REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
5Dec94

3. REPORT TYPE AND DATES COVERED
Final Report

4. TITLE AND SUBTITLE
Field-Portable Reflectance Spectrometer

5. FUNDING NUMBERS
C: DACA33-94-C-0033

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10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Unclassified

19941212 064

13. ABSTRACT *(Maximum 200 words)*

This study resulted in a design for an array detector based field spectroradiometer to be used for measurement of transmission and reflectance of man-made and natural materials using ambient solar illumination. This design is a significant advancement over currently available instrumentation. The design characteristics are: wavelength range from 0.35-2.5 µm; spectral resolution of 4 nm (0.35-900 µm), 10 nm (0.9-2.5 µm); weight 15 pounds, exclusive of batteries; a minimum signal-to-noise ratio of 500:1 at 2200 nm under typical solar illumination; simultaneous acquisition of all wavelengths; operates at temperatures as low as -20°C; and, maintains radiometric calibration under field conditions. During Phase I a prototype was fabricated to test and validate this design. Government agencies using image data from high spectral resolution sensors will benefit. Additional applications include mineral resource evaluation, analytical chemistry and commercial remote sensing.

14. SUBJECT TERMS
spectrometer, Radiometer, transmission, portable spectroradiometer, reflectance, solar, infrared

15. NUMBER OF PAGES
26

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

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A. Introduction

Field spectrometry for verification of remote sensing observations as well as research into new methods and algorithms for extraction of information has been hampered in the past by lack of adequate instrumentation. Spectrometers have been too heavy, lacking in adequate battery life and only able to acquire spectra in a period of minutes rather than seconds. The overall objective of this study effort was to determine whether a new generation of optics and detector technology could be applied to the problem.

The application of detector array technology in the visible and near-IR (VNIR) portion of the spectrum, employing silicon photodiodes and CCDs, is now commonplace. For instance, ASD has offered such field-portable spectrometers for sale since 1991. The region 1000-2500 nm so far has only been covered by use of scanning techniques coupled with single detectors. However, introduction of new detector technology in the form of graded index, indium gallium arsenide detectors has made it possible to build instruments to acquire spectra in the 1000-2500 nm region in as little as 0.1 seconds. ASD markets a line of field instruments called FieldSpec™ employing this technology. Nevertheless, the spectra are acquired by wavelength in serial fashion which makes them subject to error if the illumination is variable or data are taken from aircraft platforms.

The Phase I study was aimed at determining whether the InGaAs detector technology was applicable to an array detector-based field spectrometer and to test an array in a breadboard instrument.

B. Phase I Objectives

The specific objectives of the Phase I study were as follows:

1. To develop a baseline design for a field-portable spectroradiometer to cover the 1.0-2.5 µm wavelength region utilizing line array detectors. The requirements proposed were as follows:

   a. Wavelength coverage of 1.0-2.5 µm, with resolution (FWHM) of at least 10 nm. ASD's existing VNIR detector array based spectroradiometer will provide 3 nm spectral resolution in the 0.35 to 1.05 µm range.

   b. To use fiber optic bundles to bring the light into the spectrometer.

   c. To be light weight and use a sub-notebook computer for the data system. The weight goal is 10 lbs without batteries. This weight goal includes the weight of ASD's existing VNIR array spectrometer.

d. To have a minimum signal-to-noise ratio of 600:1 at 2200 nm, 30% reflectance, for a single 500 ms integration time and 45° solar zenith angle as defined by the Lowtran-7 atmospheric model. Higher SNR will be possible by averaging scans.

e. To have a dynamic range sufficient to measure surface radiance at 0° solar zenith angle and 100% reflectance without saturating.

f. Acquire all wavelengths simultaneously.

g. To operate at temperatures as low as -20°C.

h. To be radiometrically calibrated and maintain calibration under field conditions.

2. To evaluate all the array detector types available for the 1.0 to 2.5 µm wavelength region for their sensitivity and applicability to field use.

3. To select an off-the-shelf detector for evaluation and develop requirements for a study contract to the manufacturer to examine the feasibility of building a detector to specifications for this application.

4. To build a breadboard spectrometer system to test the off-the-shelf detector, grating, and readout electronics, and to acquire data to verify the model for the complete system design.

5. Perform a full characterization of the breadboard instrument. Determine the radiometric stability and calibration, wavelength stability and calibration, and spectral resolution of the bread-board instrument. In conjunction with modeled target radiances, determine the SNR of the breadboard instrument. Use the breadboard instrument to make reflectance measurements using ambient solar illumination.

6. Formulate a final design, and model the performance of, an array-based, field-portable spectrometer for development in Phase II.

C. Phase I Study Results

During the course of the Phase I study, all the tasks listed in the original Phase I proposal were completed. In addition, all but one of the objectives listed original Phase I proposal were met. As a result of the phase I study, we estimate that the instrument proposed for phase II development will weight about 12 pounds, or about 2 pounds more than the original goal of 10 lbs.

Design Considerations

We proposed to use a dispersive spectrometer design with a flat-field-corrected, concave, holographic grating. The use of this type of grating precludes the need for any additional spectrometer optics. By minimizing the number of optical elements in the spectrometer, throughput is maximized and stray light is minimized. Because the desired spectral resolution has been fixed at 10 nm, the required dispersion of the grating is determined by the overall width of the active portion of the detector array. Given a grating with sufficient resolving power, the width of the entrance slit, W_{slit}, is determined by:

$$W_{slit} = W_{element} * \left((N_{elements} \times \Delta\lambda) \big/ \lambda_{range} \right)$$

Where $W_{element}$ is the width of a single element in the detector array, $N_{elements}$ is the number of elements in the array, $\Delta\lambda$ is the desired spectral resolution in nanometers, and λ_{range} is the spectral range of the spectrometer in nanometers. The height of the entrance slit is the same as the detector height. While increasing the entrance slit increases the instrument SNR (due to increased throughput), spectral resolution will be degraded. After discussions with the sponsor, we chose to cover the ranges 900-1800 nm and 1700-2500 with two spectrometers. For a detector pitch of 50 µm, the sampling interval is 3.5 nm. The resolution can be chosen to be either 7 nm if a 100 µm diameter fiber is chosen or between 7 and 14 nm if a 200 µm fiber is used with the appropriate entrance slit size. The latter is preferable in order to maximize the SNR.

The interior of the spectrometer will be baffled to limit stray light reaching the detector. Because the proposed design uses an array detector, complete baffling is not possible. With a 2.6 µm-cutoff about half of the photons integrated by the detector are produced by thermal emission of the spectrometer itself. Because of the impracticability of cooling the entire spectrometer, a shutter will be provided to obscure the entrance slit. This will allow a separate measurement of the thermal background radiation which can then be subtracted from subsequent measurements.

During the Phase I study, we examined other possible spectrometer designs. While a Fourier transform design does have a substantial advantage in throughput over a dispersive design, the requirements for linearity of the detector and analog electronics, detector dynamic range, and fixed pattern detector noise are much more stringent than for a dispersive design. For this reason we did not choose the design.

Another possible design enhancement we examined during Phase I was the use of fiber optic tapers. Fiber optic detector face plates can be constructed to provide a light collecting surface either larger or smaller than the actual detector. A tapered fiber optic has a higher numerical aperture at the small diameter end than it does at the large end. Because most detectors are sensitive to light over almost a full 180° range of incidence angles, the light delivered to the focal plane of a typical f-2.0 spectrometer greatly underfills the acceptance solid angle of the detector. Using a tapered fiber optic face plate would allow collection of light at f-2.0 at the focal plane of the spectrometer, while delivering it to the detector at f-1.0 or less. Because the area of the face plate at the focal plane of the spectrometer would be greater than the detector, the spectrometer entrance slit, and thus the throughput of the spectrometer, could be increased proportionally. This approach received only cursory examination because no information could be found on the behavior of face plates beyond the visible portion of the spectrum. Instead a simpler approach was taken to use a cylindrical lens over the detector to halve the f number in the slit direction to allow a doubling of the slit length that provides a doubling of the SNR without an appreciable reduction in system performance.

Baseline Design

In the course of the Phase I study, a baseline design was developed that has the following characteristics:

1. Wavelength coverage from 900-2500 nm using two, 256 element graded index, InGaAs detector arrays. The arrays are produced by two different manufacturers in the United States. The available arrays have room temperature wavelength cutoffs of 1900, 2200, and 2600 nm. These arrays are not yet produced in volume and the packaging is not suitable for a small, portable instrument. In addition, the cooling requirements for the arrays are excessive. The Reticon multiplexer employed dissipates approximately 0.5 watts which requires about 20 watts of power to bring the detector to 50°C below ambient. We recommend a new package design and a new detector multiplexer be developed for the array detectors in Phase II.

2. The detector size readily available is 250 µm high on 50 µm centers. Heights of 500 µm and 1 mm have been made, but have the disadvantage that the yield is much lower and hence the price is higher and that dark current is too high for the multiplexer.. The modeling studies were done with 250 µm detector heights.

3. The instrument system will consist of three spectrometers covering the ranges 350-900 nm, 900- 1800 nm and 1800-2500 nm. The VNIR region will utilize the current ASD spectrometer consisting of a 100 mm focal length holographic, flat field grating combined with a 512 element photodiode array detector. The light enters the spectrometer through a fiber bundle consisting of 19-100 µm diameter fibers. The two shortwave infrared (SWIR) spectrometers utilize a similar spectrometer with gratings optimized for the different wavelength regions. Each of the SWIR spectrometers is fed with 5-100 µm diameter fibers. The detector arrays are capped with a cylindrical lens that reduces the 500 µm high slit image to 250 µm. The three bundles lead to SMA connectors on the top plate of the instrument. Extension cables of arbitrary length can be attached to the instrument in the field.

4. The weight of the instrument is expected to be approximately 12 lbs, slightly greater than the present FieldSpec-FR. The increased weight is the result of increasing the case size to accommodate a larger number of subnotebook computer types and make use of fiberglass for the case material to increase shock resistance. The battery weight is yet to be determined. The cooling requirements for the 2.6 μm detector array are not yet known, but could range from 10-38 watts depending on whether the array must be cooled to -50° C to reduce the dark current to below 1 nA to keep the multiplexer from saturating for integration times greater than 1 s. The battery weight will be 7-20 lbs in NiCd depending on the detector cooling requirements. A 20% weight saving will result if NiH batteries can be used. The temperature sensitivity of NiH is still an open question.

5. The model calculations predict the signal-to-noise ratio of the instrument will be approximately 500:1 at 2200 nm for a 100% reflectance target for a single 0.5 s integration time and 45° sun angle. The SNR will increase linearly with integration time until the multiplexer saturates. Beyond that point, the SNR can be increased by the square root of the number of spectra averaged. The instrument will have an automatic gain and offset mode in which the dynamic range is set 20% below the saturation level for a 100% reflective target.

6. The SWIR detectors are read out in approximately 9 ms. The detectors are subsequently cleared of charge and the signal integration begins anew. By this method, all detectors are receiving signal simultaneously.

7. The instrument is capable of operating at -20° C. The two critical components are the computer screen that will be provided with a heater and the battery power supply. The battery type most suited for cold operation is the lead-acid gel cell. However, gel cells are approximately twice as heavy as nickel-cadmium batteries. Nickel-hydride batteries are 20% lighter than NiCd but both lose efficiency below freezing. If the batteries can be kept warm before use, then the ohmic heating under load should be sufficient to maintain efficiency at -20° C.

8. Radiometric calibration is a major requirement for the proposed instrument. There is nothing in the inherent design precluding use of the instrument as a radiometer. The factors contributing to stability in calibration are as follows:

    a. Detector gain. The gain of the InGaAs graded index detectors is dependent on the temperature. The arrays will be cooled to a temperature between -30 and -50° C and the temperature maintained to ± 0.5°. This should be sufficient to maintain absolute calibration to ± 0.5%.

b. The dark current offset is a critical function of detector temperature as well as the Planck radiation from the instrument itself. This effect is only important for the 2.6 μm-cutoff detector. The instrument temperature cannot be controlled under field conditions. Therefore, dark current must be measured at regular intervals and subtracted from the total signal. The measurement is made by closing off the incoming light with a shutter in front of the slit. The dark current will be different for each detector in the array and, therefore, the algorithm for subtraction must treat each detector output accordingly. In the current ASD instrument designs utilizing a silicon array detector in the VNIR, each detector output is considered independently.

Radiometric calibration in the field can be carried out with a secondary standard such as a Licor Model 1800-02 Optical Radiation Calibrator that has been calibrated throughout the wavelength region using a laboratory primary standard. Since the 50 Watt lamp requires significant power, the calibrator must be powered by the mains or with a generator. Wavelength calibration will be carried out with the combination of an emission line generator using Hg and Ar gasses and a transmission standard such as Mylar for the SWIR spectrometers.

Evaluation of Array Types

Aside from the desire for a spectrometer that would acquire all spectral bands simultaneously, the use of array detectors provides a multiplex advantage over a scanning spectrometer. Thus, an N element detector will provide a SNR that is a factor of $\sqrt{N}$ higher than a single element detector of the same size. If the area of the detector is doubled, the SNR will increase 141%. In the selection of a detector, this multiplex advantage must be considered along with the size of the individual elements and the quantum efficiency of the detector.

Several options are available or are nearing availability for detector arrays in the SWIR spectral region. These include lead-sulfide (PbS), indium-gallium-arsenide (InGAs), mercury-cadmium-telluride (HgCdTe), indium-antimonide (InSb) and platinum-silicide (PtSi); all but the first two require cooling down to liquid nitrogen temperatures and are not suitable for a truly portable field spectrometer. In addition, the only commercially available InSb and HgCdTe arrays have very small element size. Thus, the multiplex advantage of these arrays, as compared to the single element InGAs detectors in the FieldSpec™ FR, is more than eliminated by their small size. While PtSi arrays are available with more reasonable element sizes (e.g. a 1024 element PtSi array with 15 by 2500 μm elements is available from EG&G Reticon), the need for cooling and the low quantum efficiency (about 10% at 1.0 μm dropping to 2% at 2.5 μm) make this a poor choice. Because PbS is a photoconductive rather than a photovoltaic material like silicon, each detector must have an associated preamplifier, load resistor and bias supply. In 1993 two manufacturers, Optoelectronics and Litton, began marketing PbS linear arrays with

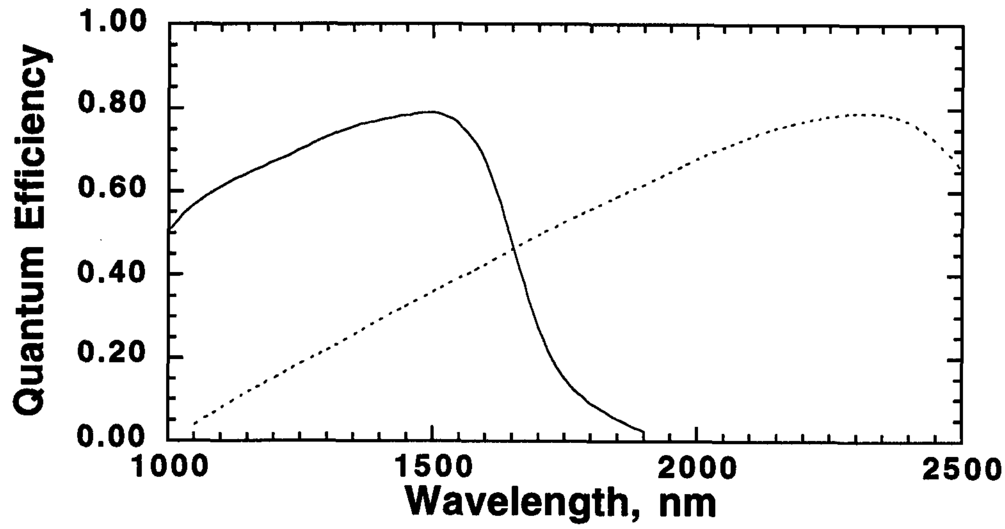

Figure 1 Quantum efficiency for InGAs detectors; data provided by Epitaxx. The solid line is for a 1.7 μm cutoff detector, the dashed line is for a 2.6 μm cutoff detector.

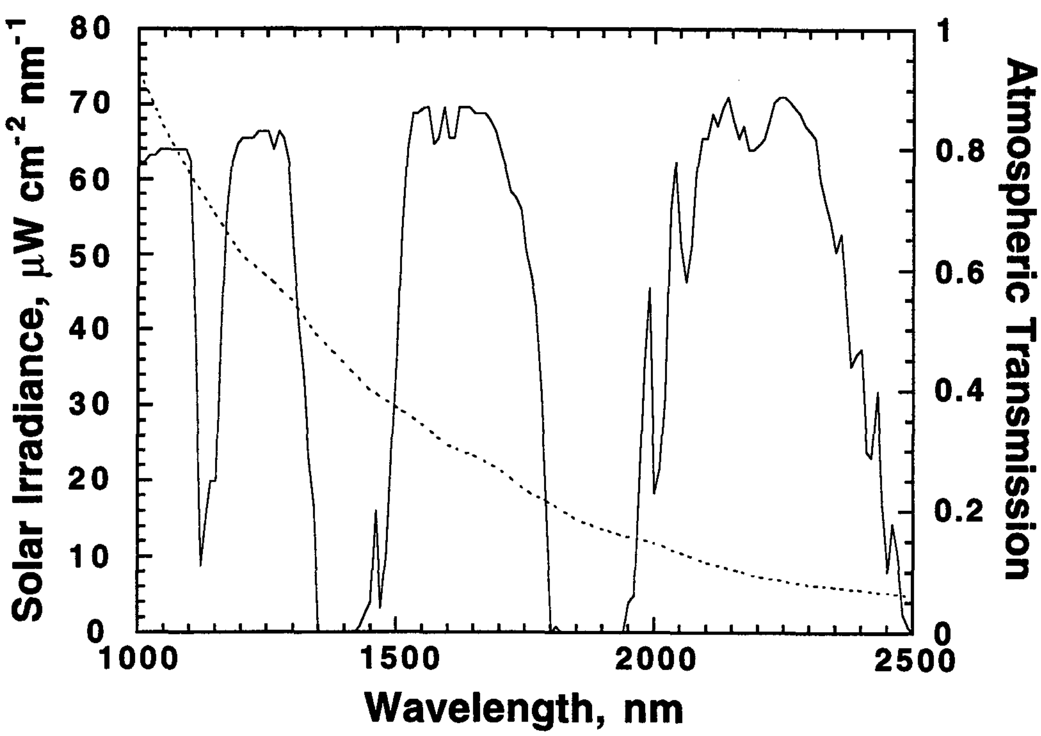

Figure 2. Solar irradiance (dashed line) at the top of the atmosphere, and single path atmospheric transmission (solid line). All of the major absorption features are attributable to water. Minor absorption features result from the presence of methane, nitrous dioxide, carbon monoxide, and oxygen.

attached multiplexers that provide silicon photodiode-like readouts. However, it appears that to acquire maximum performance it is still necessary to chop the incoming light to overcome 1/f noise. This negates the most practical aspect of an array instrument, the fact that it should require no moving parts. Both single- and

multi-element InGAs detectors are available. InGAs can be doped to provide detectors with long wavelength cutoffs of 1.7, 1.9, 2.2 and 2.6 µm (Figure 1). InGAs arrays have the advantage of less stringent cooling requirements, high quantum efficiency and reasonable size.

There are two manufacturers of InGaAs in the United States, Epitaxx and Sensors Unlimited, both located in New Jersey and both founded by the same person, Dr. Greg Olsen. Both companies have supplied quotes for manufacturing 1.9, 2.2 and 2.6 µm-cutoff, 256 element arrays. However, it appears that cooling the arrays to a low enough temperature for low-noise operation may be a problem.

The difficulty in cooling stems from the fact that the Reticon multiplexer used to read out the individual InGaAs detector elements dissipates approximately 0.5 W, heat that must be removed by thermoelectric cooling. Another 0.5 W of heat load comes from the package. The high heat dissipation stems from the fact that a high bias voltage is used that also results in high dark current in the detector. The problem is compounded by the fact that the high dark current leads to faster filling of the multiplexer well, leading to a shorter integration time before a readout is required. The higher dark current leads to more noise and a lower SNR. These problems can be mitigated by cooling to a lower temperature to raise the detector resistance, but only with a substantial increase in power. Unfortunately Reticon does not manufacture a more efficient multiplexer. Therefore, it will be necessary to develop a lower dissipation multiplexer that also has a superior noise figure.

Epitaxx, Inc. has just completed a multiplexer development for a 1024 element array on another project. This multiplexer dissipates 10 mW and has a significantly lower noise figure. We will propose in Phase II that a 256 el multiplexer of the same design be developed and used for both the 1.9 and 2.6 µm detector arrays.

Evaluation of Prototype CRAS Instrument

A breadboard spectrometer system has been constructed to test a 256 element, 2.2µm-cutoff detector in a standard package. Readout electronics for the Reticon photodiode array multiplexer have been completed and tested using an InGaAs array reject from Sensors Unlimited. A working detector was delivered on September 27. The detector test report is included in Appendix I. This detector has been incorporated into the prototype CRAS instrument. The radiometric performance of this instrument is plotted in Figure 3.

The spectrometer is a modification of the standard Littrow design used in ASD products and with the addition of a custom holographic grating supplied by American Holographic. Because of the size of the standard Sensors Unlimited detector package, a folded focal plane design was required to bring the entrance and exit beams out the side of the spectrometer housing. This mounting requirement necessitated a larger case than is now used in the FieldSpec, resulting in a weight increase to approximately 12 lbs.

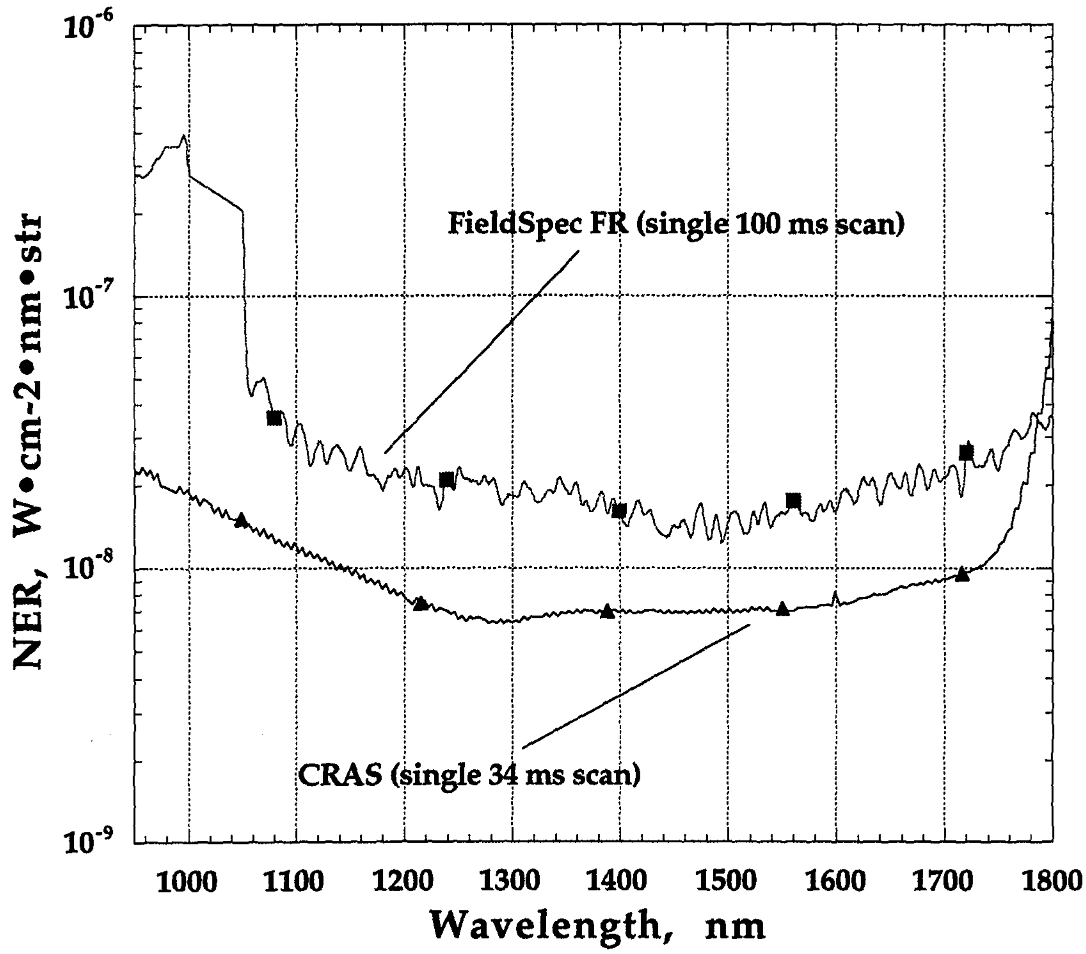

Figure 3. Noise equivalent radiance (NER) of the prototype CRAS instrument as compared to the FieldSpec™ FR. The NER for the prototype CRAS instrument is on the order of two to three times better than for the FieldSpec™ FR. The FieldSpec™ FR uses a single element InGaAs detector and a spectrometer that scans this region of the spectrum each 100 milliseconds. NER for both instruments was calculated from single scans. Both instruments gain a square root of the number of scans improvement in NER as more scans are averaged.

To use the prototype CRAS instrument, follow these steps:

- Choose a power source: 1) connect the battery to the battery box (black box with coil cable attached), connect the coil cable to the instrument; or, 2) connect the appropriate connectors of the AC/DC power supply to 120 VAC and the instrument.

- Turn the CRAS spectrometer on with the power switch in the upper right-hand corner of the instrument top plate.

- Turn the Zeos computer on by pressing the space bar.

- Type **CD\LIRA** to switch to the proper directory, then **LIRATEST** to run the software.

The LIRATEST program provides basic control functions and the ability to collect raw data from the prototype instrument. The raw data collected by this program have neither a wavelength nor radiometric calibration applied. Any further processing of instrument data (e.g. wavelength calibration, radiometric calculations) must be performed off-line. For this study, a spreadsheet program was used to convert the raw data collected using the LIRATEST program to radiance spectra. The available software commands for the LIRATEST program are listed in Table 1. Typically, the following steps should be followed when using the LIRATEST software:

- The **F1** & **F2** commands are first used to select an integration time that is appropriate for a given light level. To view the spectra, the screen is toggled between the instrument status display and the spectrum graphical display by typing the '**g**' command. Commands that require no user input (like **F1** & **F2**) can be typed when either display is active.

- Because the dark noise of the individual detector elements varies widely, it is useful to subtract this dark signal. This is done by typing the '**N**' command. The LIRATEST program will then average the next 100 spectra as the dark signal. This spectrum will be subtracted from subsequent spectra. Because the prototype instrument has no internal shutter, the tip of the fiber optic probe should be covered prior to entering this command. The '**n**' command can be used to toggle dark noise correction on and off.

- The 'O' command is used to add a fixed offset back into the data. This was sometimes used to ensure that the displayed spectra had no negative values (negative values are truncated to zero when stored). If this command is used, the user must subtract an average dark spectrum from all collected spectra. This dark spectrum is collected in with the same instrument settings, but with the fiber optic tip shuttered. Because this command requires user input, it can be typed only when the instrument status display is active.

- The LIRATEST program initially displays single scan spectra. Using the '**s**' command the user can specify a different number of scans to be averaged for each spectrum displayed or collected. This command is useful when data with an increased NER is required. Because this command requires user input, it can be typed only when the instrument status display is active.

- The '**S**' command is used to store spectra. Spectra are stored in a text format with one 16 bit integer value for each of the 256 detectors in the array. The file name used is "**SAVE????.DAT**", where the "**????**" is set to "**0000**" for the first set of spectra stored and is incremented for each subsequent set stored ("**0001**", "**0002**", etc.). Because this command requires user input, it can be typed only when the instrument status display is active. Note: each time the LIRATEST program is run, the file name used resets to "**SAVE0000.DAT**" and any previously saved files will be overwritten if they are left in the \LIRA subdirectory.

F1	Decrease array integration time
F2	Increase array integration time
q or Q	Quit the software
g	Toggle graphics mode
N	Take dark noise baseline
n	Toggle noise subtraction
O	Change digital offset
s	Change the number of samples in each average
S	Save spectra

Table 1. Available commands for the LIRATEST program.

Final Design

The final design of the all-array spectrometer has the following components:

1. A 3-spectrometer system consisting of flat-field, holographic grating spectrometers with detector arrays in the focal planes. The spectrometers are fed light through a removable, fiber optic bundle that has a single probe end and splits into three sub-bundles in the spectrometers. The individual sub-bundles are formed into the entrance slits for each spectrometer.

2. A 512 element, silicon photodiode array detector is used for the 350-900 nm region in the first spectrometer. The second spectrometer contains a 256 el, 1.9 µm cutoff InGaAs array cooled to -30°C. This spectrometer covers the region 900-1800 nm The third spectrometer contains a 256 el, 2.6 µm cutoff InGaAs array cooled to -50°C. This spectrometer covers the region 1800-2500 nm.

3. Readout electronics interfaced to the extended parallel port (EPP) for connection to any 486 or Pentium PC mounted in the case.

4. Instrument operation and control software written in Windows. The keystrokes for operation will be designed for cold weather operation with gloves.

D. Technical Feasibility

All aspects of the design proposed for implementation in Phase II have either been prototyped or thoroughly modeled during the Phase I study. The only key component that has not been prototyped is the 2.6μm cut-off InGaAs array detector. One of the vendors, Epitaxx, has delivered several 2.6μm cut-off InGaAs array detectors to Ball Aerospace Corp. ASD uses a single element 2.6μm cut-off InGaAs detector in a current product, supplied by both Epitaxx and Sensors Unlimited, Inc. While neither of these detectors are of the same design required for this effort, they do indicate that the fabrication of the 2.6μm cut-off InGaAs array detector proposed for Phase II has a low level of risk.

Appendix I :

Sensors Unlimited InGaAs Array Detector Performance Data

InGaAs Linear Photodiode Array

Model No. SU256L-2.2TE-250A

Serial No. SU256L-138

Test Date: 19 September 1994

Handling Precautions:

Use normal precautions to protect device from static discharge.

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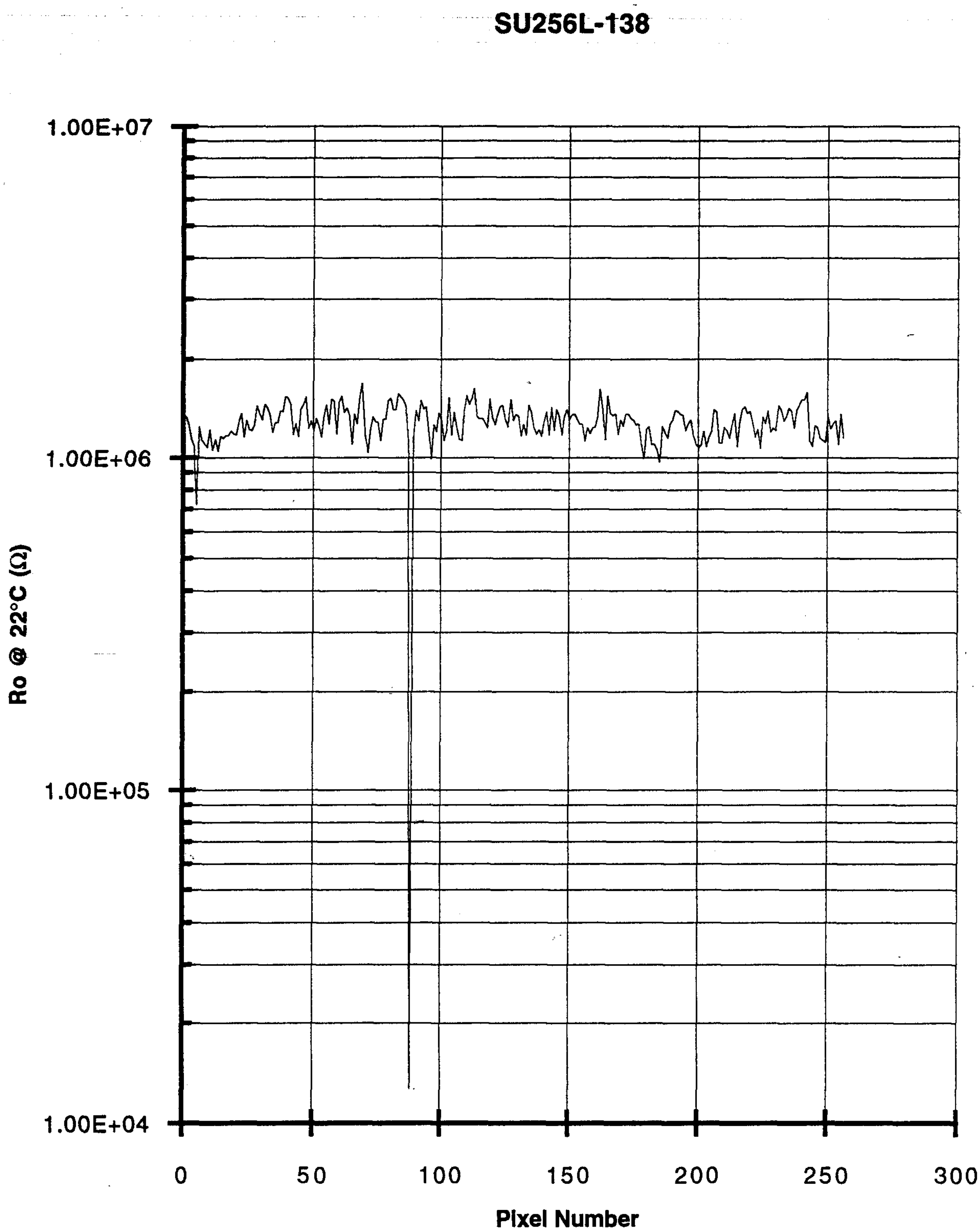
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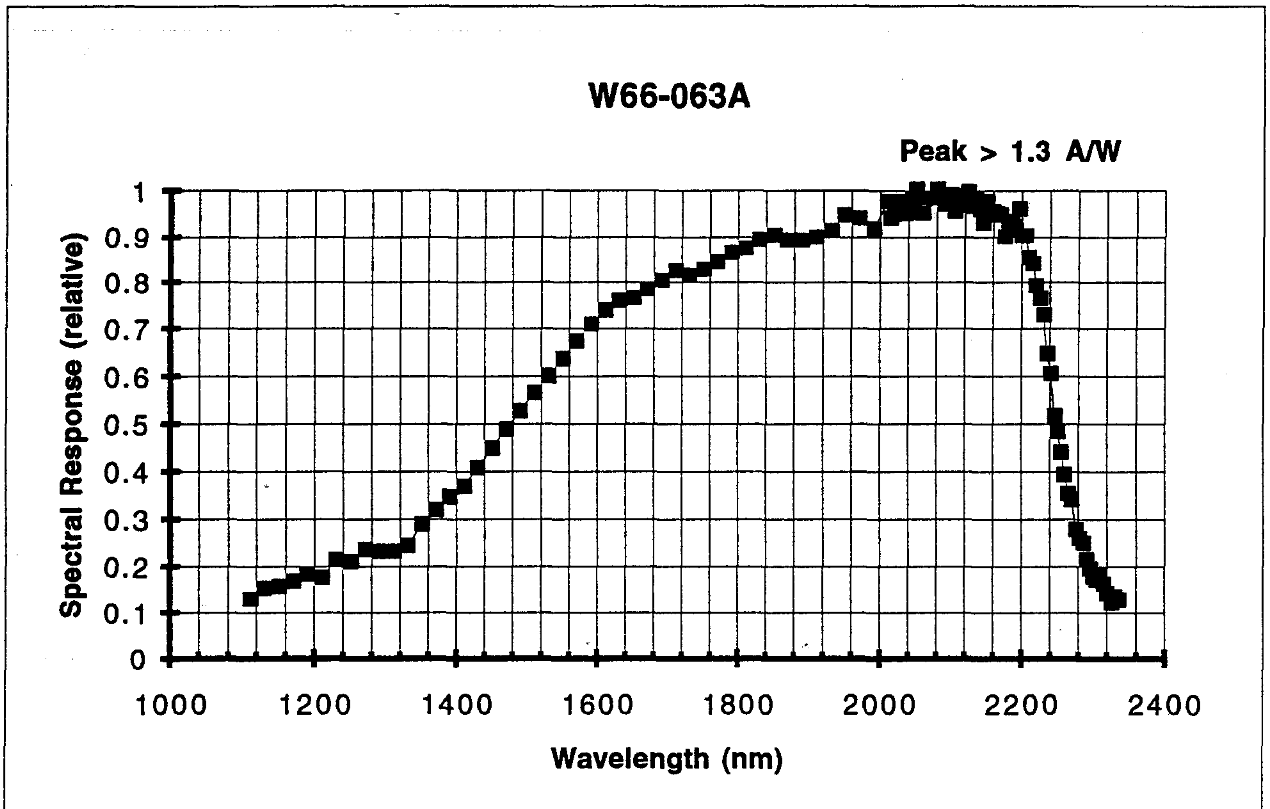
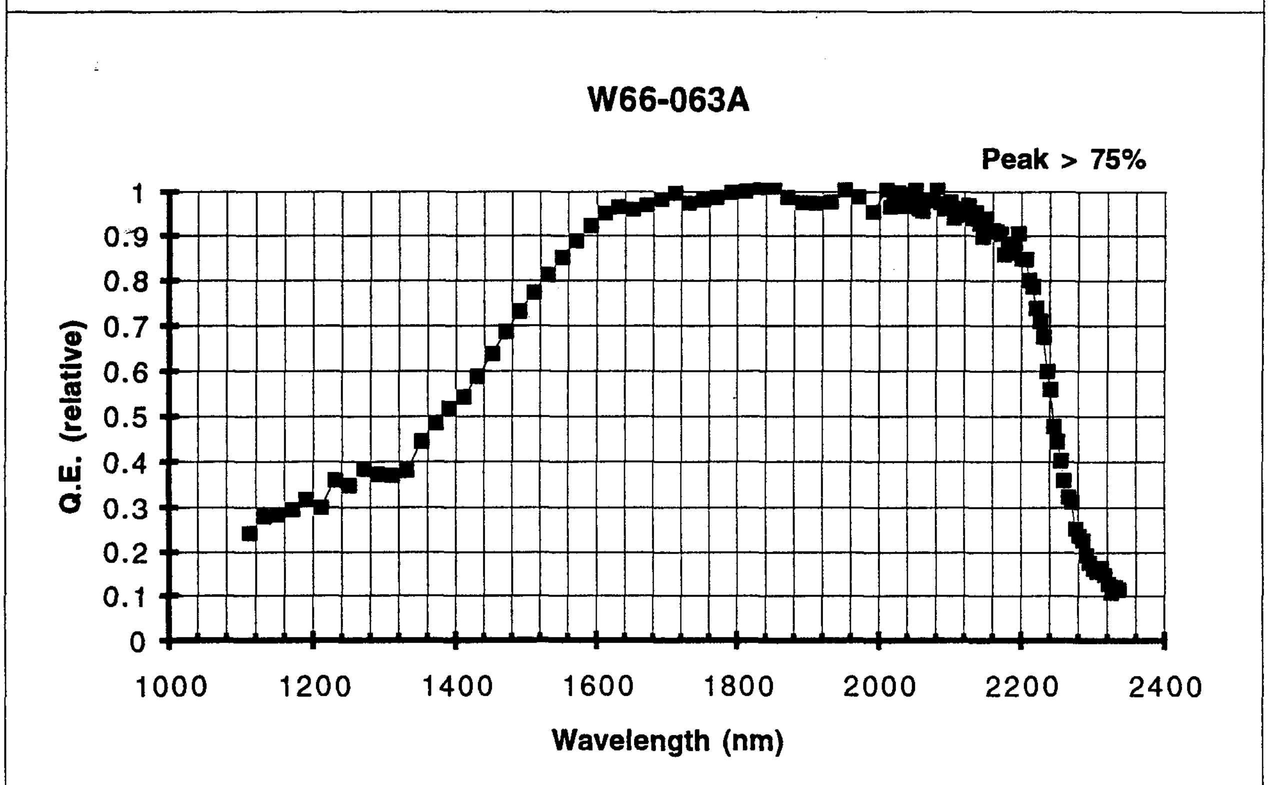
SENSORS UNLIMITED, INC.





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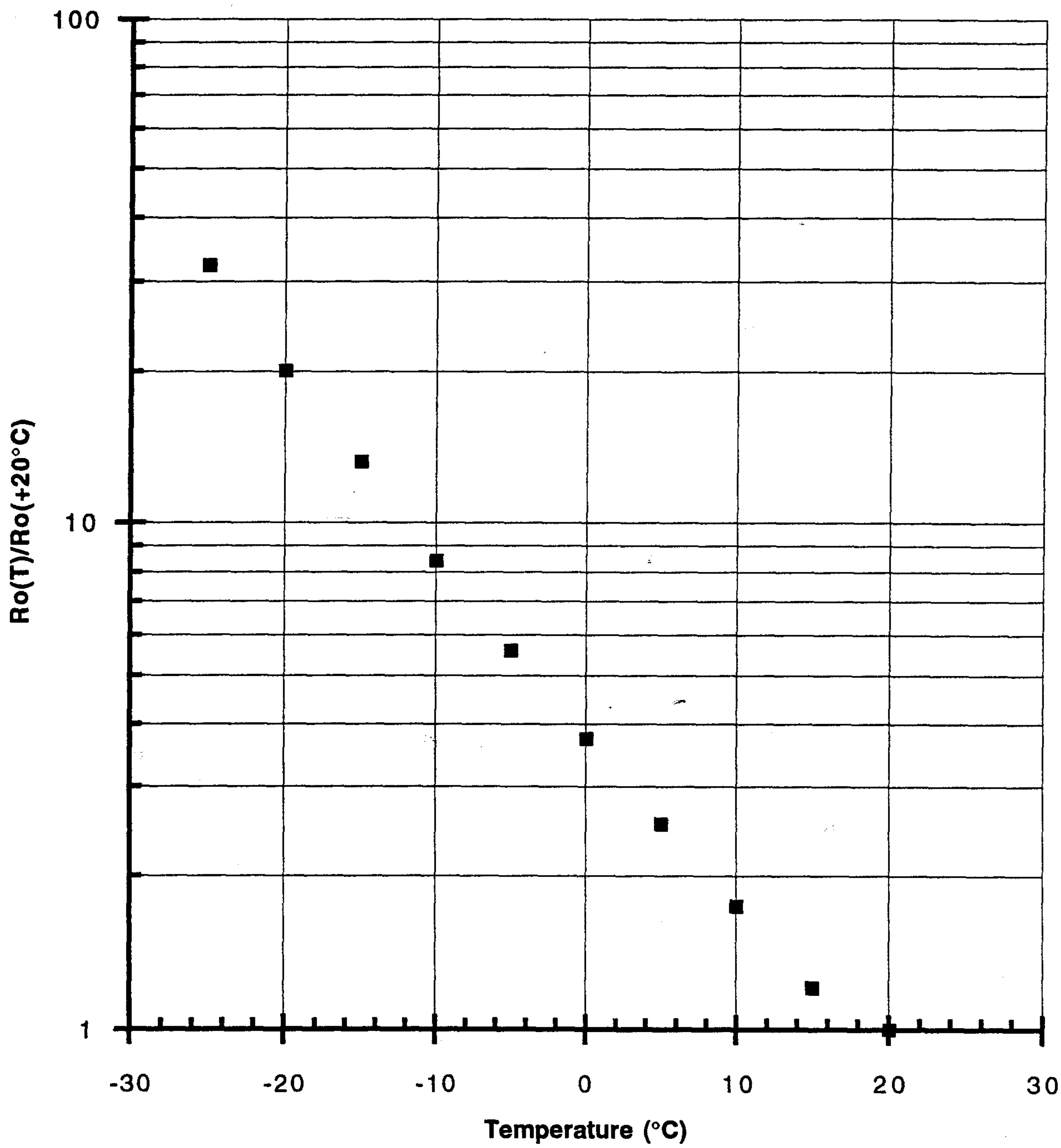

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Introduction

The RL0064/0128/0256MB family of integrated CMOS circuit chips is intended to provide flexible low-noise amplification and multiplexing components for interfacing with separate photosensitive arrays, such as gallium-arsenide, germanium or amorphous-silicon, or IR special-purpose arrays. These chips may also be used as general-purpose multi-input multiplexers for medical, scientific, or industrial instrumentation applications. These devices are available in die form. A simplified block diagram of the device is shown in Figure 1.

The various versions provide 64, 128, 256 bonding pads each with charge-sensitive preamplifiers, and the ability to sample and hold the pre-amplifier outputs (charge integrators with correlated double sampling and hold capability).

For additional application flexibility (i.e., interdigitated hybrids) both left-side bonding and right-side bonding arrangements are available, as shown on Figure 4 (see Typical Applications). The MB Series is fabricated in standard Reticon CMOS silicon gate technology, allowing dual or single supply operation. Very small photodiodes are connected to the multiplex switches for ease in testing.

Key Features

- Left or right bond pad versions for interdigitated hybridizing
- Arrays with 64, 128, or 256 independent CMOS buffer-amplifier inputs
- Data storage and correlated double sampling
- Low noise - less than 1500 noise electrons for 1 MHz bandwidth, 15 μV rms
- Differential output
- Variable input-amplifier reference voltage to maximize dynamic range
- 100 micrometer bond-pad spacing
- 1 μV/100 electrons gain of pre-amplifier transducer
- Static shift-register for multiplexed clocking rate up to 5 MHz
- Low input bias current: 100 fA
- On-Chip bonding pad suitable for wire bonds or flip-chip bonds

General Description

These multiplexer arrays eliminate many of the problems encountered in other designs. For example, the input offset level is in the low millivolt range, thus permitting operation of germanium or other types of diode arrays in a zero-bias or

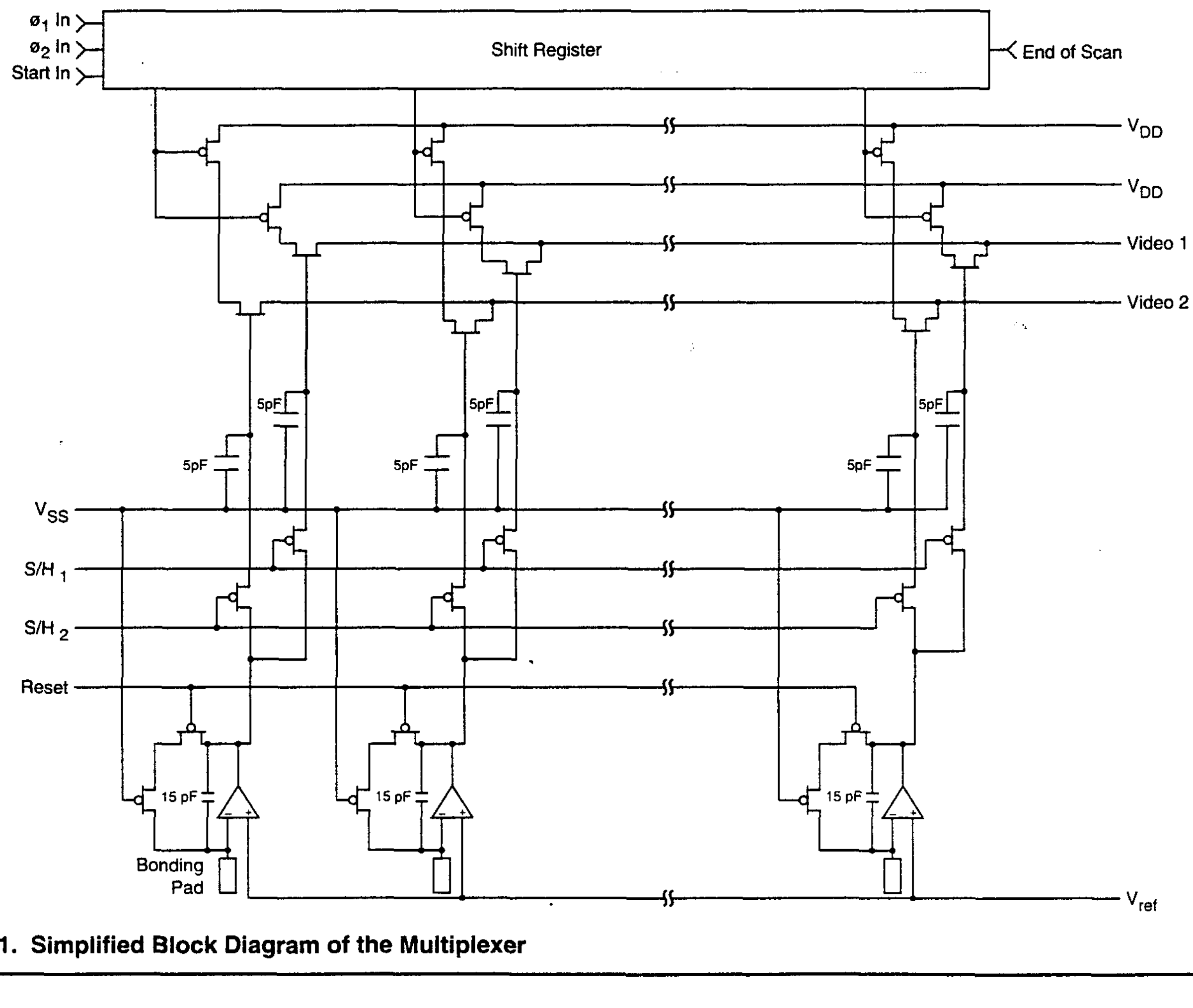


Figure 1. Simplified Block Diagram of the Multiplexer

photovoltaic mode, with extremely low leakage and minutes-long integration times. The correlated double sampling reduces further any leakage-caused offset as well as reducing low-frequency and switching noise. The timing of the switching of the analog buffers is derived by decimation from the multiplexer master clock, minimizing aliasing and other forms of switching noise.

Operation

Figure 1 shows the simplified schematic diagram of the Buffered MUX. The off-chip sensors are bonded to the pads provided. Each pad is associated with a channel which can convert an input current or charge to an output voltage by using internal 15 pF feedback integration capacitors.

Switched sampling circuits follow the capacitors, they are designed to provide, along with the buffer's gain, correlated double sampling for noise and offset reduction. The stored voltage-output samples appear at the gate of source-follower pairs, each pair of samples in turn are read out sequentially, becoming the active differential output when addressed by the shift-register multiplexer.

By activating one sample and hold switch at the start of the integration time, the other to end the integration, as shown in the timing diagrams of Figure 2, one of the sampled pair of data pulses contains any noise which may have occurred on the signal, the other contains any noise on the signal as well as the integrated and converted optical signal. The pair of pulses can be differentially combined to subtract off the noise which may have occurred.

A start pulse is required to initiate the scan (see start pulse specification). Upon entry of the start pulse, the stored voltage output samples are sequentially interrogated, under control of a static shift register, through the amplifier multiplex switches as the loaded bit is clocked down the shift register. An End-Of-Scan (EOS) signal occurs at the termination of each scan.

Reset switches are provided on each video for use in signal processing (see Typical Application).

The RL0064/0128/0256MB series is designed to operate with either a single-ended +5 to +10V supply, or with split supplies in the range of 5 to 10V total (±2.5 to ±5V). The channel inputs should be operated within 1V of either rail. Logic inputs are active-low and should swing rail to rail. Because of the various power-supply configurations, and the necessity for full-range swing, these logic inputs typically require external interface elements if combined with TTL logic elements.

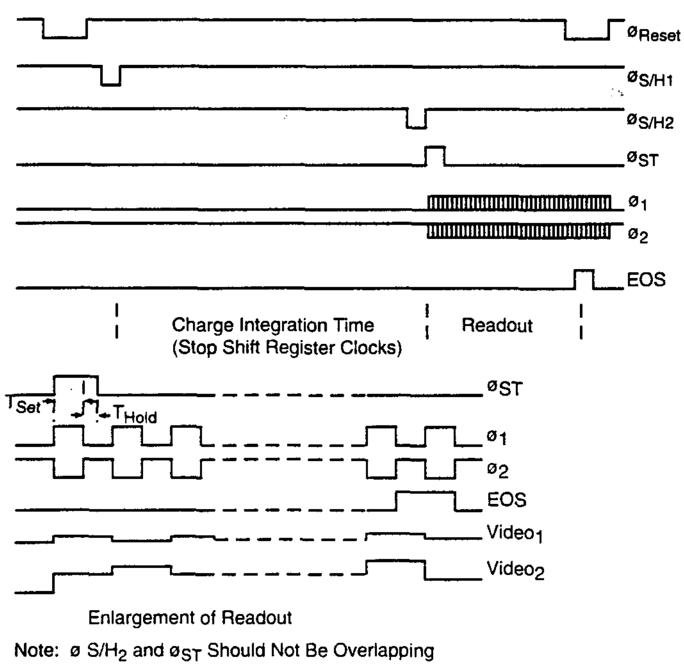
The photodiode sites, indicated in Figure 1, are used for testing. They are in parallel with a sensor pad, each represents a capacitance of .1 pF. Figure 2 depicts the general I/O timing requirements for the multiplexer family, the detailed clock specifications and timing are covered under Clock, Start, and, EOS Specifications. Figure 3 shows a typical measured noise versus frequency characteristic for the devices. Figure 4 shows the pinout arrangements, and Figure 5 shows the bond pad dimensions.

The total output noise measured at each S/H source follower output is less than 15 µV rms with a 1MHz bandwidth. When a detector is connected to the input pads, the equivalent output noise will be about 15 times the gain of the detector and multiplexer, or 15X(1+Cdet pF/15 pF) µV rms for each respective channel.

Electrical Specifications

1. Static Shift Register Clocks $ø_1$ and $ø_2$)

These clocks operate the shift register. For optimum multiplexer operation the clocks should not overlap, if the application requires clock overlap, they should not overlap by more than 50%. Since the shift register is static the clock rise (tr) and fall (tf) times are not as critical as with a dynamic shift register.



Note: ø S/H2 and øST Should Not Be Overlapping

Figure 2. General MB Series Timing Diagram

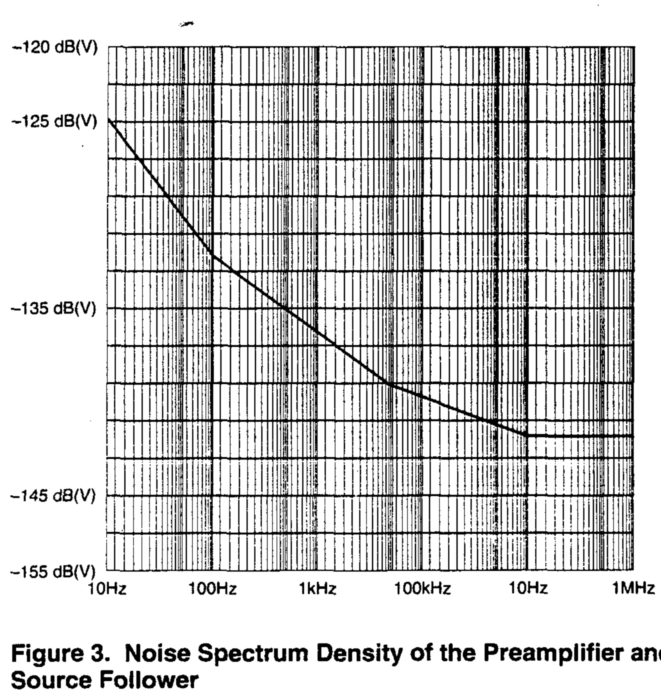


Figure 3. Noise Spectrum Density of the Preamplifier and Source Follower

2. Start Pulse ($\o_{st}$)

The start pulse loads the shift register with a voltage pulse to initiate the scanning process. It loads the register on each $\o_1$ high to low (positive to negative) transition as long as the start pulse is held high. Therefore to ensure that only one bit is loaded, the start pulse should be high during only one $\o_1$ falling edge. Figure 2 illustrates the timing relationship with respect to $\o_1$. The clock amplitude of $\o_{st}$ should be similar to the static shift register clocks ($\o_1$ and $\o_2$). The setup time (t_{set}) should be at least 30 ns, the hold time at least 20 ns.

Note: The shift register will load multiple bits if the start pulse is high for more than one $\o_1$ falling edge.

3. End of Scan (EOS)

The EOS pulse is generated at the output of the shift register to mark the termination of the scan. The last position accessed with the $\o_2$ clock going positive. On the next $\o_1$ rising edge, the output pulse is applied to the gate of the EOS transistor.

4. Sample and Hold (S/H1, S/H2)

The two sample and hold gates are used to facilitate the double correlated sampling. Each pair of gates are linked to one bonding pad then split to each of the video outputs. The circuit design for each sample and hold pair of gates are duplicates (see Figure 1). By sampling one gate immediate preceding the integration of the image and sampling the other to signify the end of the integration (immediately preceding the start pulse), a simple differential circuit as shown in Figure 8 would provide the user with a signal which contains only the integrated signal since all switching noise would have been subtracted out.

5. Bias

Bias is used to bias the operational amplifier, and should be connected to V_{SS} through a 100KΩ resistor in series.

Typical Application

Figure 7 shows the interdigitated application of the mirrored devices where both left and right side devices are used with an array of sensor diodes. All three chips are bonded in a hybrid substrate, the pads bonded as shown. The clock inputs and video outputs are then bonded either to another dice on the substrate, or to pin connections on a package to accommodate inputs and outputs for the clocks and the video. In this particular application photodiodes are accessed by using two devices, one for accessing the even numbered diodes, and the other for the odd numbered diodes in the array. When the multiplexers are scanned, integrated-image charges will appear in sequence at the output, each one proportional to the light exposure at a given site.

Reset switches are provided for use in signal processing. They can be used to integrate signal charges on a capacitor (i.e., the video line capacitor or an external capacitor) then used to reset the capacitor after each multiplex site has been read out (see Figure 2).

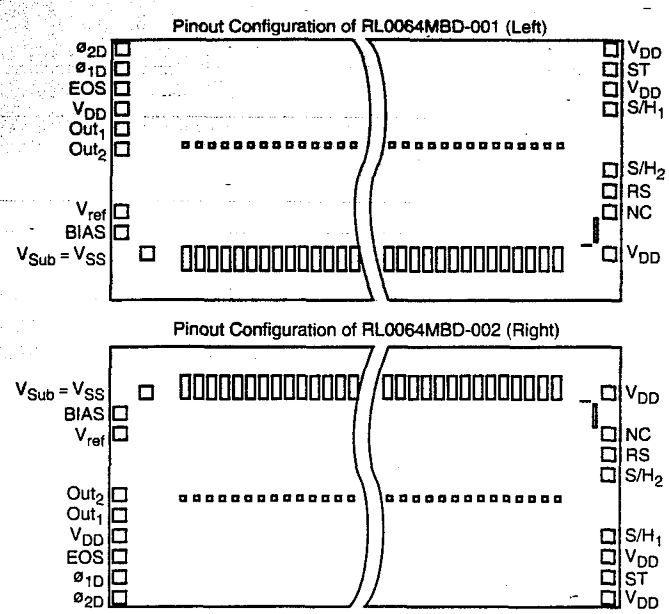


Figure 4. Pinout Configurations

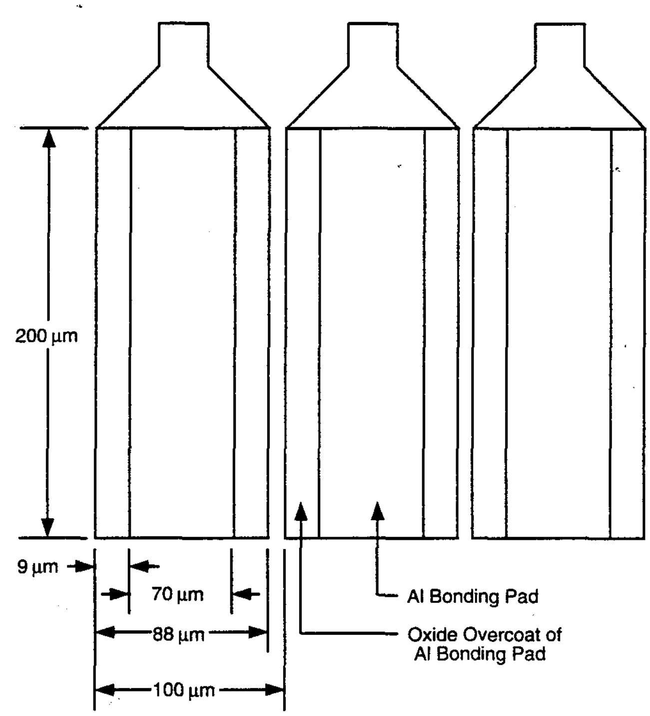


Figure 5. Switch Connection Bonding Pads

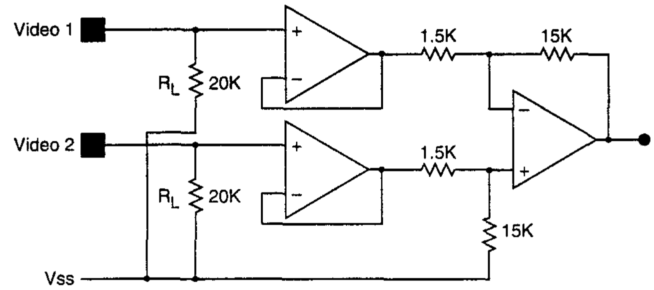


Figure 6. Differential to Single Video Output

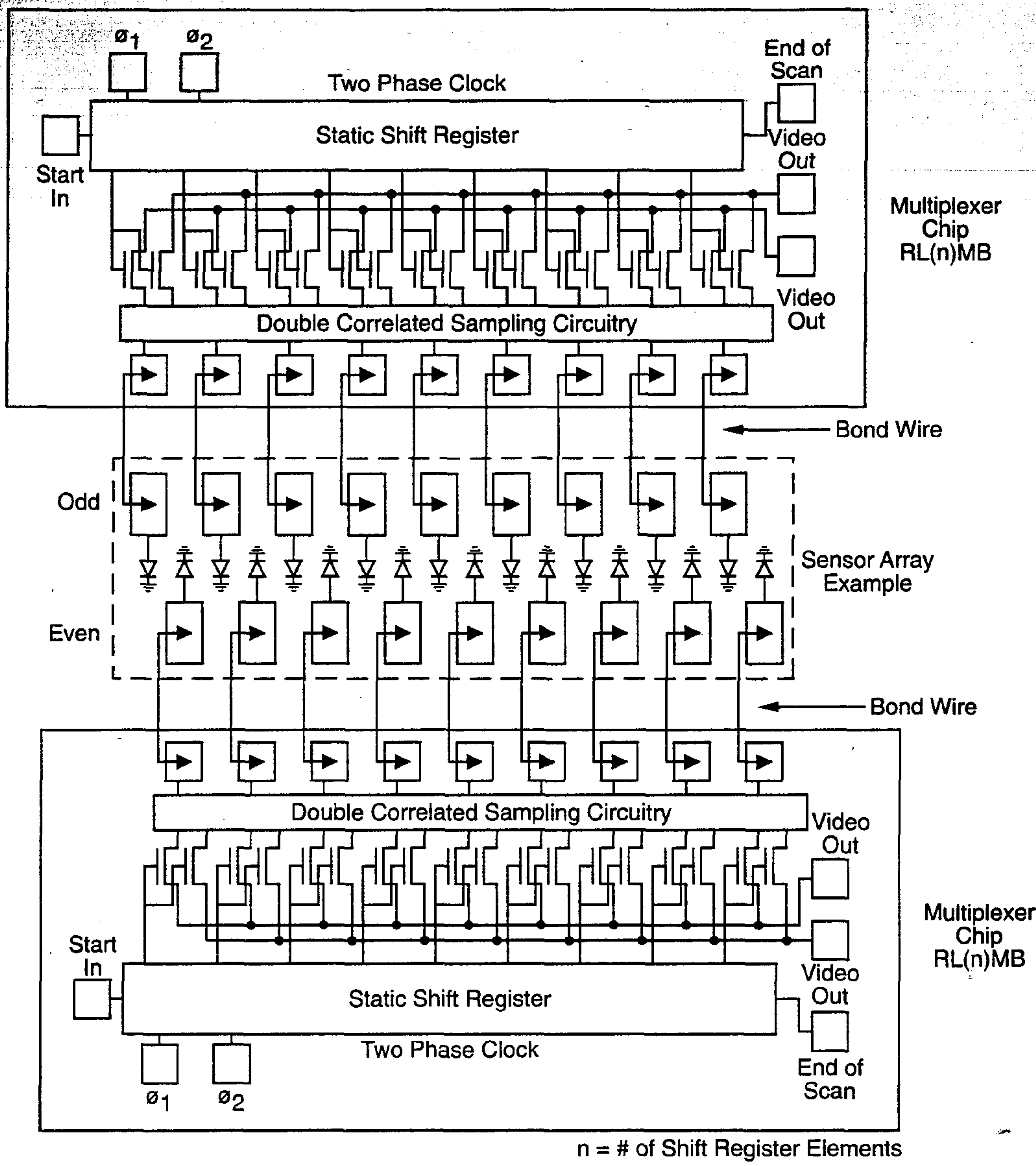


Figure 7. Interdigitated Array Using Left and Right MB Series Multiplexers

Table 1. Electrical Characteristics

Electrical, at T_a = +25°C, V_+ = +5V, V_- = -5V, V_{ref} = 0V, unless otherwise noted)

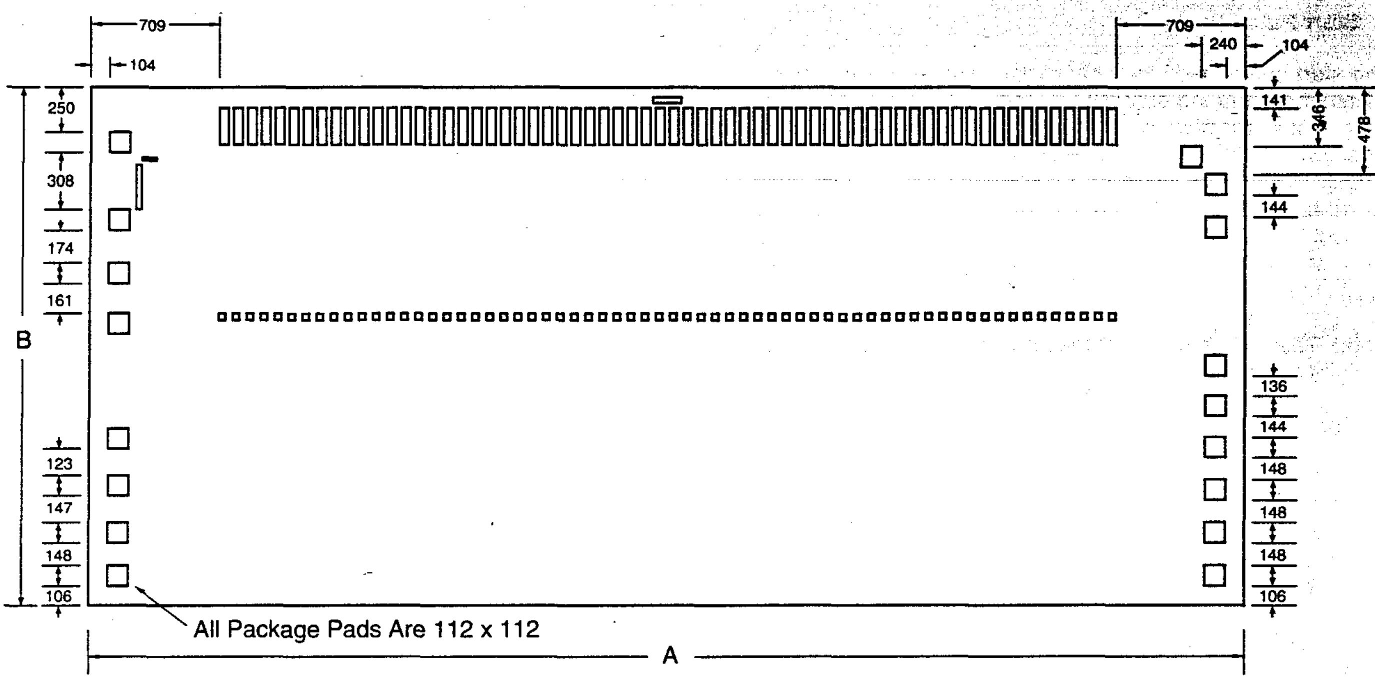
Parameter	Conditions	Min	Typ	Max	Units
Analog Input					
Input range				±100	µA
				±80	pC
Input impedance			Switched virtual ground		
Input offset voltage			±5	±10	mV
Digital inputs [1]					
V_{ih} (inactive)			V_{DD} (V_+)	V_{DD}	V
V_{il} (active)		V_{SS}	V_{SS} (V_-)		
Miscellaneous Charactertistics					
Data readout switching speeds [2]	1KΩ load	0		5	MHz
Sample pulse	Duration	2		10	µs
Reset pulse	Duration	2		10	µs
Slew rate	Input		1	V/µs	
Settling time	Input 0.1%		2	µs	
Settling time	Multiplexer		Limited by output R-C time constant		
Output swing	1KΩ load	V_{SS} + 2		V_{DD} - 1	V
Output current	Short circuit			15	mA
Output impedance	Dynamic		1000		Ω
Power supply	V_{DD} - V_{SS}	5	10	12	V
Supply current	RL0256MB			25	mA
Bias supply	Resistor to V_{SS}		100		KΩ

Notes:
1 Not normally capable of direct interface with TTL
2 Static shift register

Table 2. I/O Capacitance [1,2]

	256 MB	128 MB	64 MB
$\varnothing_1$	45	25	13
$\varnothing_2$	45	25	13
$\varnothing_{Start}$	5	5	5
EOS	5	5	5
S/H 1	40	20	10
S/H 2	40	20	10
Video 1	85	45	25
Video 2	85	45	25
Reset	40	20	10
Video Reference	125	65	35

Notes:
1 Capacitance in Picofarads
2 The readings are typical values



All Dimensions are in Microns ±1 Micron

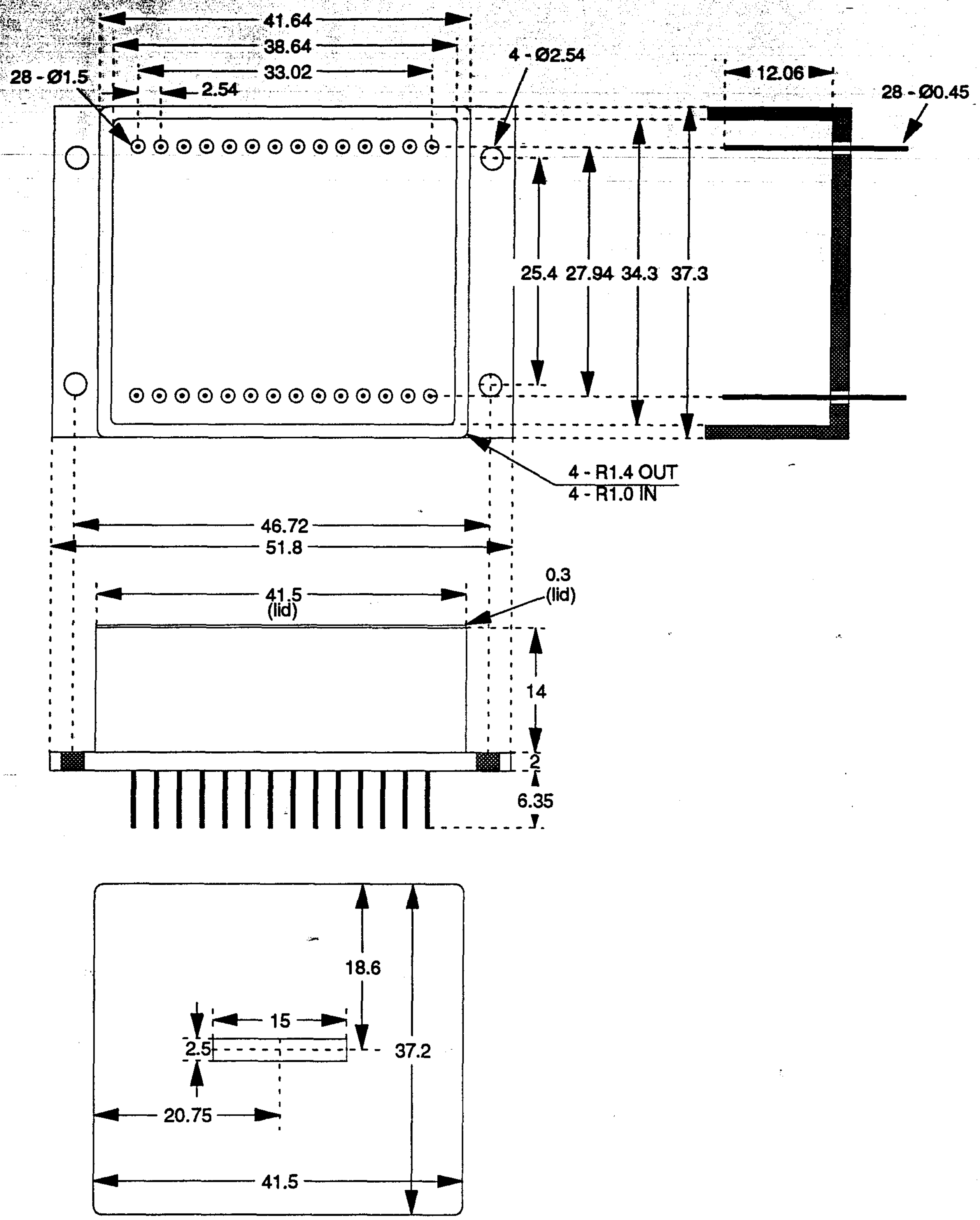
Part Name	A	B	Units
RL0064MB	7.88	2.83	mm
RL0128MB	14.28	2.83	mm
RL0256MB	27.08	2.83	mm

Figure 8. Die Dimensions and Pad Layout

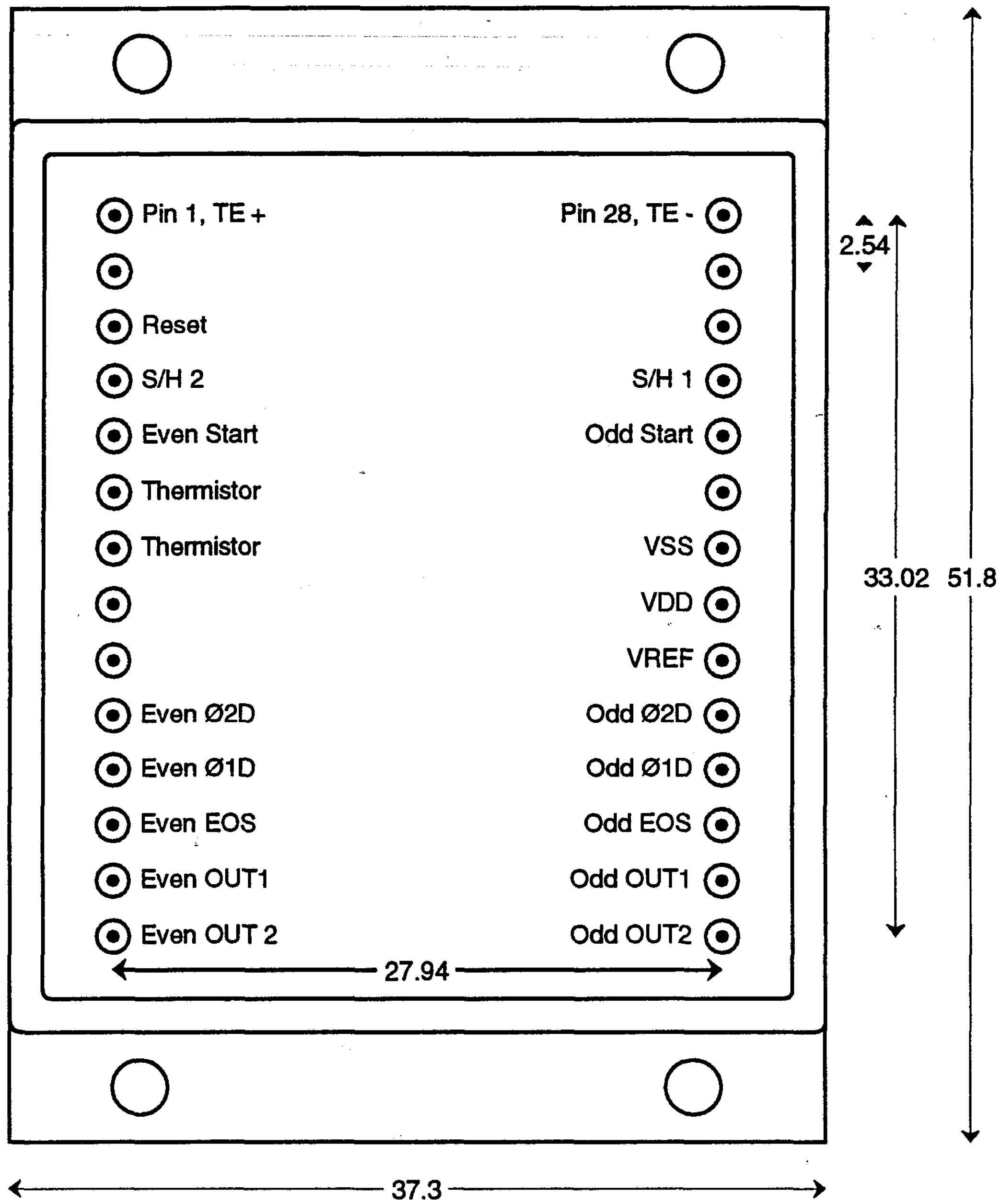
Ordering Information

Left	Right
RL0064MBD-001	RL0064MBD-002
RL0128MBD-001	RL0128MBD-002
RL0256MBD-001	RL0256MBD-002

055-0343
March 1993



Sensors Unlimited, Inc. 3490 U.S. Route 1 Princeton, N.J. 08540 Phone (609) 520-0610 Fax (609) 520-0638	Dwg.Title SU256L-TE Package		
	Dwg. No. 940523.002		
	Chk. By	Dwg. By mjc	Apr. By
	Scale 1.5:1	Dimensions	Date 5/23/94
Materials:	Comments:		



Sensors Unlimited, Inc. 3490 U.S. Route 1 Princeton, N.J. 08540 Phone (609) 520-0610 Fax (609) 520-0638	Dwg.Title SU256L-TE Pinouts		
	Dwg. No. 940523.001		
	Chk. By	Dwg. By mjc	Apr. By
	Scale 3:1	Dimensions mm	Date 5/23/94
Materials:	Comments:		

SENSORS UNLIMITED, INC.

Thermistor Calibration

Thermometrics Model HM75NF302J

SU256L-138

$$R(T_{(K)}) = R_0 e^{\left(\frac{A_1}{T^1}+\frac{A_2}{T^2}+\frac{A_3}{T^3}\right)}$$

$$\frac{1}{T_{(K)}} = A + B\{\ln R\} + C\{\ln R\}^3$$

Parameter	Value
R_0	2.16537×10^{-3}
A_1	$+4.2982242\times10^{3}$
A_2	$+2.8730737\times10^{4}$
A_3	-1.7506072×10^{7}
A	1.43239×10^{-3}
B	2.34815×10^{-4}
C	1.12420×10^{-7}

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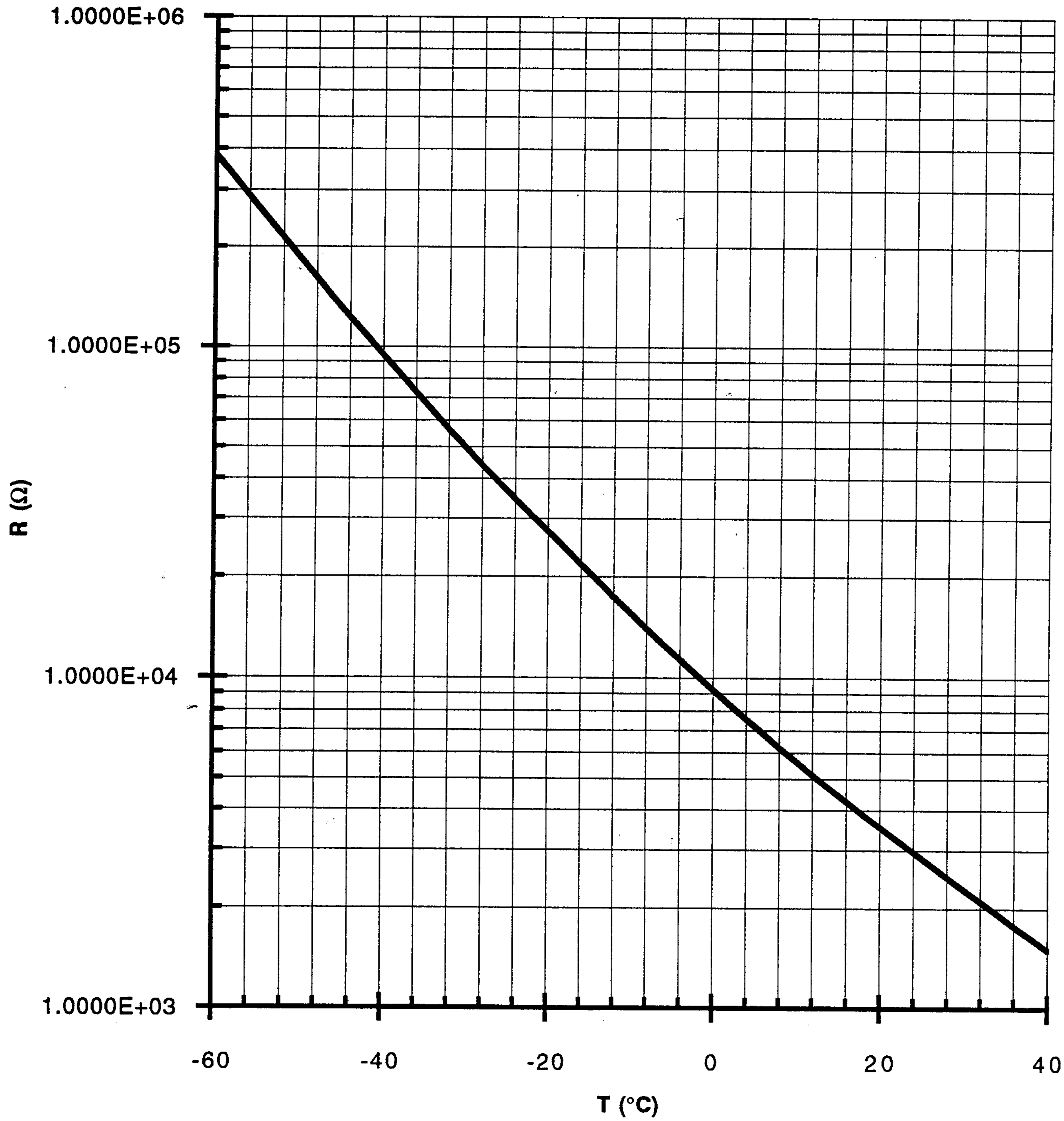
Thermistor Data, SU256L-138



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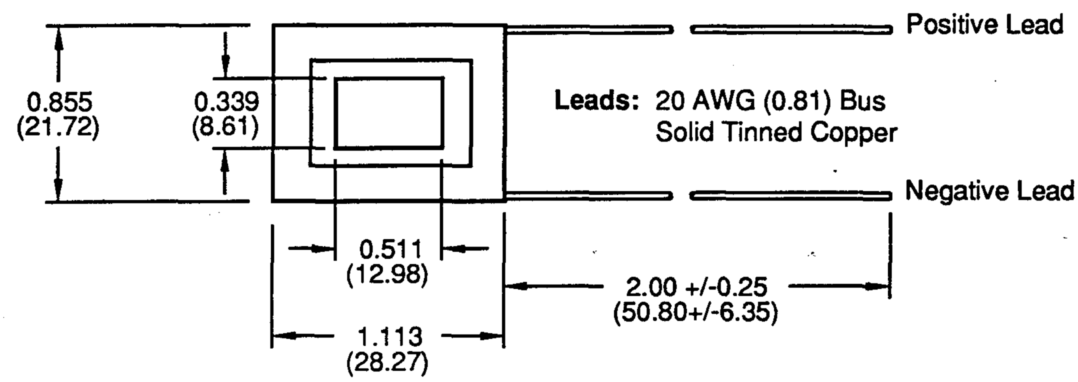
marlow industries, inc.®
10451 Vista Park Road • Dallas, Texas 75238-1645 • USA
TEL 214-340-4900 • TWX 910-860-5161 • FAX 214-341-5212

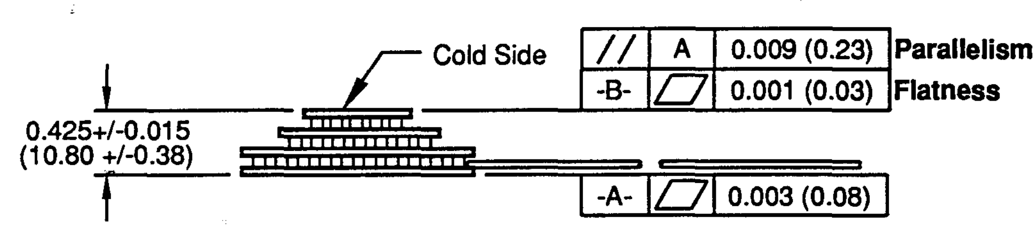
Thermoelectric Cooler MI3040

Performance Values

Hot Side Temperature (°C)	27°C	50°C
ΔTmax (°C-dry N_2):	98	111
Qmax (watts):	5.6	6.25
Imax (amps):	4.5	4.5
Vmax (vdc):	7.3	8.2
AC Resistance (ohms):	1.54	—

Mechanical Characteristics





Ceramics: Beryllium oxide (BC)

Dimensions in inches and (mm). Tolerances unless otherwise specified are ±.010 (0.25).

Model Number

The complete model number consists of the base model number followed by the type of metallization and type of ceramic (BC for beryllium oxide ceramics). See Installation recommendations below regarding metallization.

- -01 means both exterior ceramic surfaces are metallized
- -02 means hot side exterior ceramic surface is metallized
- -03 means no metallization

For example, an MI3040 with only the hot side metallized and above stated ceramics is specified as an MI3040-02BC.

Options

Pretinned metallized ceramic surface(s) with 96°C or 117°C solder.
Thermistor mounted on edge of cold side ceramic. (Calibration available.)

Installation

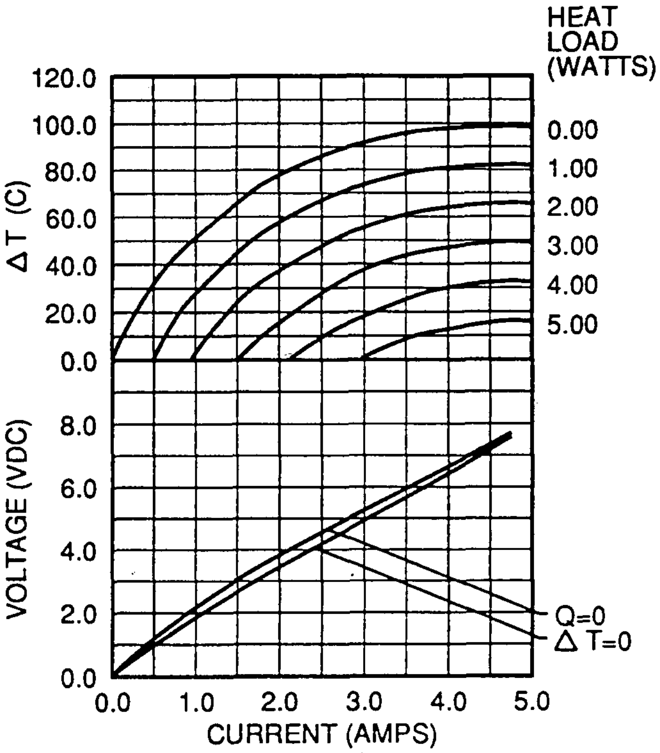
Recommended mounting methods: Bonding with thermal epoxy or soldering with metallized ceramics. For additional information, please refer to our TEC Installation Guide.

Thermoelectric Cooler **MI3040**

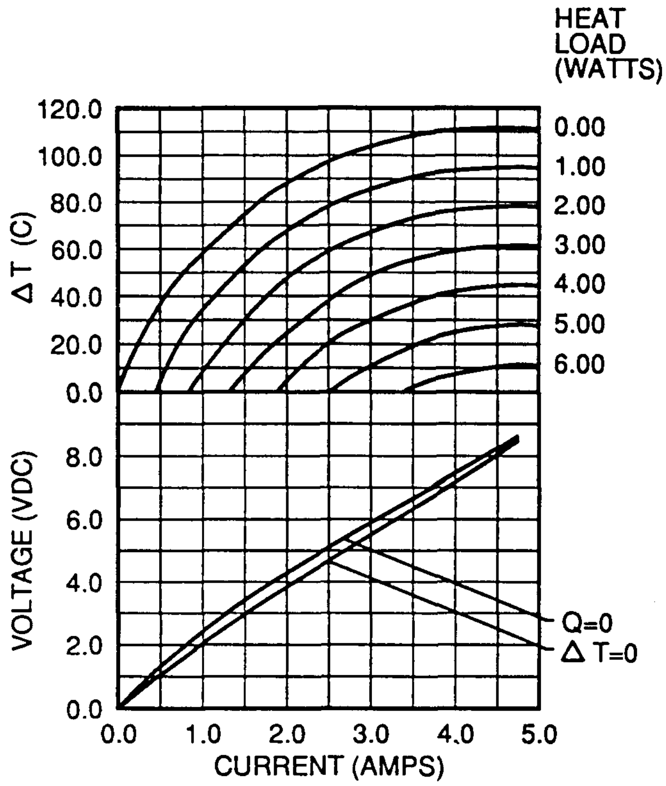
Typical Performance

Environment: One atmosphere dry nitrogen

Hot Side Temperature: 27°C



Hot Side Temperature: 50°C



For performance information in a vacuum or with hot side temperatures other than 27°C or 50°C, consult one of our Applications Engineers.

Operation Cautions

For maximum reliability, storage and operation below 85°C in a non-condensing environment is recommended. To minimize thermal stress, use linear/proportional temperature control or a similar method rather than an ON/OFF method.

Never abrade or machine beryllium oxide (BC) ceramics without following appropriate safety procedures. Material Safety Data Sheet avaliable upon request.

Ordering Information

Our Customer Service Department and Applications Engineers will assist you in selecting the cooler that best meets your needs. We can also provide support through local representatives in most international locations.

Please contact our home office:

marlow industries, inc.®
10451 Vista Park Road
Dallas, Texas 75238-1645 USA
TEL 214-340-4900 TWX 910-860-5161
FAX 214-341-5212

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FAX National (0737) 833140
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