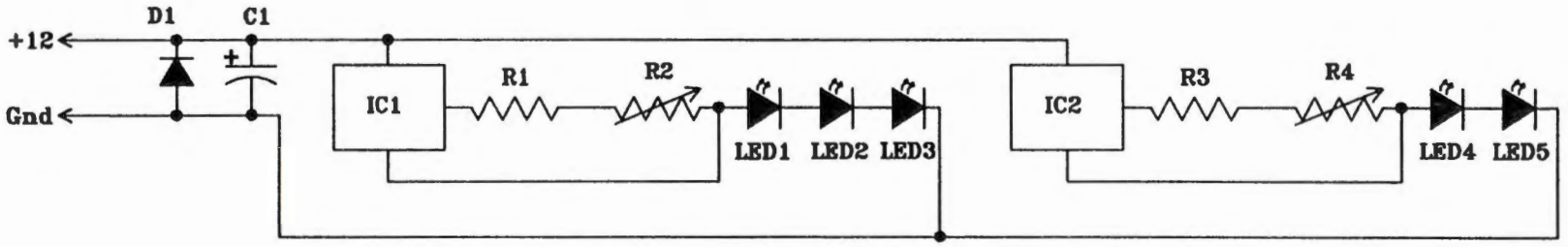


Figure 5. Emitter assembly.



Label	Device	Specifications
C1	Capacitor	4.7 μF, 63 V
D1	Diode	1N4001
IC1-2	Adjustable Regulator	LM317LZ
LED1-5	Light Emitting Diode	American Bright BIR-BL734
R1	Resistor	36 Ω, 5%, 0.25 W
R2	Variable Resistor	0 to 1 KΩ, 10%, 0.5 W
R3	Resistor	36 Ω, 5%, 0.25 W
R4	Variable Resistor	0 to 1 KΩ, 10%, 0.5 W

Figure 6. Emitter circuit schematic.

current regulation from 1 to 33 mA. The current regulation circuitry provides constant output as long as the supply voltage remains between 9.5 and 15 VDC.

Detector Design

An assembly drawing of a detector array is shown in Figure 7. The detector array consists of a housing, double-convex lenses, lens cover, mounting plate, printed circuit board, and rear cover plate (See Appendix A for mechanical drawings and circuit board layouts). All detector array components are similar to the emitter array components described above with the exceptions of the lenses and the printed circuit board. Lenses used in the detector are plastic double convex lenses (U.S. Precision Lens, part no. 7292-1). The double convex lenses limit the field-of-view and focus incident light toward the active area of each photo-detector. This increases the intensity of light received by the detector, thus increasing the baseline level (b_{ij}). This is important because accumulation of foreign matter on the lens covers over time will cause reduction in b_{ij} levels. An intense light signal at the detector leads to long periods of operation between lens cover cleaning.

A schematic of the circuit contained on the printed circuit board is shown in Figure 8. The photo-detector (IC1-IC5) used is the TLS245 infra-red light-to-frequency converter manufactured by Texas Instruments. Output of this photo-detector is a TTL level signal with a frequency that is linearly proportional to the intensity of the infra-red light striking the active area of the device. The linear relationship between output frequency and irradiance is valid over a range of five orders of magnitude (See Appendix B for full specifications). A buffer (IC6) with open-collector output is included to drive

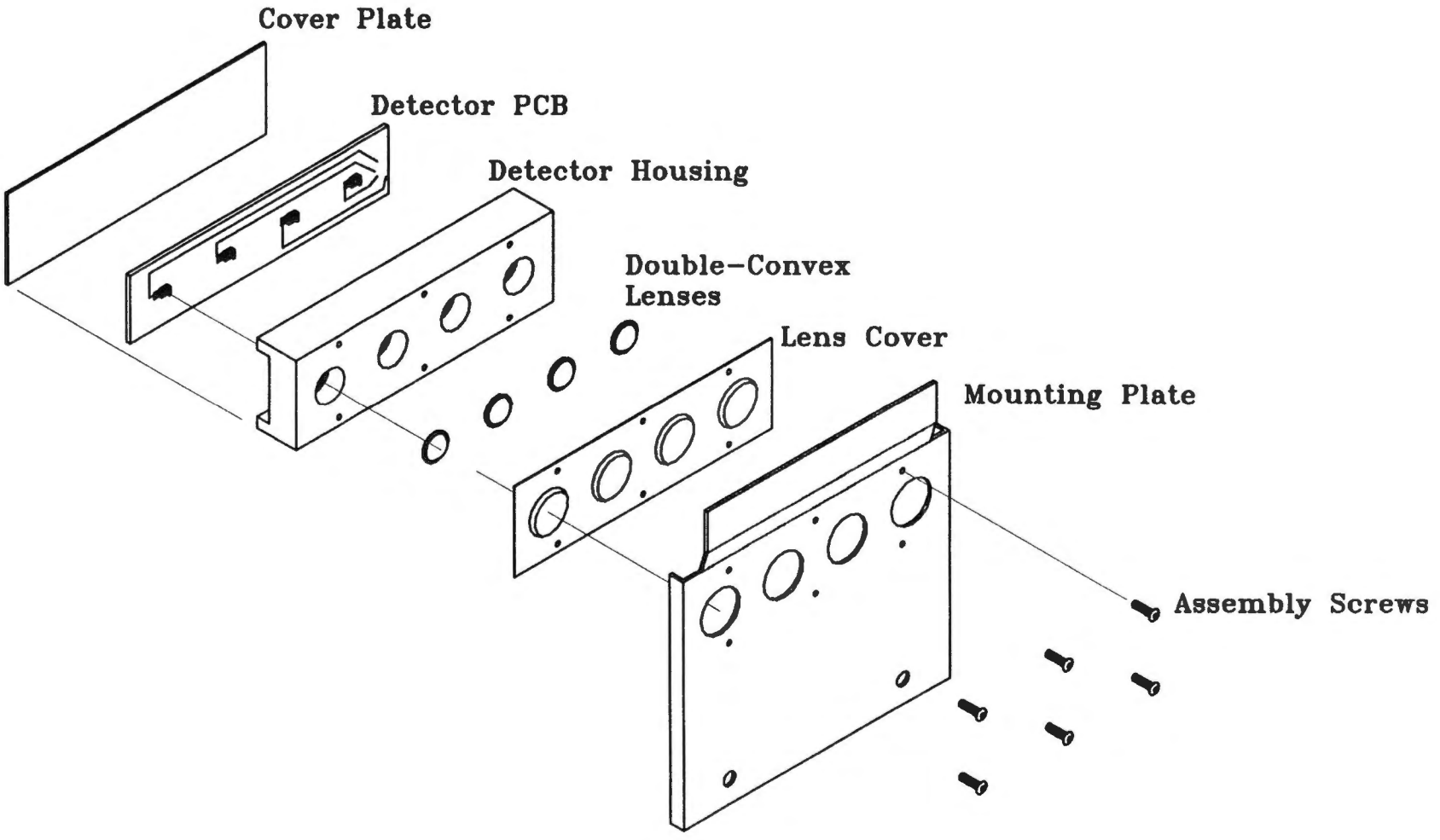
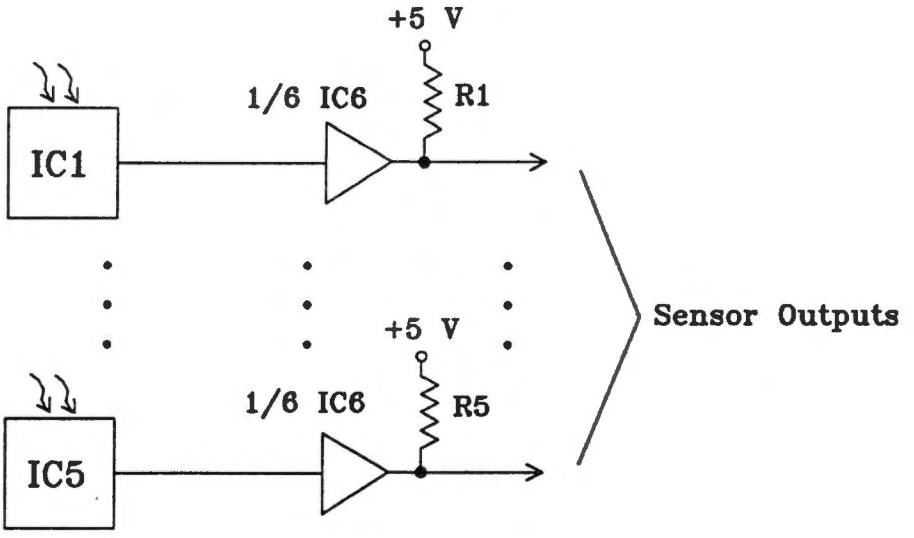


Figure 7. Detector assembly.



Label	Device	Specifications
IC1-5	Light-Freq. Converter	Texas Ins. TSL245
IC6	Buffer	SN7407N
R1-5	Resistor	270Ω 2%, 0.3 W

Figure 8. Detector circuit schematic.

the cables that carry the photo-detector signals to the data acquisition and processing system.

Data Acquisition and Processing System Design

Hardware

Overview

The data acquisition and processing system consists of a digital data acquisition unit and a lap-top computer. The digital data acquisition unit collects information from the flow sensing units and performs some initial processing. The lap-top computer, which is a Zenith Data Systems Z-Star EX with two Fujitsu PCMCIA serial interface

cards, carries out the final data processing, and functions as a user interface and data storage device. An information flow diagram that represents data acquisition and processing hardware is shown in Figure 9. Pulse train signals generated by the sensors are integrated by hardware counters which are read and cleared by a single-board computer at the end of each integration interval. The single-board computer can carry out the initial processing described above and logs data to a solid-state data drive and/or a serial port. Data transmitted through the serial port is received by the lap-top computer that also logs position information from a GPS receiver and load weight information from an on-board cotton weighing device during field test operations.

Single-board Computer

The single-board computer used to perform all data acquisition, initial processing, and storage operations in the digital data acquisition unit is the 4010 from Octagon Corp. The 4010 is a DOS-based system with a 25-MHZ processor, 2 MB of RAM, and a 512-KB solid-state disk for program storage. The 4010 has two RS-232 serial ports, and a standard parallel port, and is equipped with a PC/104 interface for connecting other PC/104 compatible devices.

PCMCIA Solid State Data Drive

The PC/104 connector allows the addition of a PCMCIA card drive from Adtron (part no. SDDP-05). The drive is capable of using a variety of PCMCIA cards. In this project, a 4MB flash (E^2PROM) disk was used. Once it has been configured with the proper low-level software drivers, DOS recognizes the PCMCIA drive as a standard disk drive.

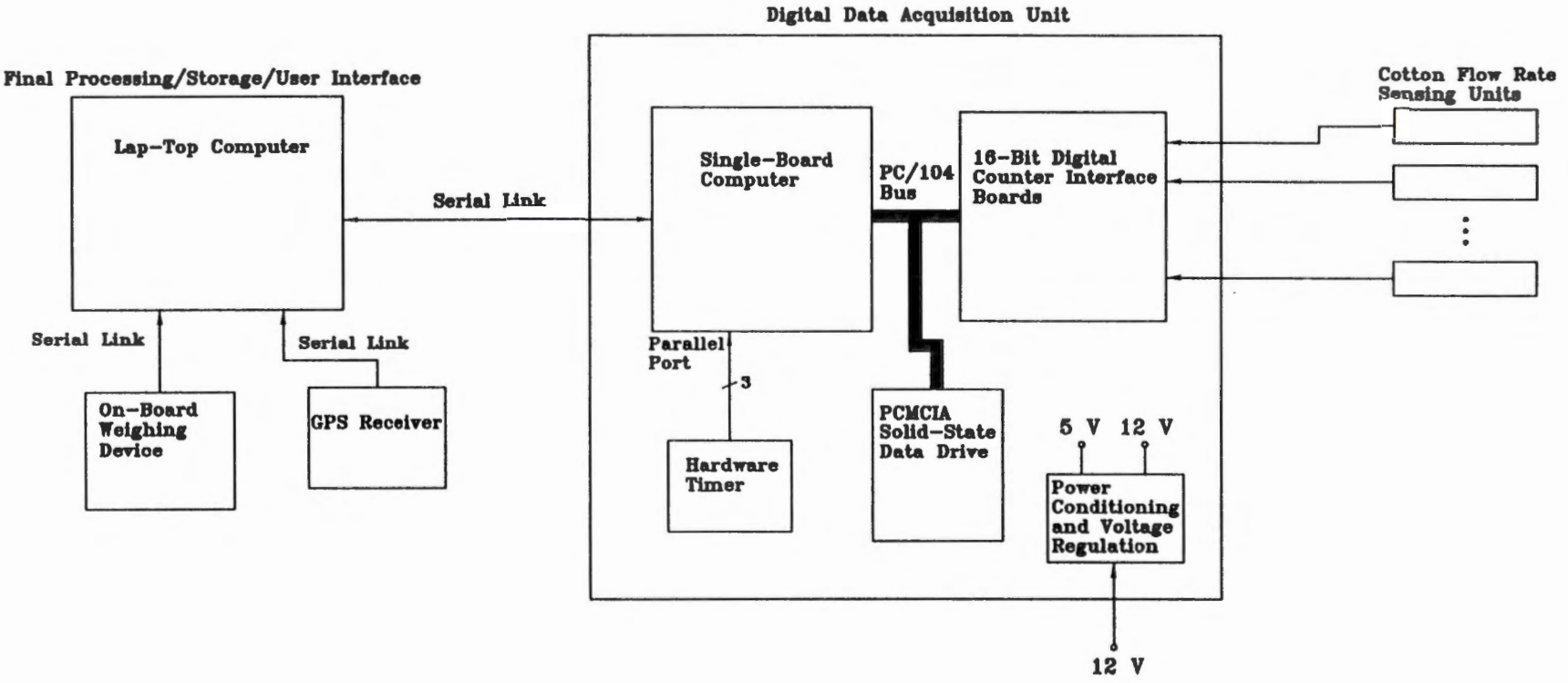


Figure 9. Information flow diagram for the data acquisition and processing system.

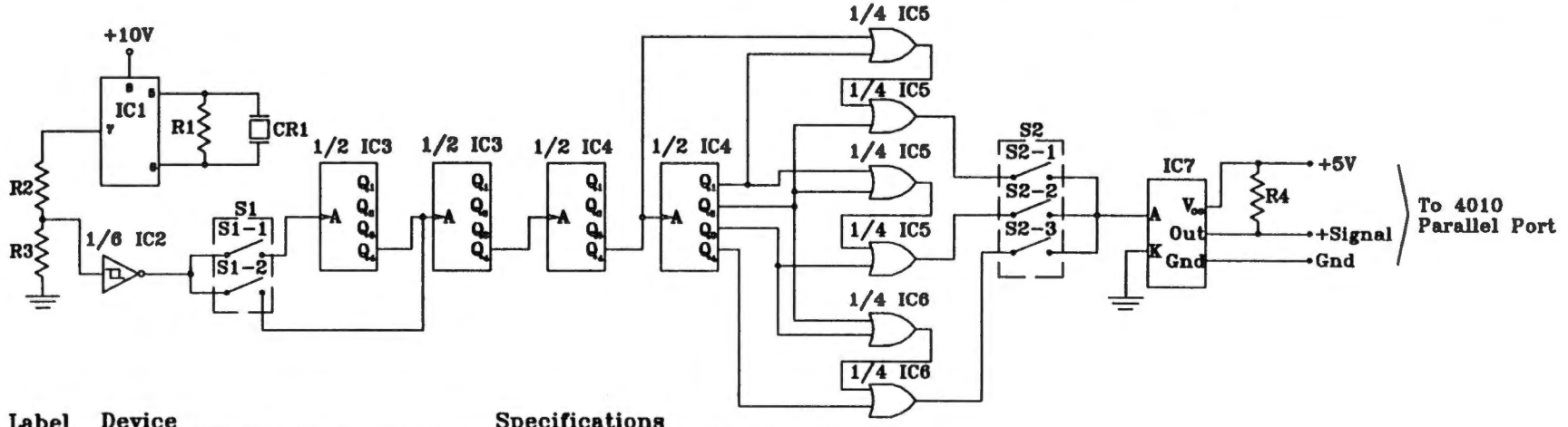
Counter Interface Boards

Also interfaced through the PC/104 bus are four interface cards from Computer Boards, Inc. Each PC104-CTR10 interface boards provides ten 16-bit counters, the four boards together providing 40 counters. Computer Boards, Inc. provided QBASIC callable routines to operate the counter interface boards. Counter board functions used in this project include configuration of the counters during system start-up, reading the counters at the end of an integration time interval, and loading the counters with zeros to clear them after they have been read.

Hardware Timer Circuit

Recall from above that the basic information gathered by the data acquisition system is the sum of photo-detector output pulses for each emitter-detector pair over each integration time interval. The computer must be capable of timing the counter read/clear operation so that the elapsed time between a clear and the next read remains a constant equal to the desired integration time interval. A hardware timer was designed and built to allow accurate integration interval measurement. A schematic of the timer circuit is shown in Figure 10. The timer produces a TTL level square-wave signal with a period equal to the integration time interval and a 7/8 duty cycle. Periods of 200, 100, 50, 25, 12.5, and 6.25 ms can be selected using the switches on the circuit board. Timer output is interfaced to the 4010 through the parallel port. Between cycles, system software poles the I/O memory location corresponding to the parallel port where the timer output is connected. A transition from low to high on the input port triggers the read/clear operation.

S1-1	S1-2	S2-1	S2-2	S2-3	Output Period
Closed	Open	Open	Open	Closed	200.00 ms
Closed	Open	Open	Closed	Open	100.00
Closed	Open	Closed	Open	Open	50.00
Open	Closed	Open	Open	Closed	25.00
Open	Closed	Open	Closed	Open	12.50
Open	Closed	Closed	Open	Open	6.25



Label	Device	Specifications
CR1	Crystal	3.2768 MHz
IC1	Divide by 10	RDD104 (from LSI)
IC2	Hex Schmitt Trigger Inverter	74LS14
IC3-4	Dual 4-Bit Binary Counter	74LS393
IC5-6	Quadruple 2-Input OR Gate	74LS32
IC6	Quadruple 2-Input OR Gate	74LS32
IC7	Opto-Isolator	OPI126 (from Optek)
R1	Resistor	10 MΩ, 5%, 0.25 W
R2-4	Resistor	1 KΩ 5%, 0.25 W
S1-2	Switch Bank	Single Throw General

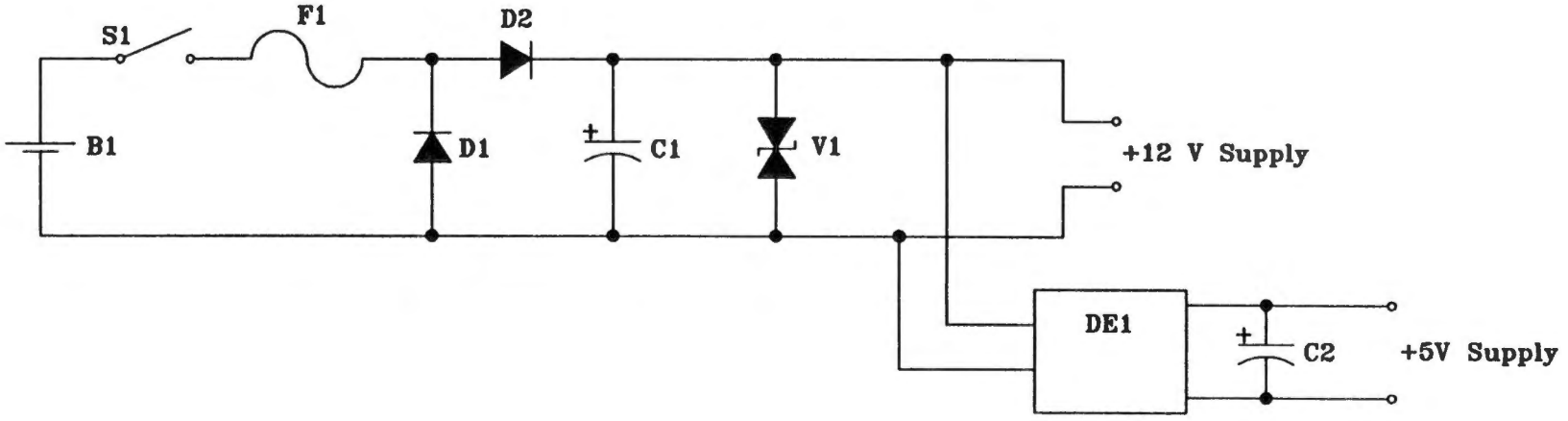
Figure 10. Hardware timer circuit schematic.

Voltage Regulation and Conditioning

Two power supply voltages of 12VDC and 5VDC are required for the system. The 12V supply powers the emitter arrays. The 5V supply powers the single-board computer and the detector arrays. The harvester electrical system is powered by a 12 V battery. This 12 V source is used with the power conditioning circuit shown in Figure 11 to provide the 12 V supply for the sensing system. The 5V power supply required by the sensing system is provided by a 12-to-5 V DC-DC converter manufactured by Intronics (part no. DC703).

Enclosure

The single-board computer, all of the devices interfaced via the PC/104 bus, the hardware timer, and the power supply circuitry are housed in a fiber glass NEMA-4 enclosure (Hammond Manufacturing, part no. PJ12106L). The enclosure has been modified as shown in Figure 12. Connectors added on the end of the box provide access to the counter interface board inputs, the RS-232 ports, and the 5 V and 12 V power supplies. A connector is also provided for power input from an external 12 V supply. To maximize the usable volume and minimize heat generation inside the enclosure, the DC-DC converter is mounted on the side of the enclosure as shown in Figure 12. The DC-DC converter as well as all of the connectors are bonded to the enclosure walls with silicone sealant to reduce the chance of water penetration.



Label	Device	Specifications
B1	Harvester Battery	+12 V DC
C1	Capacitor	6800 MF
C2	Capacitor	1100 MF
D1-2	Diode	6A, 50V
DE1	DC-DC Converter	DC703 (Intronics)
F1	Fuse	AGC 5 (Buss)
S1	Switch	Single Throw General
V1	Varistor	26 V

Figure 11. Power conditioning circuit schematic.

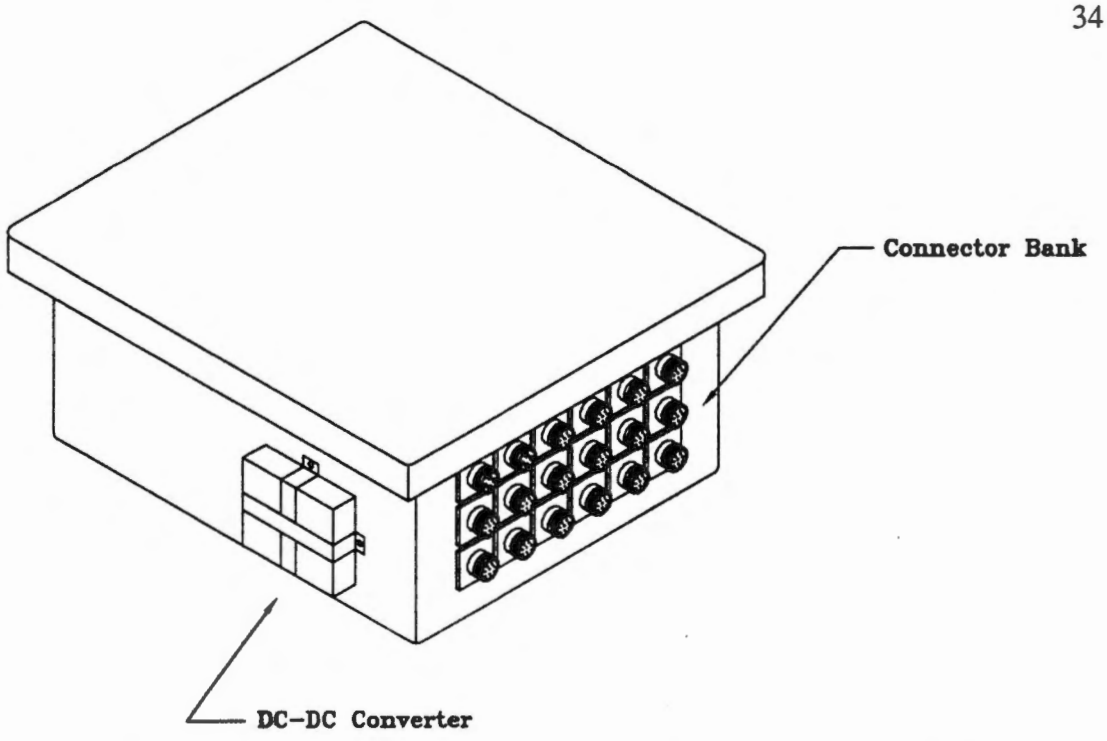


Figure 12. The digital data acquisition unit housing, a NEMA-4 enclosure from Hammond Manufacturing, modified as shown.

Software

Digital Data Acquisition Unit

All of the software for the digital data acquisition system as well as the lap-top computer was written in Microsoft QuickBASIC, version 4.5. Special drivers for the solid-state disk drive and the counter interface boards were provided by the manufacturers. Two programs for use with the data acquisition box were written. *Flowsen1.bas* was developed for field use on a Case IH 2555 four row wide cotton picker. It acquires data from 38 emitter-detector pairs, a ground speed sensor, and a fan speed sensor. It performs the initial processing steps described above and can log data to the solid-state disk or an RS-232 serial port. Because of processor speed limitations,

the program can only be used with a 200 ms integration interval. A flow chart for the program is shown in Figure 13, and the code is included in Appendix C.

Flowsen2.bas was developed for field use on a Case IH 2155 four row narrow cotton picker. It acquires data from 18 emitter-detector pairs and logs the raw data to the solid-state disk. Because it only collects data from four of the eight conveyer pipes on the harvester and performs no initial processing, this program is much faster than the other and can be used with 200, 100, 50, or 25 ms integration intervals. A flow chart for the program is shown in Figure 14, and the code is included in Appendix C.

Lap-top Computer

When *flowsen1.bas* is used with the digital data acquisition unit, the lap-top computer must acquire data from the serial port, perform final processing functions, log data to the hard drive, and display data on the screen. The program *display.bas* carries out these operations while also handling data from the GPS receiver and the on-board weighing device. For *display.bas* to operate properly, data strings coming from the sensing system, GPS receiver, and on-board weighing device must all be transmitted at a rate of 1 Hz. A flow chart of *display.bas* is shown in Figure 15, and the code is included in Appendix C.

Programs for laboratory testing are similar to the ones developed for field test applications. The most significant difference is that the laboratory test software is only required to collect information from one sensing unit (five emitter-detector pairs).

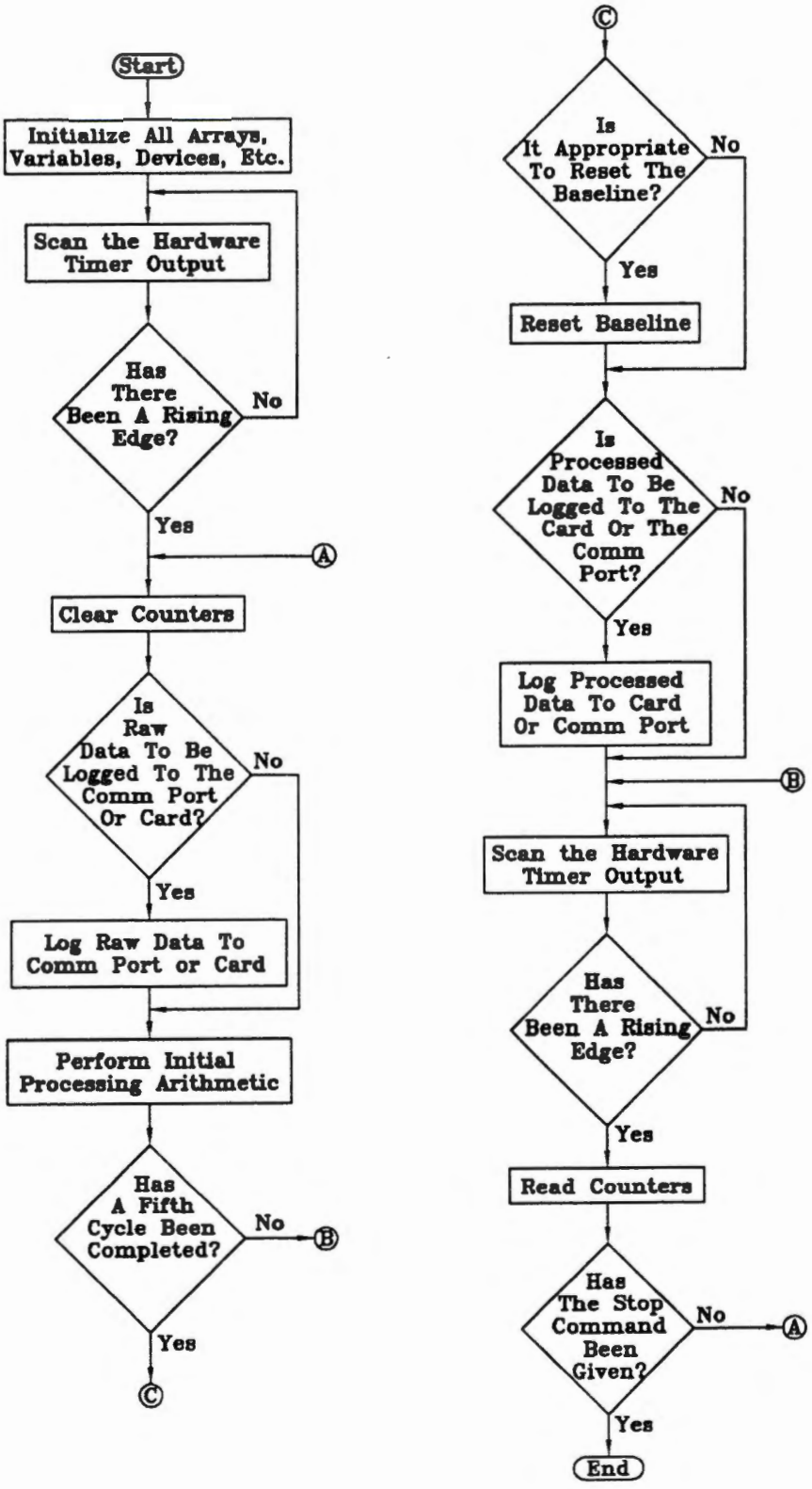


Figure 13. Flow chart for *flowsen1.bas*.

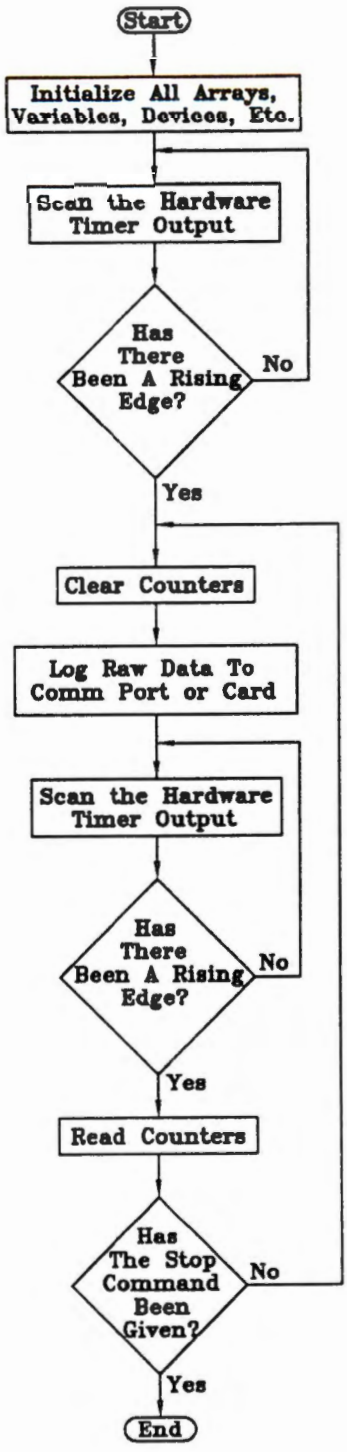


Figure 14. Flow chart for *flowsen2.bas*.

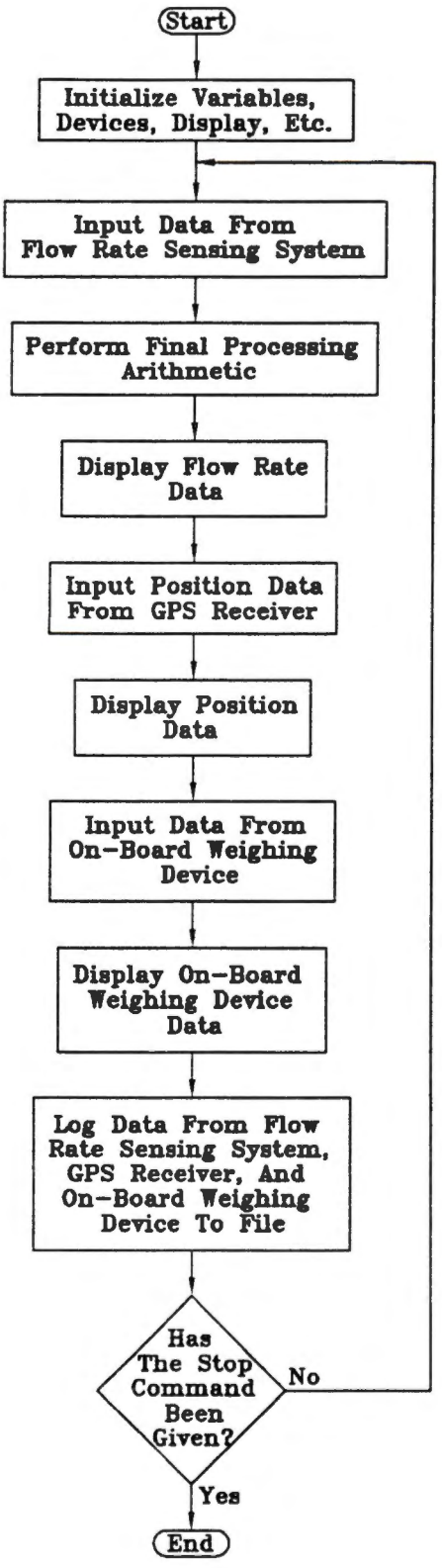


Figure 15. Flow chart for *display.bas*.

Test Equipment

Laboratory Test Equipment

A stationary test stand was designed and built for laboratory testing. A photograph of the test stand is shown in Figure 16. The test stand consists of a conveyer pipe, jet, and fan from a Case IH 2155 cotton picker, a variable speed cotton feed belt, and a catch basket suspended on load cells. The conveyer pipe has been shortened by approximately three feet, and is supported in a manner that simulates mounting geometry on a cotton picker. A 25 hp gasoline engine provides power for the conveyer fan. It supplies air to the pipe at a velocity of about 6000 fpm which is comparable to the conveyer air velocity on a 2155 picker. Cotton feed belt speed can be varied to provide average cotton loading rates up to 0.67 lb/s. This corresponds to a yield of about two



Figure 16. Photograph of the laboratory test stand.

bales per acre harvested with a Case IH 2155 four row narrow machine under normal field conditions. The catch basket is suspended by two 250-lb tension load cells (Interface, Inc., part no. SM-250). According to specifications provided by the manufacturer, the weighing system is capable of measuring a 500-lb load to within +/- 1 lb (RMS).

Field Test Equipment

For field testing, a prototype system was installed on a Case IH 2155 four row narrow cotton picker configured for 30-in. row spacing. Sensing units were mounted on the conveyer pipe walls in the positions originally occupied by the pipe plug sensors (standard equipment on the Case IH 2155) which were removed. The data acquisition box was mounted above the water tank, and the lap-top computer was positioned in the cab of the machine. Figure 17 illustrates the mounting locations of system components. A cotton weighing device was installed in the picker basket as documented by Palmer (1997). The device described by Palmer is an interior basket made of light-weight materials and suspended by load cells at the top four corners. This weigh-basket has four-bar linkages that tie it to the picker frame, thus limiting motion in the horizontal plane. A photograph of the weigh-basket is shown in Figure 18. The basket is capable of accurately weighing a 1500-lb load of cotton within +/-25 lb (Palmer, 1997).

An important feature of the Case IH cotton picker is the dual-drum picking unit shown in Figure 19. Plant lifters guide cotton plants into the picking unit. Once inside the picking unit, plants come in contact with spindles from the front picking drum. The front drum normally removes the majority of cotton from the plant. The rear picking

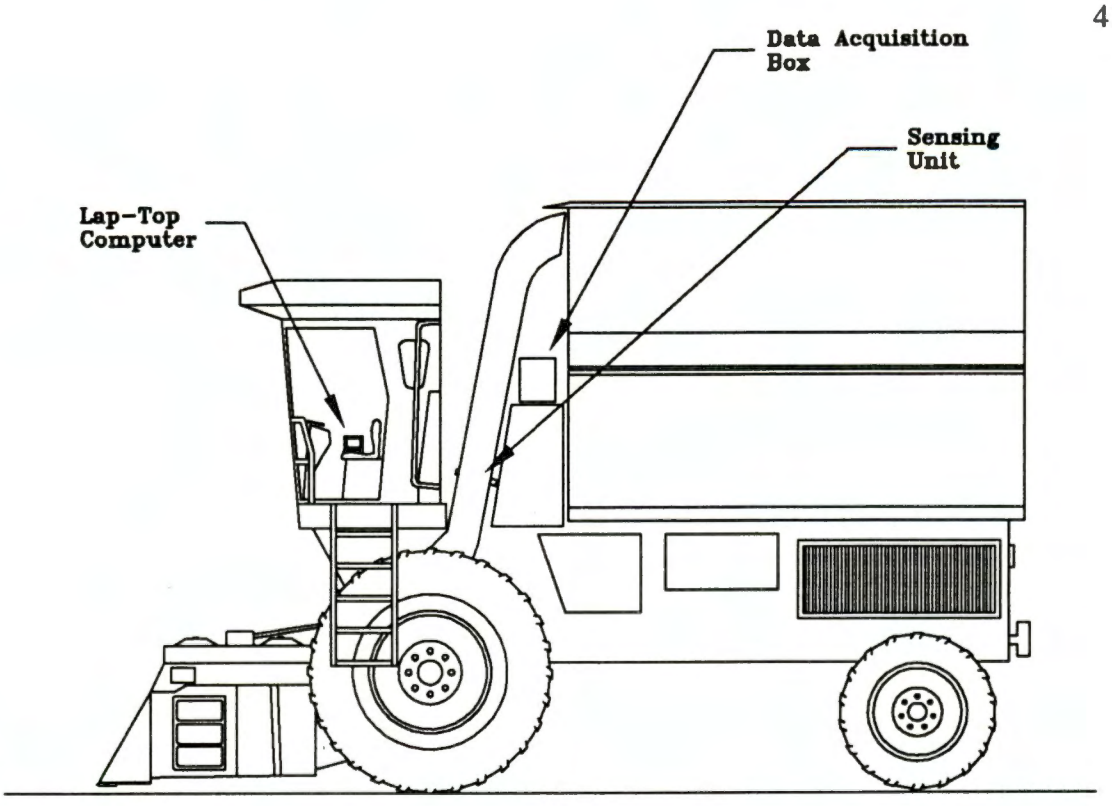


Figure 17. System component mounting locations.

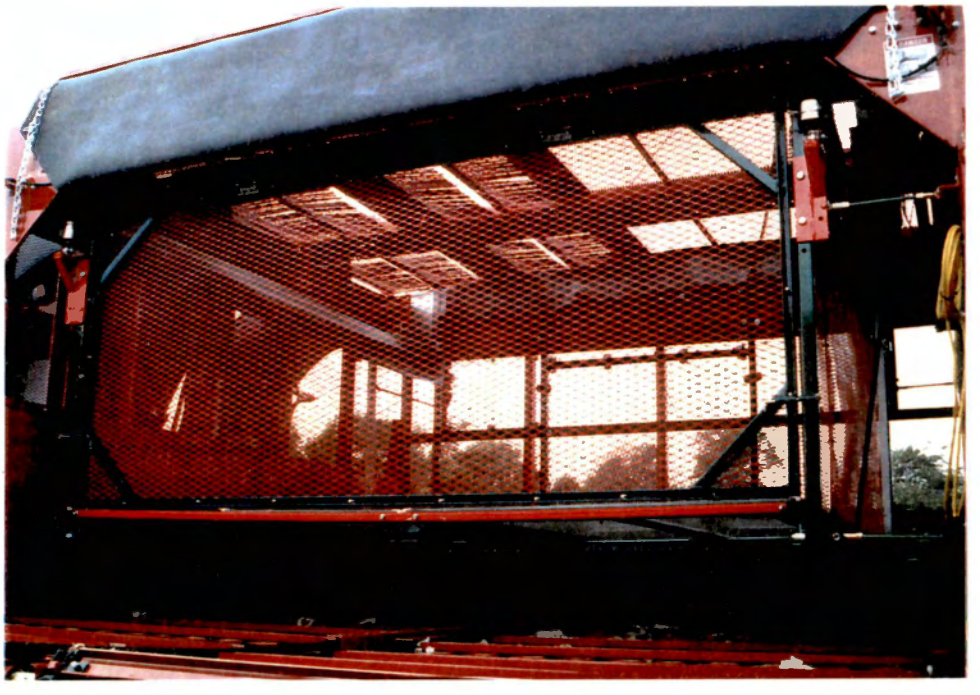


Figure 18. Photograph of the on-board weighing device.

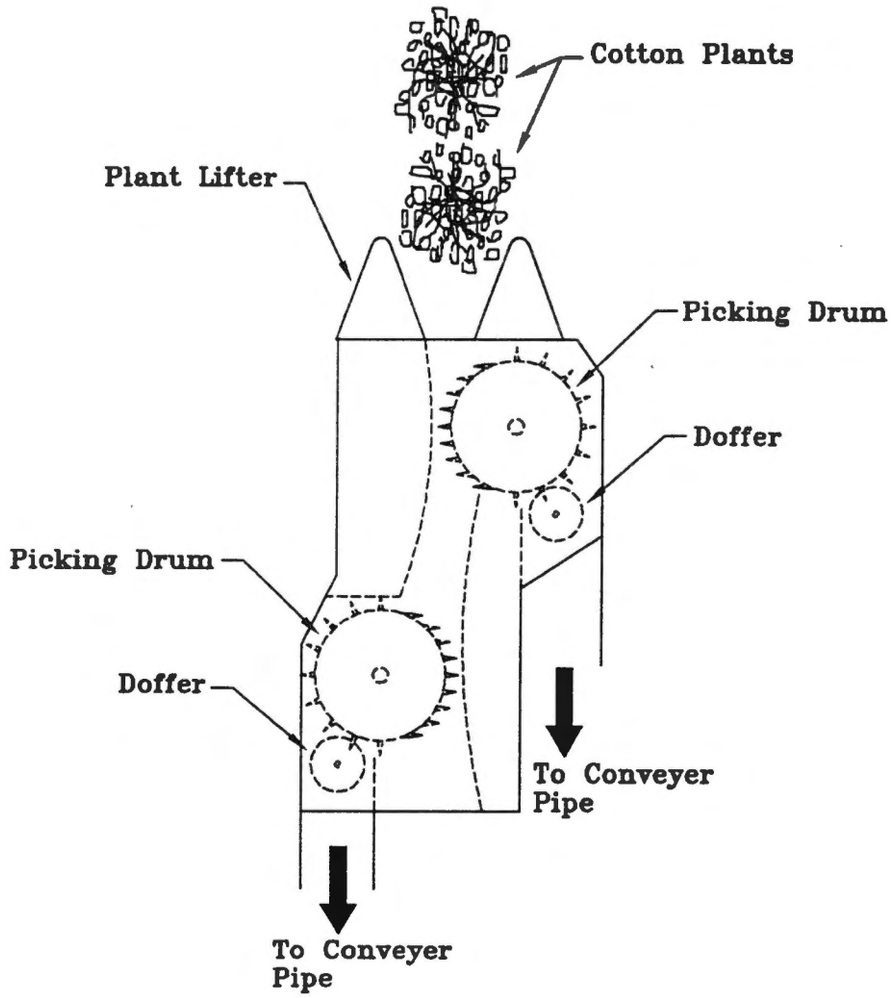


Figure 19. Schematic of the Case IH picking unit.

drum spindles contact the plant and remove the remainder of the harvestable cotton. Each drum in the picking unit has its own conveyer pipe, and the conveyer pipe serving the front drum will carry larger cotton flow rates than the one serving the rear drum.

For field testing, sensing units were installed on all conveyer pipes. However, due to some modifications taking place during the harvest season, only about one-third of the field test data set includes data from all sensing units. The remaining two-thirds of the data set includes only data from sensing units mounted on pipes serving front picking

drums. If the amount of cotton picked by rear picking drums is linearly proportional to the amount picked by front drums, measuring the flow rate generated by either front or rear drums will provide adequate information to predict the total picking rate. To demonstrate that the two flow rates are proportional in the data set collected during field test operations, raw sensing unit outputs from front and rear drums were summed for each load harvested, and the sums generated by rear picking drum sensing units are graphed against the sums generated by front picking drum sensing units in Figure 20. It is evident that a linear relationship exists between the front and rear drum sensing unit outputs in this data set. In fact, with the omission of one outlier, 97.2 percent of the variation in rear drum sensing unit output is due to variation in front drum sensing unit output. Some of the variation from the straight line presented in Figure 20 may be due

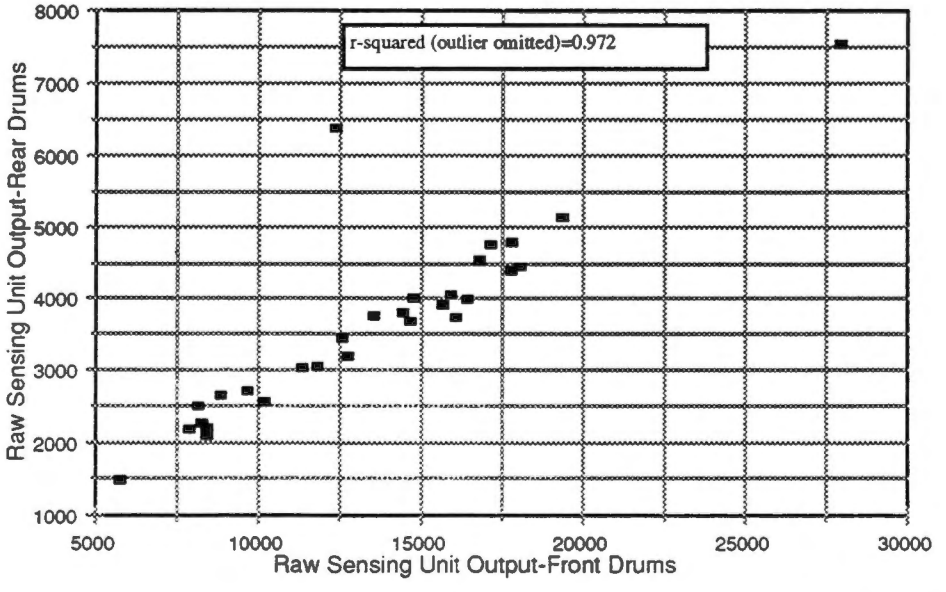


Figure 20. Relationship between outputs from sensing units on pipes serving front and rear picking drums.

to changing front to rear drum harvest rate ratios. However, the data set is not large enough to prove or disprove this theory. Instead, the decision was made to use only data from front drum sensing units in the analyses that follow.

It should be stressed a linear relationship between front and rear drum picking rates may not be present in many situations, so future application of the technology should include all conveyer pipes on a harvester.

Testing Procedures

Laboratory Test

In January, 1997, a laboratory test was conducted to quantify accuracy of the prototype sensing system. A sensing unit was mounted on the test stand, and interfaced with the data acquisition box. An integration interval of 200 ms was selected, and a program similar to *flowsen2.bas* was used for raw data collection. Thirty-three loads of cotton were cycled through the system. The total load weights varied from 3.4 to 24.0 lb with average cotton flow rates up to 0.53 lb/s. A portion of the data from the sensing system was used for system calibration. The rest of the data was post-processed to yield a predicted average flow rate for each second. These predicted flow rates were integrated over time to calculate a predicted load weight for each test run. Predicted load weights were compared with the load weights as measured by the catch basket load cells.

Field Test

The system was installed on a Case IH 2155 cotton picker and tested between October 18 and November 12, 1997 at The University of Tennessee Milan Experiment Station in Milan, Tennessee. Preliminary testing in central Mississippi during September and early October led to several system adjustments which were made for the Tennessee tests. Mississippi test results indicated that relative motion between emitter and detector arrays due to conveyer pipe deformation during harvest operations was causing serious errors in sensor output. To alleviate this problem, braces were added to the Tennessee machine to fix all conveyer pipes in a more rigid geometry. The Mississippi tests also allowed detection of a problem in the automatic baseline correction procedure. Automatic correction was not being implemented quickly enough to follow changes in the baseline. To allow the system more opportunities to accurately correct for baseline variation, the integration interval was changed from 200 ms to 25 ms for the Tennessee tests.

As mentioned above, the data collected during the Tennessee tests is from only the four conveyer pipes that serve front picking drums. The test procedure was similar to that used in the laboratory. The program *flowsen2.bas* was used for raw data collection. Eighty-seven loads of cotton were harvested. Total load weights varied from 275 to 1361 lb with average cotton flow rates up to 0.57 lb/s/pipe. A portion of the data was used for system calibration. The rest of the data from the sensing system was post-processed to yield a predicted average flow rate for each second. These predicted flow rates were then integrated over time to calculate a predicted load weight for each load.

The predicted load weights were compared with the load weights as measured by the on-board weighing device load cells.

Chapter 4--Results

Laboratory Evaluation

The main objective of the laboratory test was to quantify sensor accuracy and determine whether to proceed as planned or make major changes to the system design. Thirty-three test loads of cotton were run through the system. Total load weights varied from 3.4 to 24.0 lb with average cotton flow rates up to 0.53 lb/s. The first six loads were used with a linear regression procedure to determine the value of the scaler K in the final processing equation (Equation V). These six loads were then eliminated from the data set, leaving 27 loads for accuracy determination. For each load, the predicted flow rates were integrated over time to produce a predicted load weight. Percent error for each load was calculated using the following formula.

$$E = \frac{PW - AW}{AW} \qquad \text{Equation VI}$$

where E = error

PW = predicted load weight

AW = actual load weight

The distribution of error terms is shown in Figure 21. The distribution centered around the -2 to 2 percent range. Only six of the 27 error values were outside the -6 to 6 percent range. The average of the absolute value of the error terms was 4.4 percent. These results were deemed adequate to justify continuing with the sensor development project as planned.

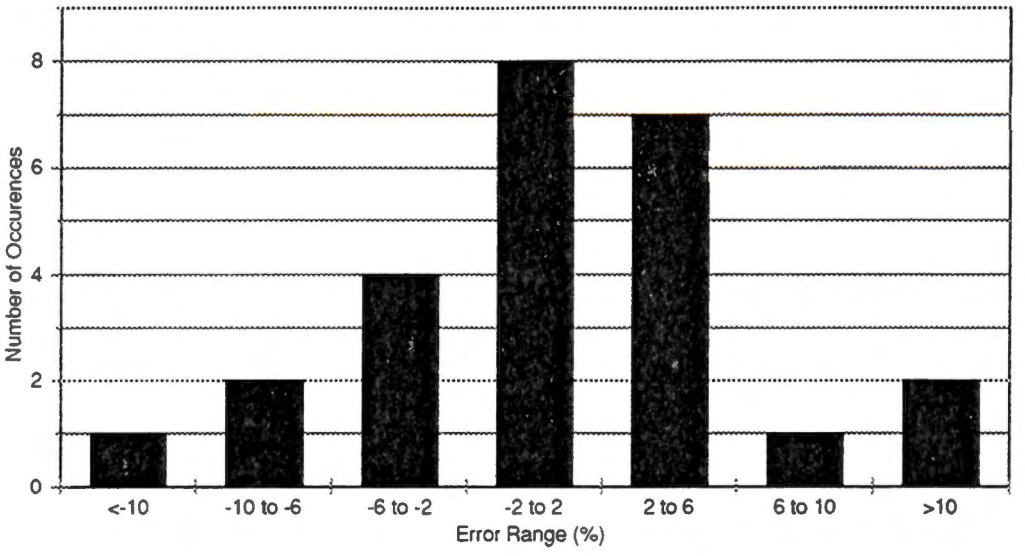


Figure 21. Distribution of errors from the January, 1997 laboratory test.

Field Evaluation

The 1997 harvest season field test was designed to meet several objectives. Documentation of system accuracy was the ultimate goal, but effects of several factors on sensor performance were also investigated. Information gathered during the field test allowed determination of (1) the amount of cotton that must be harvested before the *i* values (emitter-detector rank in terms of relative flow rate within a conveyer pipe) can be established, (2) the number of calibration loads necessary for optimum system performance, (3) whether accuracy degrades over time, and (4) whether accuracy is dependent on flow rate.

Rank Determination for Weighting Coefficients

Weighting coefficients (C_i) are systematically assigned so that C_1=1.0, C_2=0.8, C_3=0.6, C_4=0.4, and C_5=0.2. The subscript i is not arbitrary; it represents each emitter-detector pair's rank in terms of relative flow rate within a conveyer pipe. Ranks are

determined by harvesting cotton and summing normalized difference values (x_{ij}) for each emitter-detector pair. These sums are then used to rank the emitter-detector pairs. The emitter-detector pair with the greatest sum is assigned i=1, and the emitter-detector pair with the least sum is assigned i=m where m is the number of emitter-detector pairs in the sensing unit.

To determine the minimum amount of cotton that must be harvested before the ranks (i values) can be established, the following analysis was carried out. The field test data set was divided into three load weight classes of 200 to 400 lb, 400 to 800 lb, and 800 to 1300 lb. Five loads were randomly chosen from each load weight class. An additional ten loads from the 800 to 1300 lb class were paired, and the pairs were merged to simulate five loads from a 1600 to 2600 lb class. Emitter-detector pair ranks were determined using data from each load in the data subset.

Resulting ranks were all equivalent, regardless of which load from the data subset was used for determination. This leads to the conclusion that ranks will be correctly established as long as they are based on harvest of more than 400 lb of cotton.

Field Calibration Procedure

A calibration procedure for determining the scaler (K) in the final processing equation (Equation V) is necessary. A number of loads are harvested and weighed. Linear regression is performed with the load weights used as the dependent variable, and the sum of normalized differences ($\sum_{j=1}^{n} A_j$) for each load used as the independent variable.

To determine the optimum number of loads to be used in the regression, the model was calibrated using 4, 8, and 12 loads. The first 12 loads were dropped out of

the data set, and errors were calculated for the remaining 75 loads according to Equation VII. Correlation analysis showed only an extremely weak relationship between error and number of runs used for calibration with $r=0.13$ ($p<0.05$). For illustration, the absolute values of these errors were averaged, and the resulting average absolute errors were compared. When the model was calibrated using 4, 8, and 12 loads, the average absolute errors were 4.8, 4.8, and 4.9 percent, respectively. For this data set, four loads provided adequate calibration.

The results given below are all based on eight calibration loads. Since the first eight loads harvested were used for calibration, only the remaining 79 are included in the accuracy measurements that follow.

Accuracy and Time

Several parameters that could affect system performance varied with time during the 1997 harvest season. Cotton moisture content was not measured during the test, but weather conditions caused a noticeable increase in moisture content during the late days of the harvest season. Cotton conditions also changed with time due to aging and weathering. Another time varying factor, equipment wear took a toll during the season. For example, the lens covers were not cleaned during the harvest season, allowing debris and foreign matter build-up that could also affect sensor performance.

Although the effects of these changing factors were not evaluated individually, system accuracy over time was documented to obtain some indication of whether the combination of these factors had an effect. Correlation analysis was used to determine whether time had an effect on accuracy. No statistically significant correlation between

time and error was present in the data set ($r=-0.11$, $p>0.34$). For illustration, the average of the absolute value of the error for each day in the test is shown in Figure 22. While the error varied day-by-day, there was no clear trend over time.

Accuracy and Flow Rate

As with most sensors, this system can only be effective over a finite range of flow rates. Correlation analysis was used to determine whether flow rate had an effect on system accuracy in the field test data set. No statistically significant correlation between flow rate and error was present ($r=-0.11$, $p>0.31$). For illustration, average absolute error as a function of flow rate is shown in Figure 23. No relationship between flow rate and system performance was evident over the range of flow rates tested.

Overall System Performance

The distribution of errors for the system is shown in Figure 24. The distribution indicates that for all but four loads, the system predicted the total weight accurate to

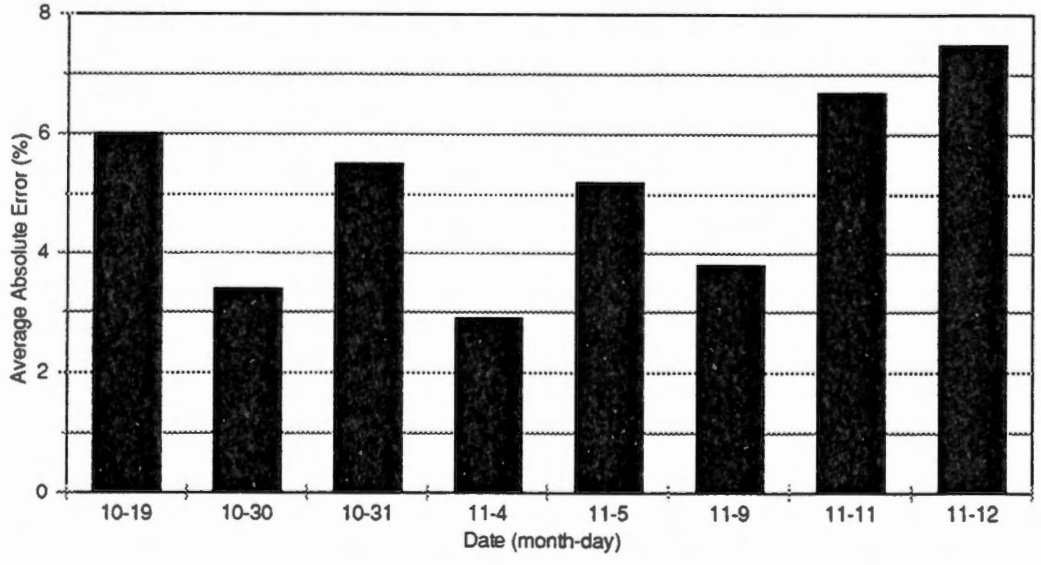


Figure 22. Average absolute error for each day in the Fall, 1997 field test.

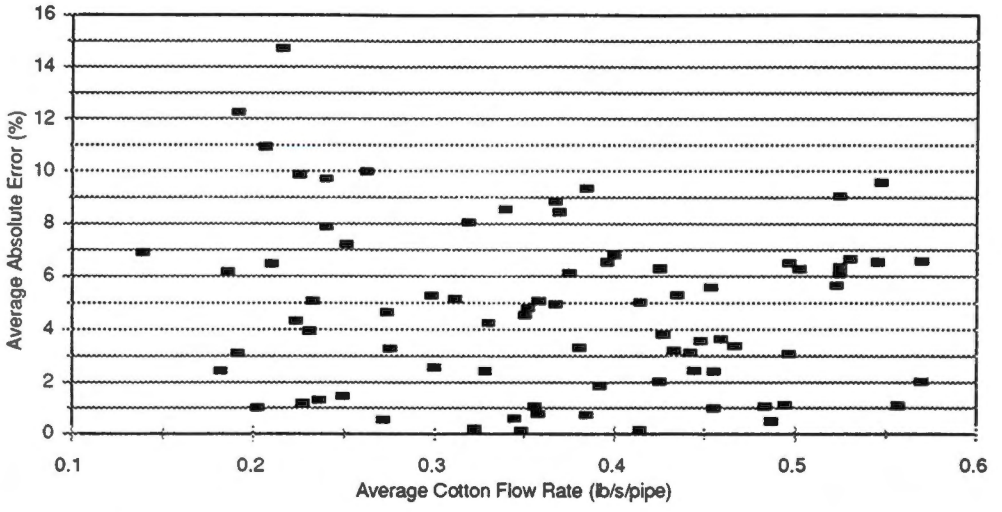


Figure 23. Average absolute error at each flow rate experienced during the Fall, 1997 field test.

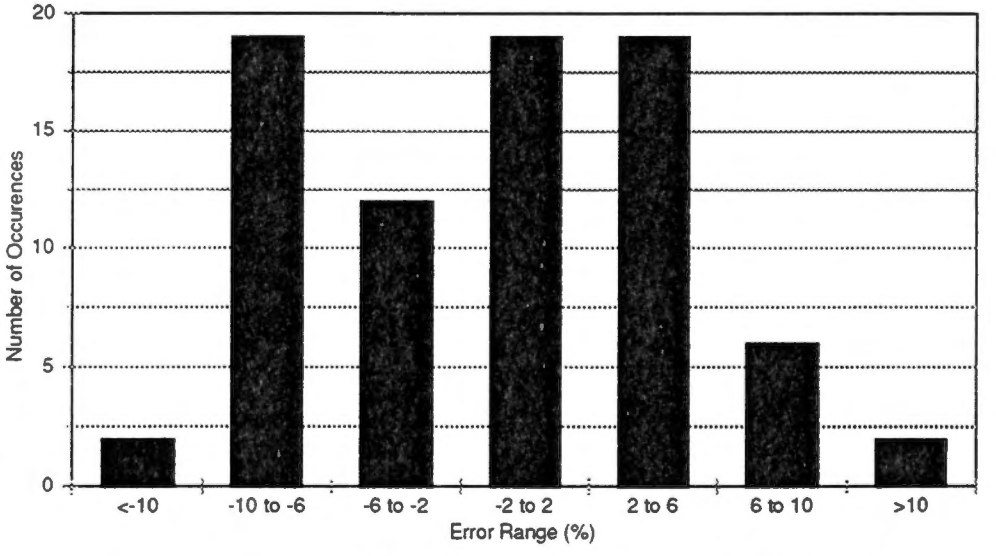


Figure 24. Distribution of errors from the Fall, 1997 field test.

within +/- 10 percent of the true value. The distribution included an unexpectedly large number of values between -6 and -10 percent. This suggests some refinements are needed to tighten the distribution around the -2 to 2 percent range. The average absolute error was 4.7 percent.

Error measurements were all based on total load weights. No consideration was given to dynamic system performance or accuracy of real-time flow rate measurement. A qualitative indication that the system performed well is given in Figure 25. This graph represents the weight of cotton in the picker basket increasing during harvest of a load. The top curve represents the cotton weight measured by the on-board weighing device. The bottom curve represents the cotton weight predicted by the sensing system. To separate the two curves for illustration purposes, the bottom curve is offset by -25 lb. The curves are parallel, indicating that the system properly responded to changes in flow rate during harvest.

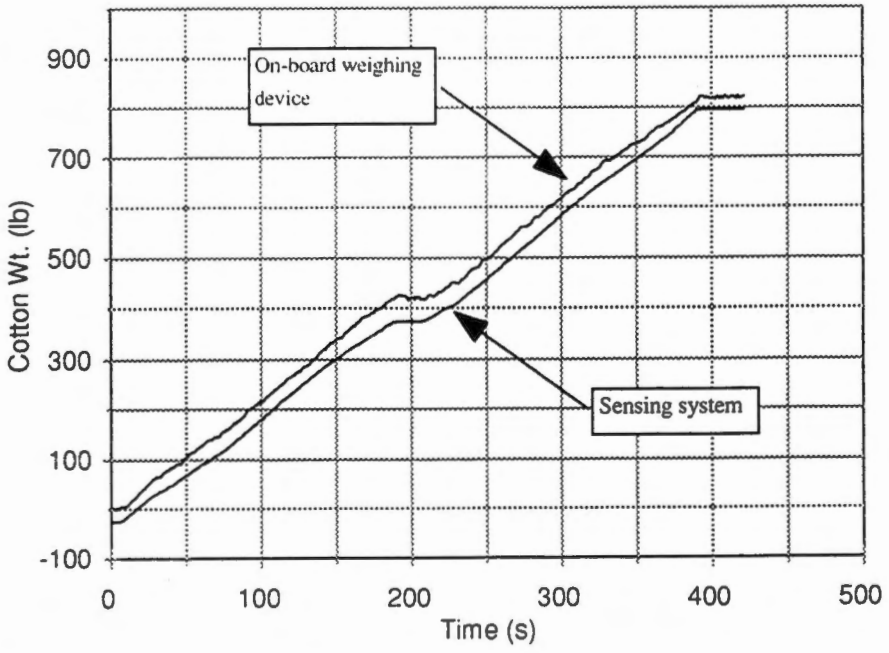


Figure 25. Cumulative load weight as measured by the on-board weighing device (upper curve) and the sensing system (lower curve). Note that the lower curve has been offset by -25 lb for clarity.

Chapter 5--Conclusions and Recommendations

Conclusions

A system has been designed for sensing the flow rate of pneumatically conveyed cotton in a duct. The system was prototyped, and after preliminary laboratory testing, was installed on a Case IH 2155 four row cotton picker. The unit was field tested during the 1997 harvest season. Field test results indicate that the system is capable of measuring cotton flow rate with some degree of accuracy. Seventy-five of 79 loads harvested were measured with a maximum error of +/-10 percent of the total load weights. The average absolute error for the 79 loads was 4.7 percent of the total load weights. Measurement accuracy was independent of flow rate over the range tested (up to 0.57 lb/s/pipe). The system performed similarly throughout the harvest season, indicating little if any effect on accuracy from changing crop conditions.

Recommendations

System Refinements

Late in the 1997 harvest season, the test crew determined that signal noise was being introduced to the system, probably from some of the longer data cables that connect sensing units to the digital data acquisition unit. This noise may have been responsible for a portion of the measurement error generated during the 1997 field test. Re-design of the cabling and data transmission hardware is the most important refinement that needs to be made.

Additional Testing

Future testing should to be broadened to include detailed investigation of several factors. Careful measurement of cotton moisture levels would provide a better opportunity to determine how cotton moisture content affects system performance. The system also needs to be tested over a larger range of flow rates. The highest flow rates experienced in 1997 were around 0.57 lb/s/pipe. Cotton planted on 40-in. row centers, and yielding 4 ba/a will produce flow rates as high as 1.75 lb/s/pipe. Additional testing is needed to determine whether the system will give adequate results when measuring flow rates of this magnitude.

References

Bae, Y.H., S.C. Borgelt, S.W. Searcy, J.K. Schueller, and B.A. Stout. 1987. Determination of spatially variable yield maps. ASAE Paper No. 87-1533. St. Joseph, MI: ASAE.

Borgelt, S.C. and K.A. Sudduth. 1992. Grain flow monitoring for in-field yield mapping.ASAE Paper No. 92-1022. St. Joseph, MI: ASAE.

DeBaerdemaeker, J.R., R. Delcroix, and P. Lindemans. 1985. Monitoring the grain flow on combines. ASAE Pub. No. 01-85. Presented at Agrimation Conference and Exposition. St. Joseph, MI: ASAE.

Friend, K.D. 1987. Article or seed counter. Patent No. 4,635,215. Washington: United States Patent and Trademark Office.

Howard, K.D., J.L. Pringle, M.D. Schrock, D.K. Kuhlman, and D. Oard. 1993. An elevator-based combine grain flow sensor. ASAE Paper No. 93-1504. St. Joseph, MI: ASAE.

Kepple, Daney D. 1988. Unlocking mysteries of cotton yield variations. *Agrichemical Age* 32(9), pp. 24A-24B.

Laws, Forrest. 1997. Yield monitor helps gauge profitability. In *Southeast Farm Press*, December 3, 1997, pp. 26-27.

Mangold, Grant. 1998. Insight--yield monitor countdown. *Successful Farming* 96(1), pp. 10.

Moriasi, Daniel. 1997. Graduate Student, Louisiana State University Department of Biological and Agricultural Engineering. Personal communication.

Ovsborn, Jesse H. and Robert W. Hahn. 1990. Cotton flow monitoring system for a cotton harvester. Patent No. 4,961,304. Washington: United States Patent and Trademark Office.

Palmer, M.S. 1997. The design and implementation of a field-scale monitoring system to evaluate spatial variability within production cotton fields. Unpublished M.S. thesis. The University of Tennessee.

Pang, S.N. and G.C. Zoerb. 1990. A grain flow sensor for yield mapping. ASAE Paper No. 90-1633. St. Joseph, MI: ASAE.

Paolini, F., M. Paraluppi, and L. Vinci. 1997. Flow detector. Patent No. 5,621,392. Washington: United States Patent and Trademark Office.

Pfeiffer, D.W., J.W. Hummel, and N. Miller. 1993. Real time corn yield sensor. ASAE Paper No. 93-1013. St. Joseph, MI: ASAE.

Pringle, J.L., M.D. Schrock, R.T. Hinnen, K.D. Howard, and D.L. Oard. 1993. Yield variation in grain crops. ASAE Paper No. 93-1505. St. Joseph, MI: ASAE.

Sadjadi, F.A. 1996. Smart crop yield monitor. Patent No. 5,480,354. Washington: United States Patent and Trademark Office.

Searcy, S.W., D.S. Motz, A. Inayatullah, and K.J. Goering. 1997a. Cotton yield mapping. In *Proc. 1997 Beltwide Cotton Conferences,* pp. 601-602.

Searcy, S.W., D.S. Motz, and A. Inayatullah. 1997b. Evaluation of a cotton yield mapping system. ASAE Paper No. 97-1058. St. Joseph, MI: ASAE.

Sray, Al. 1997. Yield ahead. In *Farm Chemicals*. 160(5), pp. 64, 68-69.

Stafford, J.V., B. Ambler, and M.P. Smith. 1991. Sensing and mapping grain yield variation. In *Automated Agriculture for the 21st Century*, pp. 356-365. St. Joseph, MI.: ASAE.

Steffens, D.E. and V.D. Goeckner. 1981. Corn and soybean sensor. Patent No. 4,307,390. Washington: United States Patent and Trademark Office.

Steffens, R.W. 1978. Monitor system for agricultural harvesting machines. Patent No. 4,068,223. Washington: United States Patent and Trademark Office.

Strubbs, G., B. Missotten, and J. DeBaerdemaeker. 1996. Performance evaluation of a three-dimensional optical volume flow meter. In *Applied Engineering in Agriculture* 12(4), pp. 403-409.

Thomasson, J.A., S.J. Thomson, R.K. Byler, D.A. Pennington, H.C. Pringle, and E.P. Columbus. 1997. Mass flow measurement of pneumatically conveyed cotton. In *Proc. 1997 Beltwide Cotton Conferences*, pp. 1558-1563.
USDA. 1960. Agricultural Statistics--1960.

USDA. 1996. Agricultural Statistics--1995-96.

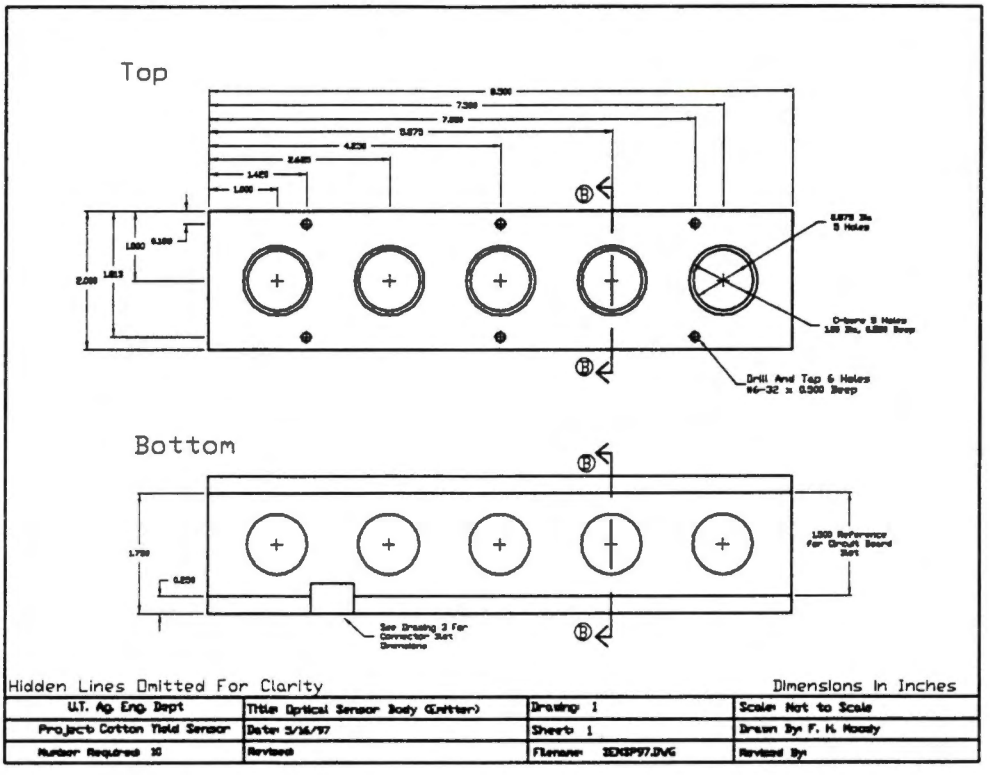
Vanden Heuvel, R.M. 1996. The promise of precision agriculture. In *Journal of Soil and Water Conservation.* 51(1), pp. 38-40.

Wilkerson, J.B., J.S. Kirby, W.E. Hart, and A.R. Womac. 1994. Real-time cotton flow sensor. ASAE Paper No. 94-1054. St. Joseph, MI: ASAE.

Appendices

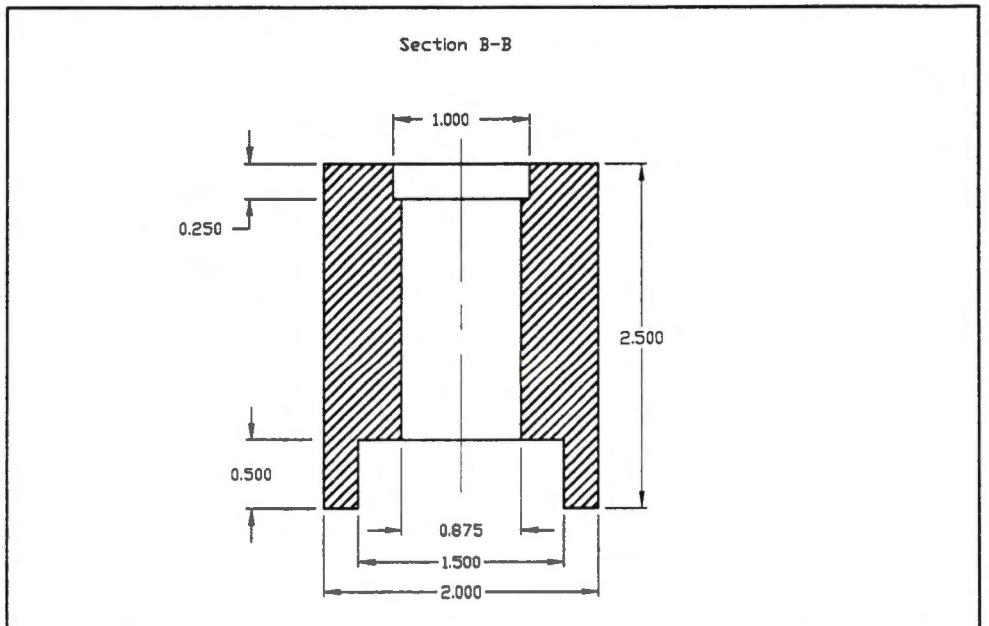
Appendix A
Mechanical Drawings

Emitter housing mechanical drawings.



Hidden Lines Omitted For Clarity — Dimensions In Inches

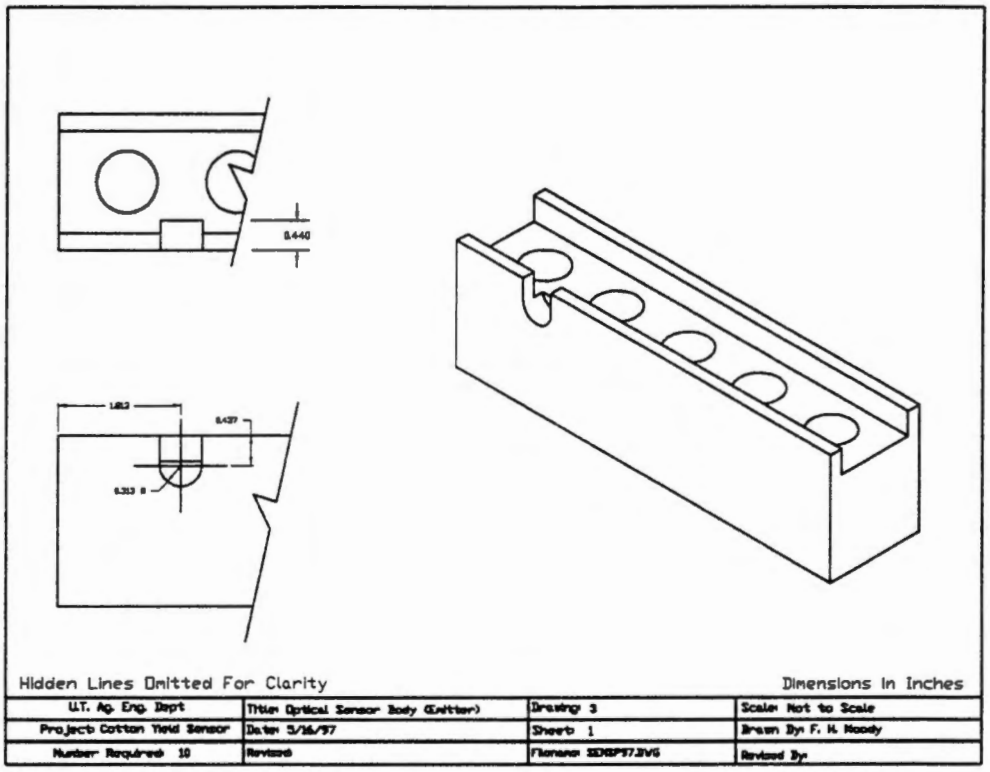
U.T. Ag. Eng. Dept	Title Optical Sensor Body (Emitter)	Drawing 1	Scale Not to Scale
Project: Cotton Yield Sensor	Date: 5/16/97	Sheet: 1	Drawn By: F. H. Moody
Number Required: 10	Revised:	Filename: 3EMSP97.DWG	Revised By:



Hidden Lines Omitted For Clarity — Dimensions In Inches

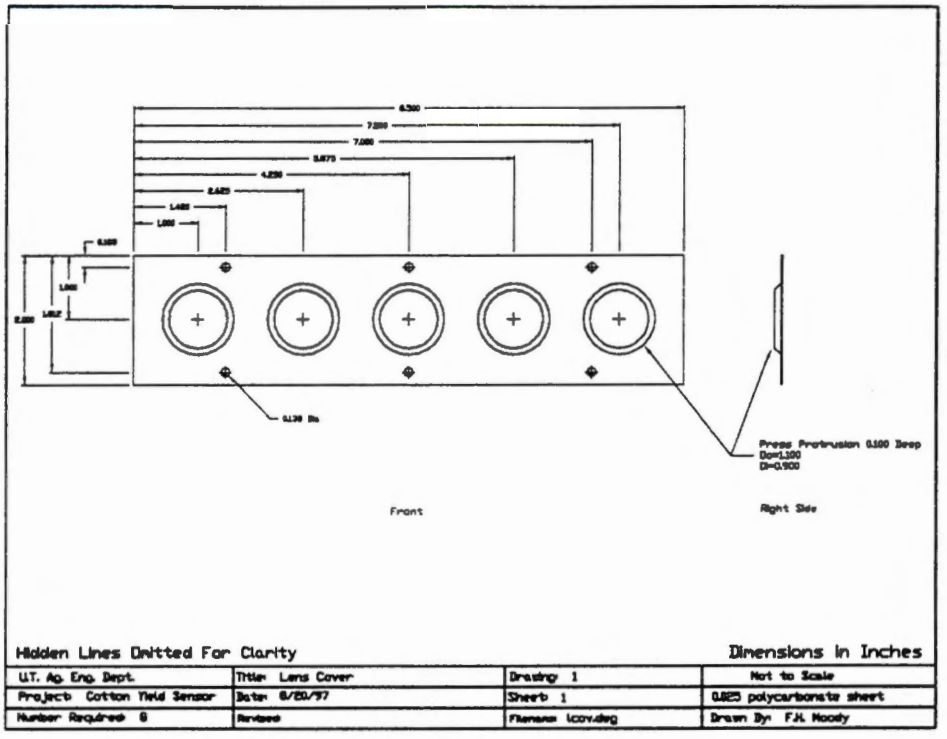
U.T. Ag. Eng. Dept	Title: Optical Sensor Body (Emitter)	Drawing: 2	Scale: Not to Scale
Project: Cotton Yield Sensor	Date: 5/16/97	Sheet: 1	Drawn By: F. H. Moody
Number Required: 10	Revised:	File: 3EMSP97.DWG	Revised By:

Emitter housing mechanical drawings (continued).

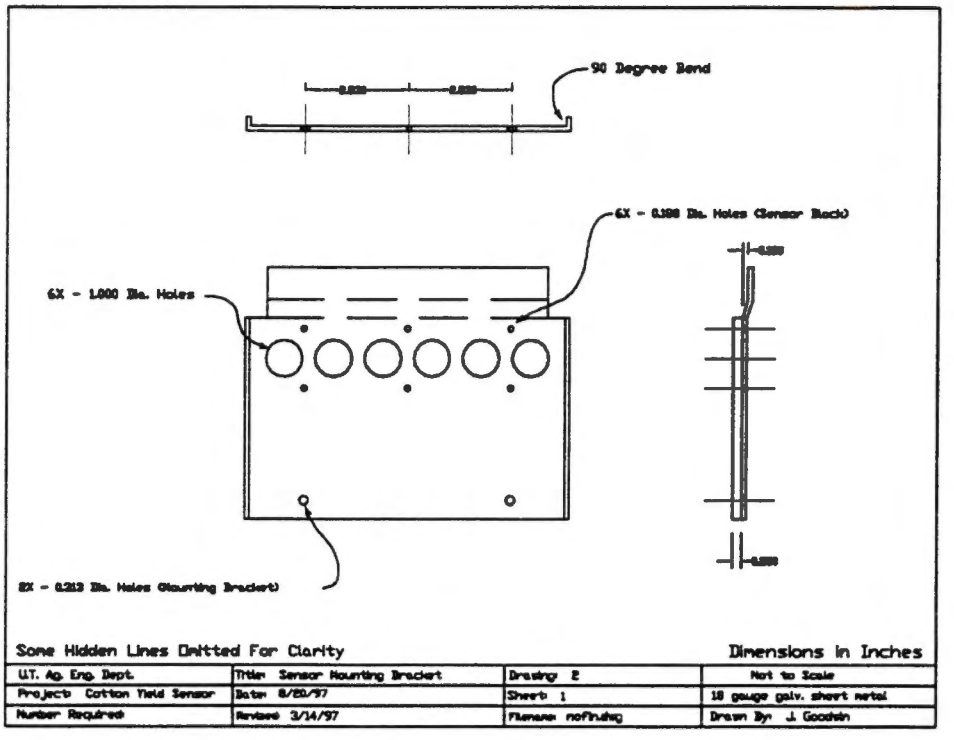


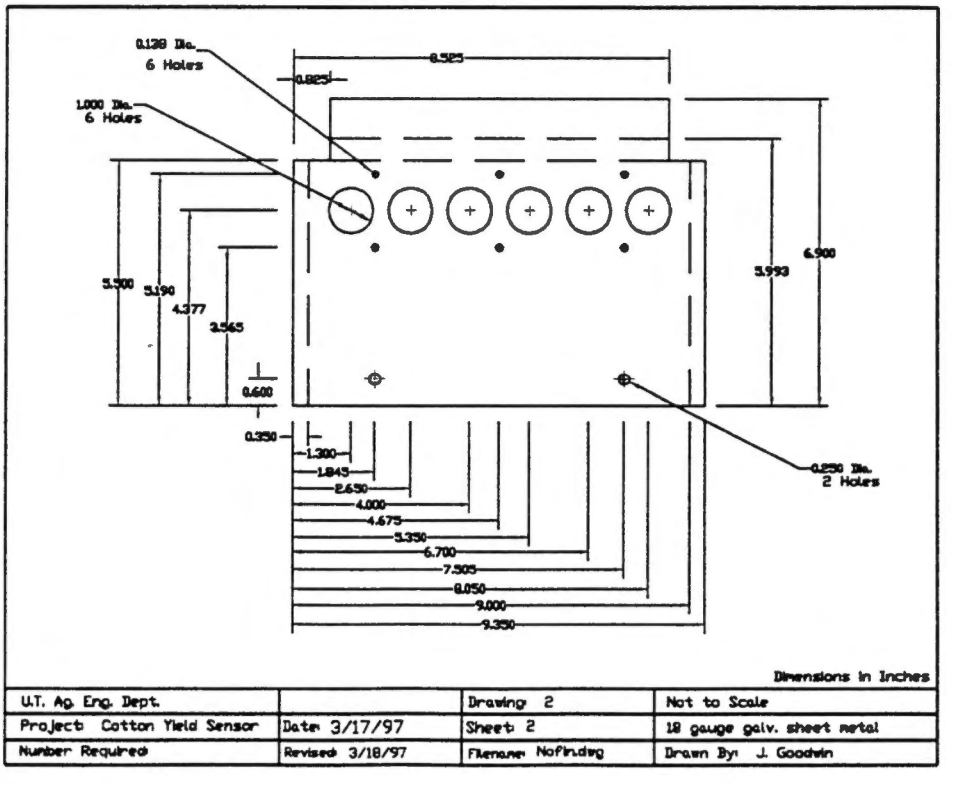
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Number Required: 10	Revised:	Filename: EMSP97.DWG	Revised By:

Lens cover mechanical drawings.

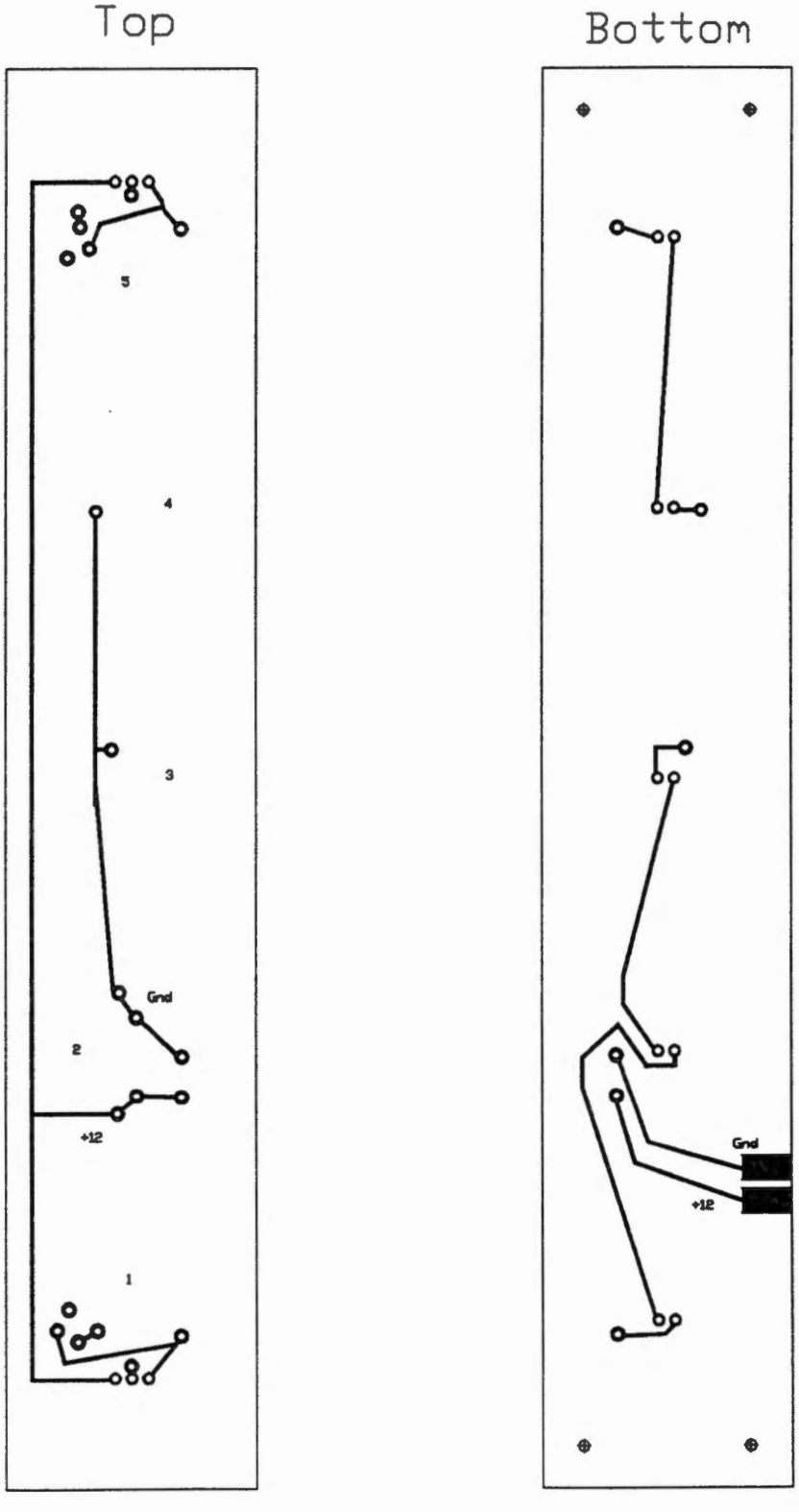


Mounting plate mechanical drawings.

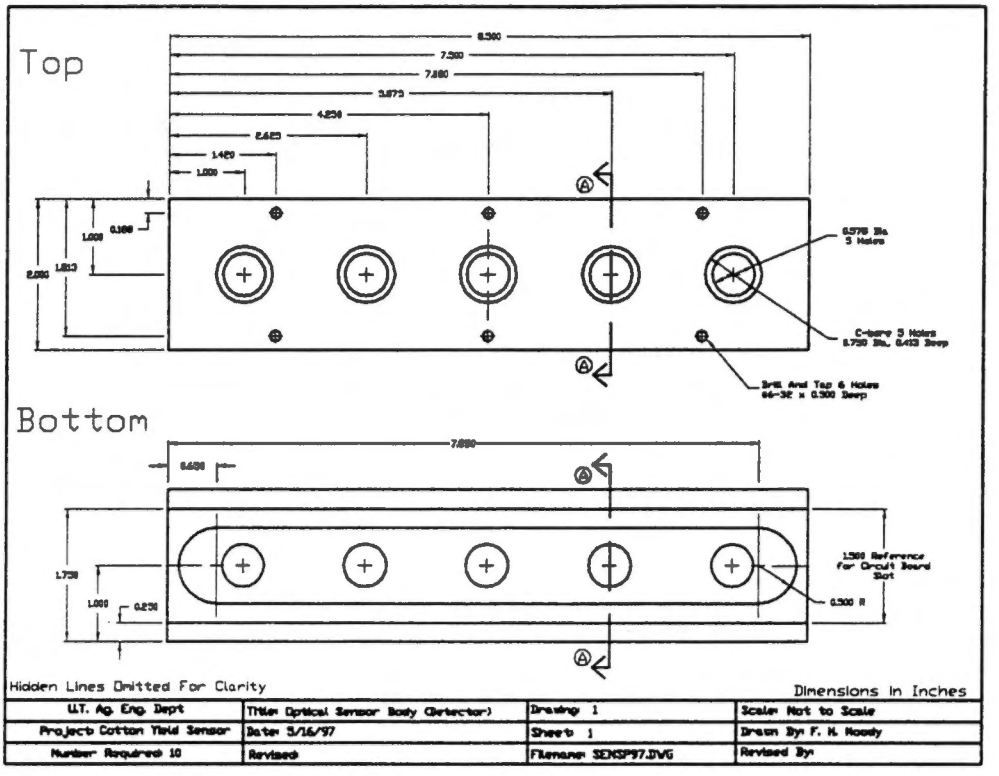


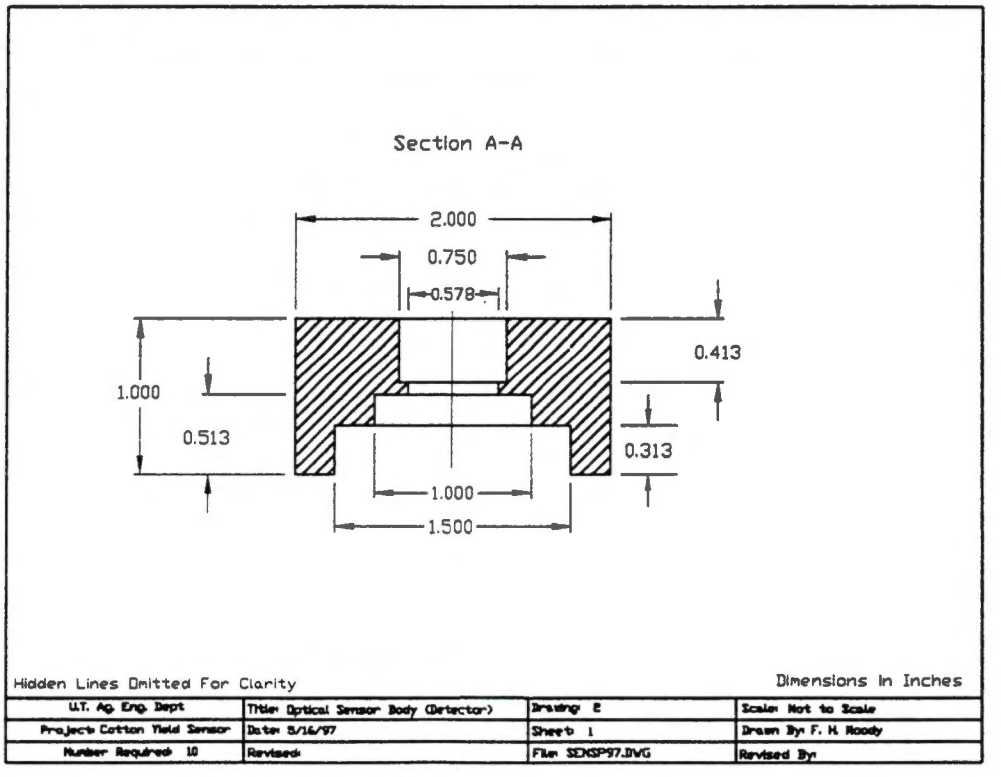


Emitter printed circuit board layout.

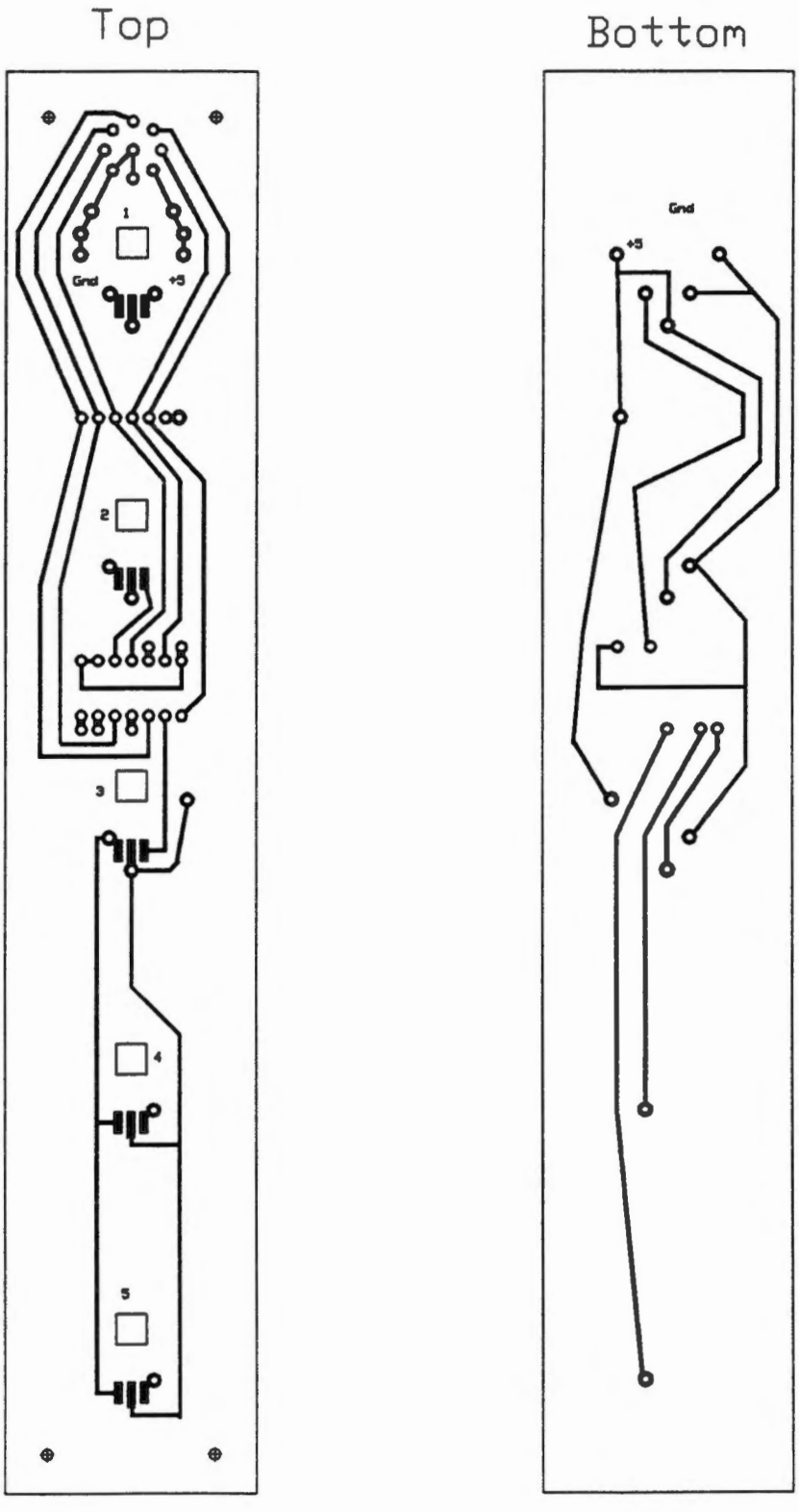


Detector housing mechanical drawings.





Detector printed circuit board layout.



Appendix B
Electronic Device Specifications

Specifications for the BIR-BL734 infra-red LED.

INFRARED EMITTING DIODES

■ MODEL: BIR-Bxxx1 , BIR-Bxxx4 , BIR-Bxxx4-1 , BIR-Fxxx1 , BIR-Nxxx1 .

■ APPLICATIONS

- Remote Control - Photo Detector - Smoke Detector - Automatic Control System

■ ABSOLUTE MAXIMUM RATINGS (Ta=25℃)

- Peak Forward Current (Pluse Width = 10us.1% Duty Cycle)
- Operating Temperature Range (-45℃ to +100℃)
- Storage Temperature Range (-45℃ to +100℃)
- Lead Soldering Temperature (1/16 inch from case 5sec @250℃)

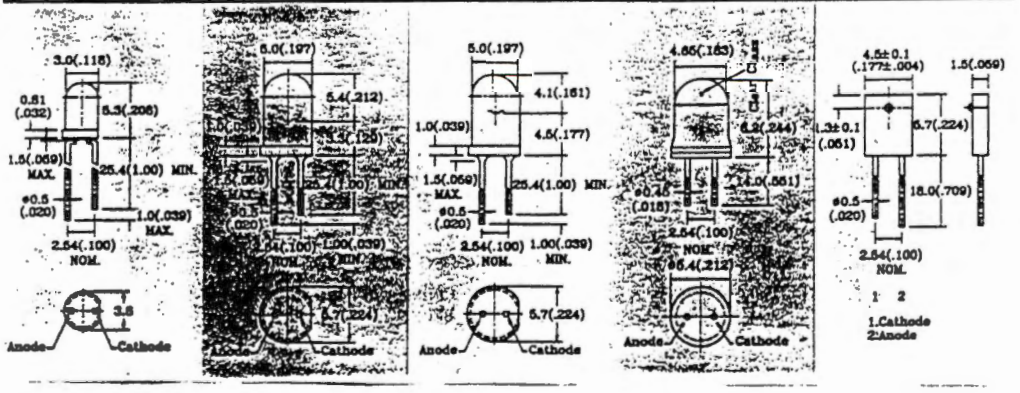
AMERICAN BRIGHT OPTOELECTRONICS CORP.
460 W. LAMBERT RD., SUITE H
BREA, CALIFORNIA 92821
(714) 257-0800 / FAX (714) 257-1310

■ ELECTRICAL AND RADIANT CHARACTERISTICS (Ta=25℃)

Package	Part No.	Chip Material	Chip Peak Wave Length λ P(nm)	Lens Appearance	Absolute Maximum Ratings △λ (nm)	Pd (mW)	Continous If(mA)	Peak If(A)	Vr (V)	Electro-optical Data(At 100mA) Vf(V) Typ.	Vf(V) Max.	Ir (uA)	Radiant Power Min.	Radiant Power Typ.	Ifp=20mA PW=10uS DC=10% Tr (ns)	Tf (ns)	Viewing Angle 2θ 1/2 (deg)	Drawing No.
T-1 Standard L0" Lead 3φ	BIR-BL731	GaAs	940	Blue Trans	50	150	50	L0	5	L4	2.0	100	5	10	500	200	18	IR-01
	BIR-BM731	GaAlAs	940	Blue Trans	50	150	50	L0	5	L5	2.0	100	7	12	500	200	18	
	BIR-BN731	GaAlAs	880	Blue Trans	50	150	50	L0	5	L7	2.0	100	10	15	500	200	18	
	BIR-BO731	GaAlAs	840	Blue Trans	50	150	50	L0	5	L7	2.0	100	12	20	500	200	18	
T-1 3/4 Standard L0" Lead 5φ	BIR-BL734	GaAs	940	Blue Trans	50	150	50	L0	5	L4	2.0	100	7	12	500	200	20	IR-02
	BIR-BM734	GaAlAs	940	Blue Trans	50	150	50	L0	5	L5	2.0	100	9	14	500	200	20	
	BIR-BN734	GaAlAs	880	Blue Trans	50	150	50	L0	5	L7	2.0	100	12	17	500	200	20	
	BIR-BO734	GaAlAs	840	Blue Trans	50	150	50	L0	5	L7	2.0	100	14	25	500	200	20	
T-1 3/4 5φ	BIR-BL734-1	GaAs	940	Blue Trans	50	150	50	L0	5	L4	2.0	100	6	12	500	200	40	IR-03
	BIR-BN734-1	GaAlAs	880	Blue Trans	50	150	50	L0	5	L7	2.0	100	12	20	500	200	40	
TO-18 5.4φ	BIR-FL3E1	GaAs	940	Water Clear	50	150	50	L0	5	L4	2.0	100	8	10	500	200	10	IR-04
	BIR-FN7E1	GaAlAs	880	Blue Trans	50	150	50	L0	5	L7	2.0	100	8	10	500	200	10	
Side Viewing	BIR-NL3C1	GaAs	940	Water Clear	50	150	50	L0	5	L4	2.0	100	6	9	500	200	40	IR-05
	BIR-NL7C1	GaAs	940	Blue Trans	50	150	50	L0	5	L4	2.0	100	6	9	500	200	40	
	BIR-NL3C1-Y	GaAs	940	Yellow Trans	50	150	50	L0	5	L4	2.0	100	6	9	500	200	40	

Remark: - Trans = Transparent
- Radiant Power Unit : (mw/cm^2)

IR-01 BIR-Bx731 IR-02 BIR-Bx734 IR-03 BIR-Bx734-1 IR-04 BIR-FLxE1 IR-05 BIR-NLxC1



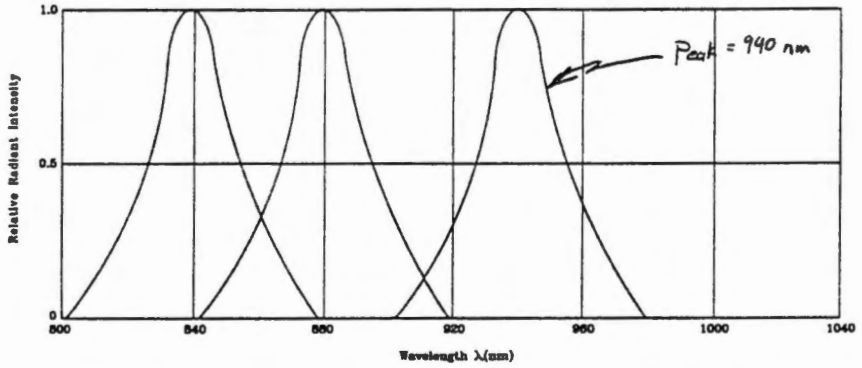
Specifications for the BIR-BL734 infra-red LED (continued).

INFRARED EMITTING DIODES

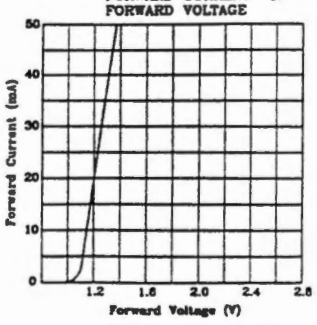
TYPICAL CHARACTERISTICS
(INFRARED EMITTING DIODES SERIES)

AMERICAN BRIGHT OPTOELECTRONICS CORP.
460 W. LAMBERT RD., SUITE H
BREA, CALIFORNIA 92821
(714) 257-0800 / FAX (714) 257-1310

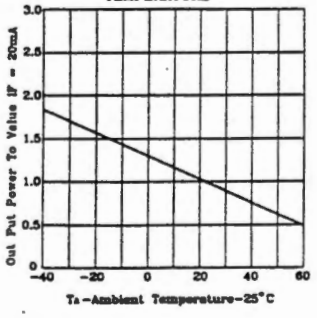
SPECTRAL DISTRIBUTION



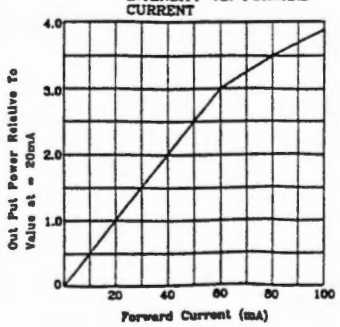
FORWARD CURRENT VS. FORWARD VOLTAGE



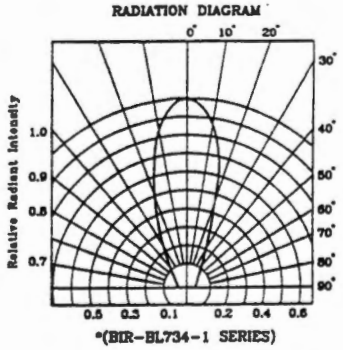
RELATIVE RADIANT INTENSITY VS. AMBIENT TEMPERATURE



RELATIVE RADIANT INTENSITY VS. FORWARD CURRENT



RADIATION DIAGRAM



*(BIR-BL734-1 SERIES)

Specifications for the TSL245 photo-detector.

TSL245
INFRARED LIGHT-TO-FREQUENCY CONVERTER

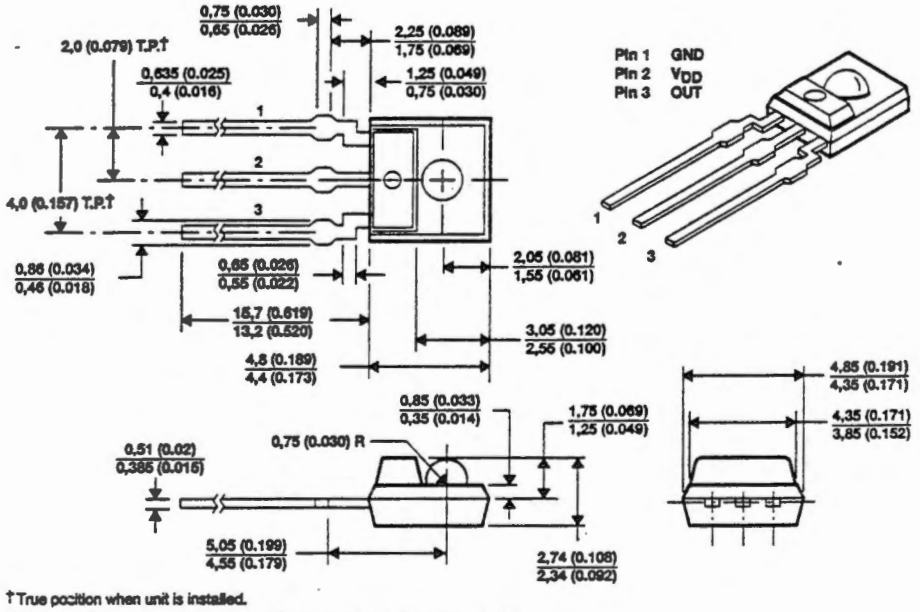
SOES018 – MAY 1995

- **High-Resolution Conversion of Light Intensity to Frequency With No External Components**
- **Direct Interface With a Microcontroller**
- **Compact Three-Leaded Plastic Package**
- **Single-Supply Operation Down to 2.7 V**
- **Nonlinearity Error Typically 0.2% at 100 kHz**
- **Advanced LinCMOS™ Technology**
- **Integral Visible-Light Cutoff Filter**

description

The TSL245 infrared light-to-frequency converter combines a silicon photodiode and a current-to-frequency converter on a single monolithic CMOS integrated circuit. The output is a square wave (50% duty cycle) with frequency directly proportional to light intensity. Because the output is TTL compatible, it allows direct interface to a microcontroller or other logic circuitry. The device responds over the infrared light range of 800 nm to 1100 nm. The TSL245 is characterized for operation over the temperature range of –25°C to 70°C.

The TSL245 is offered in a black, infrared-transmissive package (see Figure 1). The photodiode area is 1.36 mm^2 (0.0029 in^2).



† True position when unit is installed.

NOTE A: All linear dimensions are in millimeters and parenthetically in inches.

Figure 1. TSL245 Packaging Configuration

Advanced LinCMOS is a trademark of Texas Instruments Incorporated.

PRODUCTION DATA information is current as of publication date. Products conform to specifications per the terms of Texas Instruments standard warranty. Production processing does not necessarily include testing of all parameters.

Specifications for the TSL245 photo-detector (continued).

TSL245
INFRARED LIGHT-TO-FREQUENCY CONVERTER

SOES018 – MAY 1995

functional block diagram



absolute maximum ratings over operating free-air temperature range (unless otherwise noted)†

Supply voltage, V_{DD} (see Note 1) ..... 6.5 V
Operating free-air temperature range, T_A ..... −25°C to 70°C
Storage temperature range, T_{stg} ..... −25°C to 85°C
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds ..... 260°C

† Stresses beyond those listed under "absolute maximum ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under "recommended operating conditions" is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

NOTE 1: All voltage values are with respect to GND.

recommended operating conditions

	MIN	NOM	MAX	UNIT
Supply voltage, V_{DD}	2.7	5	6	V
Operating free-air temperature range, T_A	−25		70	°C

electrical characteristics at V_{DD} = 5 V, T_A = 25°C (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
V_{OH}	High-level output voltage	I_{OH} = −4 mA	4	4.3		V
V_{OL}	Low-level output voltage	I_{OL} = 4 mA		0.17	0.26	V
I_{DD}	Supply current			2	3	mA
	Full-scale frequency‡		500			kHz
k_{SVS}	Supply-voltage sensitivity	V_{DD} = 5 V ±10%		0.5		%/V

‡ Full-scale frequency is the maximum operating frequency of the device without saturation.

operating characteristics at V_{DD} = 5 V, T_A = 25°C

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
f_O	Output frequency	E_e = 920 μW/cm², λ_p = 940 nm	200	250	300	kHz
		E_e = 0		0.25	10	Hz
	Nonlinearity§	f_O = 0 kHz to 10 kHz		±0.1%		%F.S.
		f_O = 0 kHz to 100 kHz		±0.2%		%F.S.
	Step response to full-scale step input			1 pulse of new frequency plus 1 μs		

‡ Full-scale frequency is the maximum operating frequency of the device without saturation.

§ Nonlinearity is defined as the deviation of f_O from a straight line between zero and full scale, expressed as a percent of full scale.

Specifications for the TSL245 photo-detector (continued).

TYPICAL CHARACTERISTICS

OUTPUT FREQUENCY
vs
IRRADIANCE

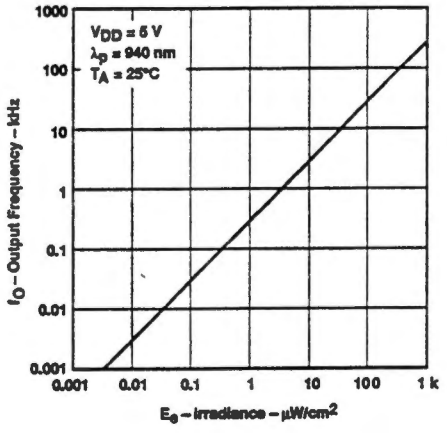


Figure 2

PHOTODIODE SPECTRAL RESPONSIVITY

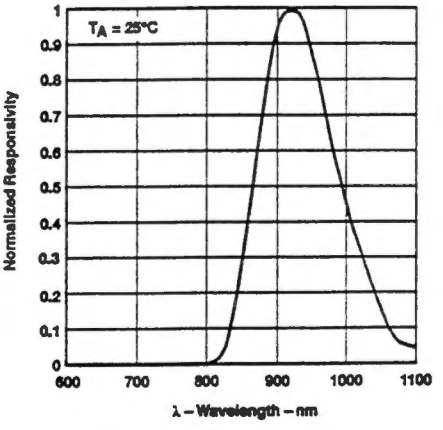


Figure 3

DARK FREQUENCY
vs
TEMPERATURE

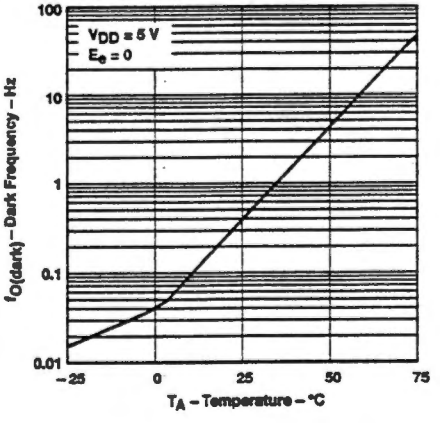


Figure 4

TEMPERATURE COEFFICIENT
OF OUTPUT FREQUENCY
vs
WAVELENGTH OF INCIDENT LIGHT

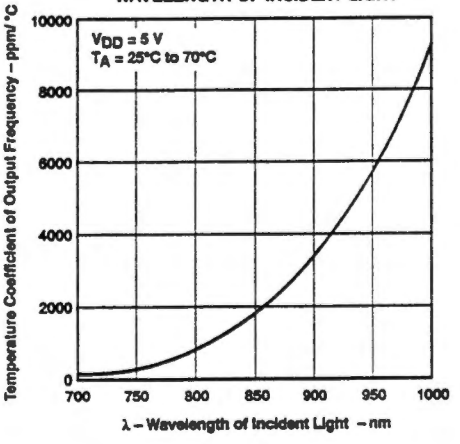


Figure 5

Specifications for the TSL245 photo-detector (continued).

TYPICAL CHARACTERISTICS

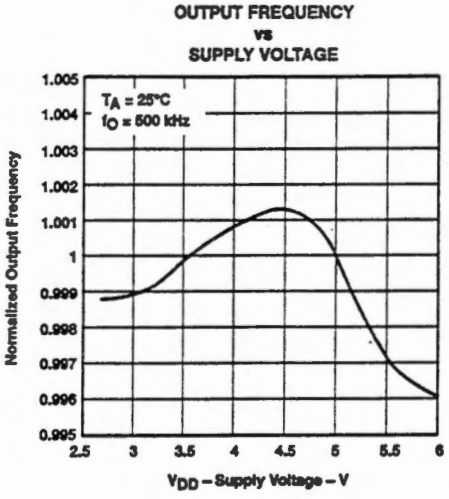


Figure 6

APPLICATION INFORMATION

power-supply considerations

For optimum device performance, power-supply lines should be decoupled by a 0.01-μF to 0.1-μF capacitor with short leads (see Figure 7).

output interface

The output of the device is designed to drive a standard TTL or CMOS logic input over short distances. If lines greater than 12 inches are used on the output, a buffer or line driver is recommended.

measuring the frequency

The choice of interface and measurement techniques depends on the desired resolution and data-acquisition rate. For maximum data-acquisition rate, period-measurement techniques should be used.

Period measurement requires using a fast reference clock with available resolution directly related to reference clock rate. The technique measures rapidly varying light levels or provides a fast measurement of a constant light source.

Maximum resolution and accuracy can be obtained using frequency-measurement, pulse-accumulation, or integration techniques. Frequency measurements provide the added benefit of averaging random- or high-frequency variations (jitter) resulting from noise in the light signal. Resolution is limited primarily by available counter registers and allowable measurement time. Frequency measurement is well suited for slowly varying or constant light levels and for reading average light levels over short periods of time. Integration, the accumulation of pulses over a very long period of time, can be used to measure exposure – the amount of light present in an area over a given time period.

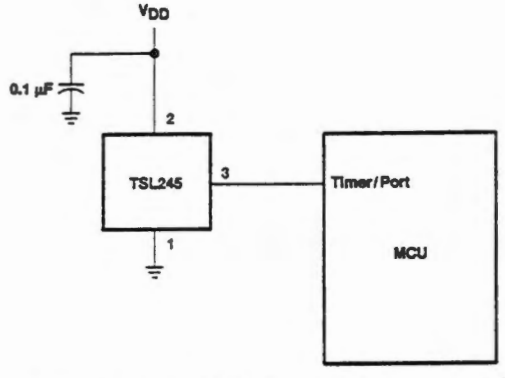


Figure 7. Typical TSL245 Interface to a Microcontroller

Appendix C
System Software Code

QuickBASIC code for *flowsen1.bas*.

```
REM*****Read in the channels in use from*****
REM*****a data file on the PCMCIA card*****
DIM LEP%(1 TO 40)
DIM REP%(1 TO 40)
OPEN "f:\choice\chan.txt" FOR INPUT AS #1
INPUT #1, noc%
INPUT #1, nor%
FOR i% = 1 TO nor%
 INPUT #1, LEP%(i%)
 INPUT #1, REP%(i%)
NEXT i%
CLOSE #1
REM*****Read in the data logging choice*****
REM*****from a file on the PCMCIA card*****
OPEN "f:\choice\choice.txt" FOR INPUT AS #1
INPUT #1, Choice%
CLOSE #1
REM*****Initialize all variables*****
CRLF$ = CHR$(13) + CHR$(10)   'Character Return and Line Feed
comma$ = CHR$(44)             'Comma
SYN$ = CHR$(64) + CHR$(64)    'Syncronization string
NUMCNTS% = 40                 'Total number of counter channels on boards
NUMCHAN% = 38                 'Max No. of Channels used by flow sensors
NUMBRDS% = 3                  'Number of Counter Boards Minus 1 for Board 0
flag% = 1                     'Flag used during first three cycles
BoardNum = 0                  'First counter board number is zero
maxloop% = 5                  'Number of loops per cycle is five
LoadValue% = 0                'Will load zeros to clear the counters
LOOPCNT% = 1                  'Beginning the first loop
cardf% = 0
REM*****Initialize all arrays******
DIM Buff&(1 TO NUMCNTS%)      'Buffer for counter data
DIM Sum(1 TO NUMCHAN%)        'Normalized sum (output)
DIM Sumin%(1 TO NUMCHAN%)     'Normalized sum *100 and converted to an
integer
DIM basel(1 TO NUMCHAN%)      'Baseline
DIM Tot(1 TO NUMCHAN%)        'Total (sum) for averaging
DIM Var%(1 TO NUMCHAN%)       'Difference between largest and smallest
DIM Avg(1 TO NUMCHAN%)        'Average
DIM lar(1 TO NUMCHAN%)        'Largest number in sequence
```

QuickBASIC code for *flowsen1.bas* (continued).

```
DIM sma(1 TO NUMCHAN%)        'Smallest number in sequence
REM*****Initialize Counters*****
  UDStat% = cbErrHandling%(PRINTALL, STOPALL)
  FOutDivider% = 0
  FOutSource% = FREQ4
  Compare1% = DISABLED
  Compare2% = DISABLED
  TimeOfDay% = DISABLED

 FOR BoardNum = 0 TO NUMBRDS%
 FOR ChipNum% = 1 TO 2

  UDStat% = cbC9513Init%(BoardNum, ChipNum%, FOutDivider%, FOutSource%,
Compare1%, Compare2%, TimeOfDay%)

 NEXT ChipNum%
 NEXT BoardNum

  GateControl% = NOGATE
  CounterEdge% = POSITIVEEDGE
  SpecialGate% = DISABLED
  Reload% = LOADREG
  RecycleMode% = RECYCLE
  BCDMode% = DISABLED
  CountDirection% = COUNTUP
  OutputControl% = ALWAYSLOW

 FOR BoardNum = 0 TO NUMBRDS%
  FOR CounterNum% = 1 TO 10
      IF CounterNum% > 5 THEN
      CountSource% = CounterNum% - 5
      ELSE
      CountSource% = CounterNum%
      END IF
      UDStat% = cbC9513Config%(BoardNum, CounterNum%, GateControl%,
CounterEdge%, CountSource%, SpecialGate%, Reload%, RecycleMode%, BCDMode%,
CountDirection%, OutputControl%)
  NEXT CounterNum%
 NEXT BoardNum
REM*****Initialize the input buffer as a zero matrix*****
FOR i% = 1 TO NUMCNTS%
```

QuickBASIC code for *flowsen1.bas* (continued).

```
 Buff&(i%) = 0
NEXT I%
REM*****Initialize the baseline at 6000*****
FOR i% = 1 TO NUMCHAN%
 basel(i%) = 6000
NEXT i%
OPEN "COM1:19200,N,8,1,CS,DS" FOR OUTPUT AS #2 LEN = 300
OPEN "f:\cotton.dat" FOR APPEND AS #3
ON ERROR GOTO 1000
REM*****Initialize timer mark*****
57 mark% = 16
DO UNTIL mark% = 0
 mark% = INP(&H379) AND 16
LOOP
DO UNTIL mark% = 16
 mark% = INP(&H379) AND 16
LOOP
DO
REM*****Clear Counters********

FOR BoardNum = 0 TO NUMBRDS%
FOR RegName% = 1 TO 10
  UDStat% = cbCLoad%(BoardNum, RegName%, LoadValue%)
NEXT RegName%
NEXT BoardNum
REM*****On the first and second passes*****
REM*****initialize lar and 2lar*****
IF LOOPCNT% = 1 and INCF%=1 THEN
 FOR i% = 1 TO NUMCHAN%
  lar(i%) = Buff&(i%)
 NEXT I%
 ELSEIF LOOPCNT%=2 ant INCF%=1 THEN
 FOR I%=1 to NUMCHAN%
 IF Buff&(i%)>lar(i%) THEN
 2lar(i%)=lar(i%)
 lar(i%)=Buff&(i%)
ELSE
 2lar(i%)=Buff&(i%)
END IF
NEXT I%
END IF
```

QuickBASIC code for *flowsen1.bas* (continued).

```
END IF
REM*****Do the preliminary arithmetic on the numbers*****
REM*****contained in the buffer*****
REM*****This step includes: Comparing the value against*****
REM*****the largest value, Data normalization,*****
REM*****and Addition of normalized data to the output sum*****
 speeda& = speeda& + Buff&(39)    'totalize output from speed sensors
 speedb& = speedb& + Buff&(40)
 FOR i% = 1 TO NUMCHAN%
 IF Buff&(i%)>lar(i%) THEN
 2lar(i%)=lar(i%)
 lar(i%)=Buff(i%)
END IF
  IF (Buff&(i%) < (basel(i%) - 50)) AND (basel(i%) <> 0) THEN
   Sum(i%) = Sum(i%) + (basel(i%) - Buff&(i%)) / basel(i%)
  END IF
 NEXT i%
REM*****Decide whether to log raw data anywhere*****
 IF (Choice% <= 2) AND (flag% >= 3) THEN
  Out$ = SYN$ + "B" + comma$ + LTRIM$(STR$(noc%))
  FOR i% = 1 TO nor%
   FOR j% = LEP%(i%) TO REP%(i%)
    Out$ = Out$ + comma$ + LTRIM$(STR$(Buff&(j%)))
   NEXT j%
  NEXT i%
  Out$ = Out$ + comma$ + LTRIM$(STR$(Buff&(39))) + comma$ +
LTRIM$(STR$(Buff&(40))) + CRLF$
  IF cardf% = 0 THEN
  PRINT #3, Out$
  END IF
  IF Choice% = 1 THEN
   PRINT #2, Out$
  END IF
 END IF
REM*****If you are on the last pass of the cycle,*****
REM*****execute the baseline reset*****
 IF LOOPCNT% = maxloop% AND INCF%=4 THEN
  FOR i% = 1 TO NUMCHAN%
   basel(i%)=2lar(i%)
  NEXT I%
 IF INCF%<4 THEN
```

QuickBASIC code for *flowsen1.bas* (continued).

```
 INCF%=INCF%+1
 ELSE
  INCF=1
 END IF
  LOOPCNT% = 0
  flag% = flag% + 1
REM*****Check the output option choice*****
REM*****and use that information to decide*****
REM*****whether to send data anywhere or not*****
  IF (Choice% >= 2) AND (flag% >= 3) THEN
   Out$ = SYN$ + "A" + comma$ + LTRIM$(STR$(noc%))
   FOR i% = 1 TO nor%
    FOR j% = LEP%(i%) TO REP%(i%)
     Sumin%(j%) = INT(100 * Sum(j%))
     Out$ = Out$ + comma$ + LTRIM$(STR$(Sumin%(j%)))
    NEXT j%
   NEXT i%
   Out$ = Out$ + comma$ + LTRIM$(STR$(speeda&)) + comma$ +
LTRIM$(STR$(speedb&)) + CRLF$
   PRINT #2, Out$
   PRINT #2, CRLF$
   IF (Choice% = 3) AND (cardf% = 0) THEN
    PRINT #3, Out$
   END IF
  END IF
REM*****Reset Sum() to zero*****
  FOR i% = 1 TO NUMCHAN%
   Sum(i%) = 0
  NEXT i%
  speeda& = 0
  speedb& = 0
 END IF
REM*****Increment the loop counter*****
 IF flag% >= 4 THEN flag% = 4
 LOOPCNT% = LOOPCNT% + 1
REM*****Check timer and decide when it is*****
REM*****time to continue*****
DO UNTIL mark% = 0
 mark% = INP(&H379) AND 16
LOOP
```

QuickBASIC code for *flowsen1.bas* (continued).

```
DO UNTIL mark% = 16
 mark% = INP(&H379) AND 16
LOOP
'Normally read counters here
h% = 1
FOR BoardNum = 0 TO NUMBRDS%
FOR CounterNum% = 1 TO 10
    UDStat% = cbCIn%(BoardNum, CounterNum%, Count%)
    Buff&(h%) = Count%
    IF (Buff&(h%) < 1) OR (Buff&(h%) > 65500) THEN
     Buff&(h%) = 0
    END IF
    h% = h% + 1
NEXT CounterNum%
NEXT BoardNum
REM*****End of Main Loop*************************
LOOP
CLOSE #2
CLOSE #3
END

1000 'Error Handling Routine
IF ERR = 61 THEN '61=Disk Full
 CLOSE #3
 cardf% = 1
 RESUME 57
END IF
IF ERR = 71 THEN '71=Disk Not Ready
 CLOSE #3
 cardf% = 1
 RESUME 57
END IF
```

QuickBASIC code for *flowsen2.bas*.

```
REM*****Initialize all variables*****
comma$ = CHR$(44)            'Comma
crlf$ = CHR$(13) + CHR$(10)   'Carriage Return, Line Feed
NUMCNTS% = 40                 'Total number of counter channels on boards
NUMBRDS% = 3                  'Number of Counter Boards Minus 1 for Board 0
BoardNum = 0                 'First counter board number is zero
LoadValue% = 0               'Will load zeros to clear the counters
REM*****Initialize all arrays******
DIM Buff&(1 TO NUMCNTS%)      'Buffer for counter data
REM*****Initialize counters with the cb routines*****

  UDStat% = cbErrHandling%(PRINTALL, STOPALL)


  FOutDivider% = 0
  FOutSource% = FREQ4
  Compare1% = DISABLED
  Compare2% = DISABLED
  TimeOfDay% = DISABLED
 FOR BoardNum = 0 TO NUMBRDS%
 FOR ChipNum% = 1 TO 2
  UDStat% = cbC9513Init%(BoardNum, ChipNum%, FOutDivider%, FOutSource%,
Compare1%, Compare2%, TimeOfDay%)
 NEXT ChipNum%
 NEXT BoardNum

  GateControl% = NOGATE
  CounterEdge% = POSITIVEEDGE
  SpecialGate% = DISABLED
  Reload% = LOADREG
  RecycleMode% = RECYCLE
  BCDMode% = DISABLED
  CountDirection% = COUNTUP
  OutputControl% = ALWAYSLOW

 FOR BoardNum = 0 TO NUMBRDS%
  FOR CounterNum% = 1 TO 10
      IF CounterNum% > 5 THEN
      CountSource% = CounterNum% - 5
      ELSE
      CountSource% = CounterNum%
```

QuickBASIC code for *flowsen2.bas* (continued).

```
      END IF
      UDStat% = cbC9513Config%(BoardNum, CounterNum%, GateControl%,
CounterEdge%, CountSource%, SpecialGate%, Reload%, RecycleMode%,
BCDMode%, CountDirection%, OutputControl%)
  NEXT CounterNum%
 NEXT BoardNum
OPEN "f:cotton.dat" FOR APPEND AS #2
REM*****Initialize timer mark*****
57 mark% = 16
DO UNTIL mark% = 0
 mark% = INP(&H379) AND 16
LOOP
DO UNTIL mark% = 16
 mark% = INP(&H379) AND 16
LOOP
ON ERROR GOTO 1000
DO
REM*****Clear Counters********
'load counters with 0 to clear the counters
'Send a starting value to the counter with cbCLoad%()
'  Parameters:
'    BoardNum    :the number used by CBCONFIG to describe this board
'    RegName%    :the counter to be loaded with the starting value
'    LoadValue%  :the starting value to place in the counter

FOR BoardNum = 0 TO 1
IF BoardNum=0 THEN
 FOR RegName% = 1 TO 10
  UDStat% = cbCLoad%(BoardNum, RegName%, LoadValue%)
 NEXT RegName%
ELSE
 FOR RegName%=1 to 8
  UDStat% = cbCLoad%(BoardNum, RegName%, LoadValue%)
 NEXT RegName%
END IF
NEXT BoardNum
REM*****Log Raw Data To The Com Port*****
out$ = LTRIM$(STR$(Buff&(1)))
FOR m% = 2 TO 5
 out$ = out$ + comma$ + LTRIM$(STR$(Buff&(m%)))
```

QuickBASIC code for *flowsen2.bas* (continued).

```
NEXT m%
PRINT #2, out$
REM*****Check timer and decide when it is*****
REM*****time to continue*****
DO UNTIL mark% = 0
 mark% = INP(&H379) AND 16
LOOP
DO UNTIL mark% = 16
 mark% = INP(&H379) AND 16
LOOP
REM*****Read Counters*****
h% = 1
FOR BoardNum = 0 TO 1
IF BoardNum=0 THEN
 FOR CounterNum% = 1 TO 10
    UDStat% = cbCIn%(BoardNum, CounterNum%, Count%)
    Buff&(h%) = Count%
    IF (Buff&(h%) < 1) OR (Buff&(h%) > 65500) THEN
     Buff&(h%) = 0
    END IF
     h% = h% + 1
 NEXT CounterNum%
ELSE
 FOR CounterNum% = 1 TO 8
    UDStat% = cbCIn%(BoardNum, CounterNum%, Count%)
    Buff&(h%) = Count%
    IF (Buff&(h%) < 1) OR (Buff&(h%) > 65500) THEN
     Buff&(h%) = 0
    END IF
     h% = h% + 1
 NEXT CounterNum%
END IF
NEXT BoardNum
REM*****End of Main Loop*************************
LOOP
69
CLOSE #2
END

1000 'Error Handler
RESUME 69
```

QuickBASIC code for *display.bas*.

```
CLS
' main display screen for yield monitor interface
beginning:

' read calibration data from COTTON.INI
OPEN "c:\case\cotton.ini" FOR INPUT AS #1
INPUT #1, GroundSpeedCal
INPUT #1, FanSpeedCal
INPUT #1, BaseLine
FOR i = 1 TO 38
  INPUT #1, c(i)
NEXT i
INPUT #1, m1
CLOSE #1

' Routine to setup diplay screen
SCREEN 12
COLOR 15      'set color to white
WINDOW (0, 0)-(100, 100)

LOCATE 10, 10: INPUT "Enter data logging file name"; f$

IF f$ <> "" THEN
  g$ = "c:\milan97\" + f$ + ".txt"
  OPEN g$ FOR APPEND AS #4
END IF
CLS
LOCATE 1, 30: PRINT "COTTON YIELD MONITOR";
LOCATE 1, 75: PRINT "V 0.3";
LOCATE 2, 2: PRINT "Filename:";
LOCATE 2, 13: PRINT f$ + ".txt"
LINE (0, 92)-(100, 91), , BF
LOCATE 5, 1: PRINT "ROW    FRONT    REAR    SUM"
LINE (0, 83)-(40, 83)
LINE (60, 83)-(100, 83)
LINE (0, 41)-(40, 41)
LINE (0, 35)-(100, 36), , BF  'middle vertical line
LINE (0, 0)-(100, 5), , BF
LINE (50, 92)-(51, 3), , BF
LOCATE 7: PRINT " #1"
LOCATE 9: PRINT " #2"
```

QuickBASIC code for *display.bas* (continued).

```
LOCATE 11: PRINT " #3"
LOCATE 13: PRINT " #4"
LOCATE 15: PRINT " #5"
LOCATE 17: PRINT " #6"
LOCATE 19: PRINT " SUM "
LOCATE 26: PRINT " LOAD TOTAL"
LOCATE 24: PRINT " FAN SPEED"
LOCATE 22: PRINT " GROUND SPEED"
LOCATE 28: PRINT " ACRES";

LOCATE 5, 50: PRINT "Global Positioning System"
LOCATE 7, 49: PRINT "LAT"
LOCATE 9, 49: PRINT "LONG"
LOCATE 11, 49: PRINT "# SAT"
LOCATE 13, 49: PRINT "HDOP"
LOCATE 15, 49: PRINT "STATUS:"

LOCATE 22, 49: PRINT "BASKET WT"

LOCATE 24, 49: PRINT "PRESSURE (S)"
LOCATE 26, 49: PRINT "PRESSURE (D)"
LOCATE 30, 35: PRINT "NOT LOGGING DATA";
'
-------------------------------------------------------------------------
OPEN "com1:9600, n, 8, 1, cs, ds" FOR INPUT AS #1
OPEN "com2:4800, n, 8, 1, cs, ds" FOR INPUT AS #2
OPEN "com3:9600, n,8,1,cs,ds" FOR INPUT AS #3
IF LOC(1) > 0 THEN
 LINE INPUT #1, a$
END IF
IF LOC(2) > 0 THEN
 LINE INPUT #2, a$
END IF
IF LOC(3) > 0 THEN
 LINE INPUT #3, a$
END IF

DO UNTIL INKEY$ = "s" OR marker$ = "s"
 a$ = ""
 DIM chute%(60)
 COLOR 14
 LOCATE 2, 15: PRINT (f$ + ".flo")
```

QuickBASIC code for *display.bas* (continued).

```
x$ = INPUT$(9, #1)
INPUT #1, count
' Read all optical detectors
FOR i = 1 TO count
 INPUT #1, detector%(i)
 IF detector%(i) < BaseLine THEN detector%(i) = 0
NEXT i

INPUT #1, GroundSpeed, FanSpeed

' Clear all chute totals
FOR i = 1 TO 12
 chute%(i) = 0
NEXT i

' Compute flow by chutes
' chute #1 {5 detectors}
FOR j = 1 TO 5
 chute%(1) = detector%(j) * c(j) + chute%(1)
NEXT j

' chute #2  {4 detectors}
FOR j = 6 TO 9
 chute%(2) = detector%(j) * c(j) + chute%(2)
NEXT j

' chute #3  {4 detectors}
FOR j = 10 TO 13
 chute%(3) = detector%(j) * c(j) + chute%(3)
NEXT j

' chute #4  {4 detectors}
FOR j = 14 TO 17
 chute%(4) = detector%(j) * c(j) + chute%(4)
NEXT j

' chute #5  {4 detectors}
FOR j = 18 TO 21
 chute%(5) = detector%(j) * c(j) + chute%(5)
NEXT j
```

QuickBASIC code for *display.bas* (continued).

```
' chute #6  {5 detectors}
FOR j = 22 TO 26
 chute%(6) = detector%(j) * c(j) + chute%(6)
NEXT j

' chute #7   {5 detectors}
FOR j = 27 TO 31
 chute%(7) = detector%(j) * c(j) + chute%(7)
NEXT j

' chute #8   {5 detectors}
FOR j = 32 TO 36
 chute%(8) = detector%(j) * c(j) + chute%(8)
NEXT j

' compute ground and fan speeds
FanSpeed = FanSpeed * FanSpeedCal
GroundSpeed = GroundSpeed * GroundSpeedCal

'print data to display
FOR x = 1 TO 12 STEP 2
 LOCATE 6 + x, 8: PRINT USING "#####    "; chute%(x); chute%(x + 1); chute%(x)
+ chute%(x + 1)
NEXT x

'COMPUTE SUM REAR
sumr = 0
FOR x = 1 TO 12 STEP 2
 sumr = sumr + chute%(x)
NEXT x

'COMPUTE SUM FRONT
SUMF = 0
FOR x = 2 TO 12 STEP 2
 SUMF = SUMF + chute%(x)
NEXT x

SUM = SUMF + sumr

RATIO = SUMF / SUM
LOCATE 19, 25: PRINT USING "######"; SUM
```

QuickBASIC code for *display.bas* (continued).

```
LOCATE 22, 14: PRINT FanSpeed
LOCATE 24, 14: PRINT GroundSpeed
TOTAL = TOTAL + SUM * m1
LOCATE 19, 9: PRINT USING "####     "; SUMF; sumr
LOCATE 26, 14: PRINT USING "#######"; TOTAL
'check for GPS data on serial port
IF LOC(2) > 20 THEN
 GPSflag = 1
 INPUT #2, gga$
 INPUT #2, utm
 INPUT #2, lat#
 INPUT #2, direction$
 INPUT #2, lon#
 INPUT #2, direction$
 INPUT #2, GPSstatus
 INPUT #2, NumbSat
 INPUT #2, HDOP

 LINE INPUT #2, x$      'trash the remaining line

'print gps data to display
 LOCATE 7, 60: PRINT USING "####.#####"; lat#
 LOCATE 9, 60: PRINT USING "####.#####"; lon#
 LOCATE 11, 60: PRINT NumbSat
 LOCATE 13, 60: PRINT HDOP
 LOCATE 15, 59
 IF GPSstatus = 0 THEN PRINT "NO POSITION FIX     "
  IF GPSstatus = 1 THEN PRINT "NON-DIFFERENTIAL FIX"
  IF GPSstatus = 2 THEN PRINT "DIFFERENTIAL FIX    "
 ELSE
  GPSflag = 0
  LOCATE 15, 59: PRINT "NO GPS SIGNAL       "
 END IF

 REM*****Look for data from the 21x*****
 v$ = ""
 tim = TIMER
 DO UNTIL LEN(a$) > 3 OR v$ = "continue"
  tim2 = TIMER
  IF tim2 >= tim + 1 THEN
   LOCATE 22, 62: PRINT "           ";
```

QuickBASIC code for *display.bas* (continued).

```
  LOCATE 24, 62: PRINT "          ";
  LOCATE 26, 62: PRINT "          ";
  LOCATE 28, 62: PRINT "No 21x Signal";
  v$ = "continue"
 END IF
 IF LOC(1) > 2 THEN
  LINE INPUT #3, a$
 END IF
LOOP
REM*****Extract the useful numbers from the 21x output*****
length% = LEN(a$)
j% = 2
FOR i% = 1 TO length%
 b$ = MID$(a$, i%, 3)
 c$ = "0" + LTRIM$(STR$(j%)) + "+"
 p$ = "0" + LTRIM$(STR$(j%)) + "-"
 IF b$ = c$ OR b$ = p$ THEN
  k% = 0
  ll% = i% + 3
  d$ = "garbage"
  DO UNTIL d$ = " " OR d$ = ""
   d$ = MID$(a$, ll%, 1)
   ll% = ll% + 1
   k% = k% + 1
  LOOP
  out$(j%) = MID$(a$, i% + 2, k% - 1)
  IF j% = 2 THEN
   LOCATE 28, 62: PRINT "          ";
   LOCATE 22, 62: PRINT out$(j%);
  ELSEIF j% = 3 THEN
   LOCATE 24, 62: PRINT out$(j%);
  ELSEIF j% = 4 THEN
   LOCATE 26, 62: PRINT out$(j%);
  END IF
  j% = j% + 1
 END IF
NEXT i%
output$ = out$(2)
IF v$ <> "continue" THEN
 FOR i% = 3 TO (j% - 1)
  output$ = output$ + CHR$(44) + out$(i%)
```

QuickBASIC code for *display.bas* (continued).

```
 NEXT i%
ELSE
 output$ = ""
END IF


'If an output file is given, output sensor & GPS data
IF f$ <> "" THEN
 FOR i = 1 TO count
  PRINT #4, LTRIM$(STR$(detector%(i))); CHR$(44);
 NEXT i
 PRINT #4, FanSpeed; ","; GroundSpeed; ",";
 IF GPSflag = 1 THEN
  PRINT #4, lat#; ","; lon#; ","; NumbSat; ","; HDOP; ","; GPSstatus; ",";
 ELSE
  PRINT #4, ",,,,,":
 END IF
 PRINT #4, output$;
 'check for a marker letter
 marker$ = INKEY$
 IF marker$ <> "" THEN
  PRINT #4, ","; marker$;
  BEEP
 END IF
 PRINT #4, ""    'send a <cr><lf> to file
 LOCATE 30, 35: PRINT "LOGGING DATA      ";
 END IF
LOOP
LOCATE 30, 35: PRINT "NOT LOGGING DATA";
CLOSE
FOR x = 1 TO 100000: NEXT x
CLS
LOCATE 30, 25: INPUT "PRESS 'C' to continue or 'E' to exit"; x$
CLS
IF x$ = "c" OR x$ = "C" THEN
 marker$ = ""
 GOTO beginning
END IF
END
```

Vita

Fred Henry Moody III was born in Bryson City, North Carolina on October 26, 1973. He graduated from Swain County High School in May of 1992, and entered The University of Tennessee the following August. The University of Tennessee granted him the degree Bachelor of Science in Agricultural Engineering in May of 1996. Immediately after graduation, he began working towards a Master of Science in Agricultural Engineering at The University of Tennessee. The master's degree was awarded in August of 1998.

He is presently working as a research associate for The University of Tennessee Agricultural Experiment Station.

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