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HARLID™

Data sheet, application note and evaluation board

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External client report / Electro-optical Engineering and Evaluation Center
DRDC Valcartier ECR 2004-300
December 2004

Canada

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **DEC 2004**	2. REPORT TYPE	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **HARLID,(Data sheet, application note and evaluation board) (U)**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Defence R&D Canada -Ottawa,3701 Carling Ave,Ottawa Ontario,CA,K1A 0Z4**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT
This contract report documents the latest version of the HARLID, sensor. It was written in order to help current and future customers to understand the technology and speed-up their development process. The information presented herein includes a data sheet of the HARLID, sensor, a detailed data sheet, an application note and a user’s manual for an evaluation board. The data sheet gives a general overview of the unit including the most important specifications. The detailed data sheet gives a description of the HARLID, principle-of-operation with an overview of its internal components. The application note shows an architecture to retrieve the angular information from the module outputs and typical amplifying circuits. Finally, the evaluation board user’s manual explains how to operate the evaluation board and perform a rapid assessment of the technology.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**40**	

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External client report / Electro-optical Engineering and Evaluation Center (EEEC/CIEE 3-022)

DRDC Valcartier ECR 2004-300

2004-12-24

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Abstract

This external client report documents the latest version of the HARLID™ sensor. It was written in order to help current and future customers to understand the technology and speed-up their development process. The information presented herein includes a data sheet of the HARLID™ sensor, a detailed data sheet, an application note and a user's manual for an evaluation board. The data sheet gives a general overview of the unit including the most important specifications. The detailed data sheet gives a description of the HARLID™ principle-of-operation with an overview of its internal components. The application note shows an architecture to retrieve the angular information from the module outputs and typical amplifying circuits. Finally, the evaluation board user's manual explains how to operate the evaluation board and perform a rapid assessment of the technology.

Résumé

Ce rapport pour client externe contient la documentation la plus récente concernant le module HARLID™. Il a été écrit dans le but d'aider les clients actuels et futurs à maîtriser la technologie et à réduire le temps de développement. L'information présentée comprend une feuille de donnée sur le HARLID™, une feuille de données détaillée, des notes d'application et un manuel d'usager pour un circuit d'évaluation. La feuille de données résume les performances et souligne les spécifications les plus importantes. La feuille de données détaillée décrit le principe d'opération du module et revoit les composants internes. Les notes d'application décrivent une architecture de circuits pouvant être utilisée pour extraire l'information angulaire des sorties du module ainsi que des circuits d'amplification typiques. Finalement, le manuel de l'usager du circuit d'évaluation explique comment utiliser le système et effectuer une évaluation rapide de la technologie.

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Executive summary

This contract report bundles the most recent information about the HARLID™ technology. HARLID™ has been on the workbench since the early nineties and has suffered a number of modifications throughout its development cycle. The technology is now considered as mature and an increasing number of customers are inquiring about its capabilities for military as well as civilian applications. Throughout the years, a large number of documents have been generated describing the various modifications/options that were added/removed from the original design. For example, the early prototypes were integrated in a large square package and were only used to demonstrate the principle. HARLID™ was then miniaturized and enclosed in its current package, a standard TO-8 case. Under this format, it was successively produced as 5-bit, 5 ½-bit and 6-bit units. Low and high sensitivity channels were introduced as well as 2-band detectors for wideband sensitivity. The latest version of the HARLID™ sensor now features hollow light-guides instead of the glass ones used in the earlier versions. A large number of more subtle modifications were also carried on to make sure that the unit could be produced cost efficiently.

PerkinElmer, the current licensee to manufacture the HARLID™ technology, has decided to contract DRDC – Valcartier to produce a summary of the most recent information about HARLID™ and to develop typical electronic circuits to interface with the module as well as an evaluation board. This work aimed at helping current and future customer understanding the technology and speed-up their development process.

The information presented herein includes a data sheet of the HARLID™ sensor, a detailed data sheet, an application note and a user's manual for an evaluation board. The data sheet gives the most important specifications about the unit including the pin-out and the look-up table required to convert measurements data into angles. The detailed data sheet gives a description of the HARLID™ principle-of-operation as well as a description of its internal components. Typical performance data is shown and the results are explained. The application note describes an architecture to extract the angular information from the module outputs. The layout of typical amplifying circuits and the expected waveforms measured at various stages of the circuit are also shown. The last document describes the evaluation board developed as part of the contract. The board was designed to get rapid access of the various HARLID™ features and to enable rapid prototyping. A list of the material included is given as well as an explanation on how to operate it.

The report also includes a bibliography listing the most important documents written on the subject. This work was done at DRDC-Valcartier between April and December 2003 under contract number CIEE-3-022.

Fortin, J., Dubois, J., Comeau, D. and Delisle, J., 2004. HARLID™, Data Sheet, Detailed Data Sheet, Application Notes and Evaluation Board. ECR 2004-300 DRDC - Valcartier.

Sommaire

Ce rapport de contrat rassemble les informations les plus récentes concernant la technologie HARLID™. HARLID™ a été en développement depuis le début des années 90 et a subi de nombreuses modifications. La technologie est maintenant considérée comme mature et de plus en plus de clients s'informent sur ses performances tant pour des applications militaires que civiles. Au fil des années, plusieurs documents ont été produits résumant chacune des modifications/options ajoutées/retranchées du design original. À titre d'exemple, les premiers modules HARLID™ étaient intégrés dans de larges boîtiers carrés et ne furent utilisés que pour démontrer le concept. La technologie a par la suite été miniaturisée et introduite dans boîtier actuel, de type standard TO-8. Sous ce format, des générations de HARLID™ à 5, 5 ½ et 6 bits ont été produites. Des canaux à hautes et basse sensibilité ont été ajoutés ainsi que des détecteurs à large bande. La dernière version du module inclue des guides de lumière creux à la place des guides en verre utilisés dans les premières versions. Plusieurs modifications plus subtiles ont aussi été apportées afin d'assurer une production rentable du produit.

La compagnie PerkinElmer, opérant sous licence pour manufacturer le HARLID™, a demandé l'aide de RDDC – Valcartier pour rassembler les informations les plus récentes sur le HARLID™ et développer des circuits d'interface typiques de même qu'un circuit d'évaluation. Ce travail a été fait dans le but d'aider les clients actuels et futurs à mieux maîtriser la technologie et à réduire leur temps de développement.

L'information présentée dans ce rapport inclue une feuille de données sur le module HARLID™, une feuille de donnée détaillée, une note d'application et un manuel de l'usager pour le circuit d'évaluation. La feuille de données résume les spécifications les plus importantes du HARLID™ incluant une description de chaque broche et la table de translation requise pour convertir les données mesurées en angles. La feuille de données détaillée donne le principe d'opération du module ainsi qu'une description de ses composants internes. Des graphiques représentant les performances attendues sont montrés et expliqués. La note d'application décrit une architecture valide pour extraire l'information angulaire à partir des sorties du module. Les schémas électriques de circuits d'amplification typiques y sont montrés au côté de graphiques représentants les formes d'ondes attendues à chaque étage du circuit. Le dernier document décrit le circuit d'évaluation développé pendant le contrat. Celui-ci a été développé afin de faciliter l'accès aux multiples fonctions du HARLID™ et de faciliter le prototypage. Une liste détaillée du matériel inclus avec le circuit d'évaluation est donnée de même que le mode d'emploi.

Le rapport inclut aussi une bibliographie énumérant les principaux écrits sur le sujet.

Ce travail a été fait au RDDC – Valcartier entre avril et décembre 2003 sous le contrat numéro CIEE-3-022

Fortin, J. Dubois, J., Comeau, D. and Delisle, J., 2004. HARLID™, Data Sheet, Detailed Data Sheet, Application Notes and Evaluation Board. ECR 2004-300 RDDC - Valcartier.

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Introduction

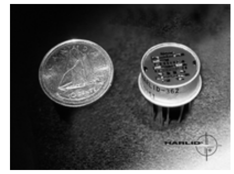
This report is the result of a contract with PerkinElmer aiming at documenting the latest version of the HARLID™ sensor. The work was done in order to help current and future customer understand the technology and speed-up their development process. The HARLID™ sensor has been on the workbench since the early nineties and has evolved quite significantly over the time. The early prototypes were integrated in a large square (40mmx40mm) package and used only as a proof-of-principle. HARLID™ was then miniaturized and enclosed in its actual package, a standard TO-8 case. Under this format, it was successively produced as 5-bit, 5 ½-bit and 6-bit units. Low and high sensitivity channels were introduced as well as 2-band detectors for wideband sensitivity. The latest version of the HARLID™ sensor features hollow light-guides instead of the glass ones used in the earlier versions. Throughout the development cycle, a number of other subtle modifications were carried on to make sure that the unit could be produced cost efficiently.

The information presented herein includes a data sheet of the HARLID™ sensor, a detailed data sheet, an application note and a user's manual for an evaluation board. The data sheet gives the most important specifications about the unit including the pin-out and the look-up table required to convert measurements into angles. The detailed data sheet gives a description of the HARLID™ principle-of-operation as well as a description of its internal components. Typical performance data is shown and the results are explained. The application note was produced in order to help users develop with the module and to speed-up prototyping. An architecture to extract angular information is given with the layout of typical amplifying circuits and graph showing expected waveform at various stages of the circuit. The last document describes an evaluation board developed under this contract. The board was designed to get rapid access of the various HARLID™ features and to enable rapid assessment of the technology. A list of the material included is given as well as an explanation on how to use the evaluation board.

This reports includes a bibliography where the most important contract reports and articles about the HARLID™ technology are listed.

HARLID ™

Data Sheet



General Description

The HARLID™ module is designed for use in laser warning receivers (LWR) to detect and provide angle of arrival (AOA) information for incident laser beams from rangefinders, target designators and active laser EO systems. The TO-8 detector module makes use of 9-element silicon and InGaAs detector arrays assembled in a sandwich configuration, in conjunction with a digital Gray code mask which provides an encoding of the signal for angle determination. The silicon and InGaAs detector array assemblies have a combined spectral sensitivity range between 500 and 1650 nm. Two side-by-side array assemblies provide high and low sensitivity channels, the first having a quantum efficiency over the full wavelength range while the second is attenuated by 15 dB to extend the dynamic range for the detection of high power lasers. The module field of view (FOV) is ±46.5° in both azimuth and elevation and the angular resolution from a 6-bit digital word is as low as ±0.8° in one plane - either azimuth or elevation - depending on the module orientation. Three reference channels are provided in each array for signal level determination.

Applications

- Laser warning receivers
- Position determining systems
- Directional aids
- Vehicle guidance

Features

- A low cost primary detector module for military EO warning and countermeasure systems.
- Wavelength range of 500 to 1650 nm
- Low and high sensitivity channels for wide dynamic range
- ±46.5° field of view in both azimuth and elevation
- ±0.8° angular resolution in one plane

Quality, Reliability and Testing

The HARLID™ module is compact and rugged, and has been designed to meet a full range of military specifications. The following MIL-STD-883 criteria have been met:

1) Acceleration testing, Method 2001.
2) Mechanical shock and sine vibration, Methods 2002 and 2007, respectively.
3) Temperature cycling, Method 1010.

All elements of all modules are measured to determine that the noise and dark current are within the specifications. Short and long wavelength illuminations are used to verify that all elements are connected. Responsivity, capacitance and response time are measured on a sample basis for each detector wafer lot. For angle readout verification, the modules are configured for azimuth measurements (at elevation angles of –45°, 0° and +45°) and transition angles on the high sensitivity channel for the 5th bit are measured (at 633 nm), as well as the transition for the 1st bit, which verifies pointing accuracy of the module (with respect to the plane of the base). A total of 16 angles are measured and compared with the design values. The measurement of a sampling of angles across the field of view is considered to fully define the angular performance of the module since the Gray code mask defines the remaining angles and it is highly accurate.

Ordering Information

For more information on pricing and availability, please contact PerkinElmer Optoelectronics- Canada, 22001 Dumberry Rd. Vaudreuil, Quebec, J7V 8P7, Canada.

Phone: 450-424-3300
Fax: 450-424-3411

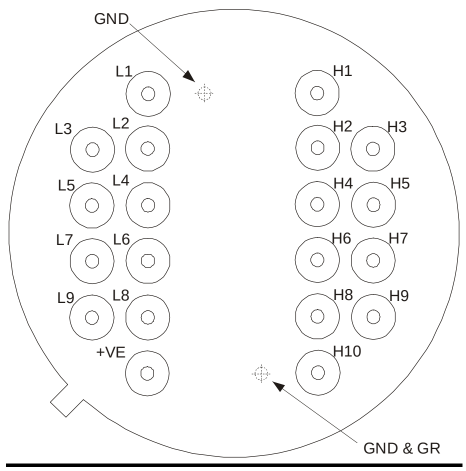
PerkinElmer Optoelectronics- Canada is licensed to produce the HARLID™ module by the Canadian Department of National Defence.

The HARLID™ module was developed by Defence R&D Canada (DRDC) - Valcartier, Quebec, Canada and is covered by US Patent 5428215 (95/06/27).

Electrical Characteristics (High Sensitivity Array)

Parameter	**Min**	**Typ**	**Max**	**Unit**
Junction area (total)		0.5		mm^2
Photosensitive area (per element, high sensitivity)		0.075		mm^2
Bias voltage		12		V
Breakdown voltage		25		V
Dark current (per element)			20	nA
Guard ring dark current			200	nA
Noise current (per element)			0.5	pA/√Hz
Capacitance (per element Si + InGaAs)		12		pF
Response time		5		ns
Spectral response	500		1650	nm
Field of view (azimuth and elevation)			±46	°
AOA accuracy azimuth (not including 0° pointing error) RMS error (σ)		0.8	1.0	°
Point error (μ)			1.0	°
Responsivity at 500 nm at 900 nm at 1064 nm at 1540 nm		 0.2 0.4 0.5 0.7		A/W
Operating temperature	-40		+85	°C
Dynamic range (of each photodiode)		60		dB
Signal ratio (unmasked to masked photodiodes)		12		dB
Attenuation of low sensitivity channel (WRT high sens. ch.)		15		dB

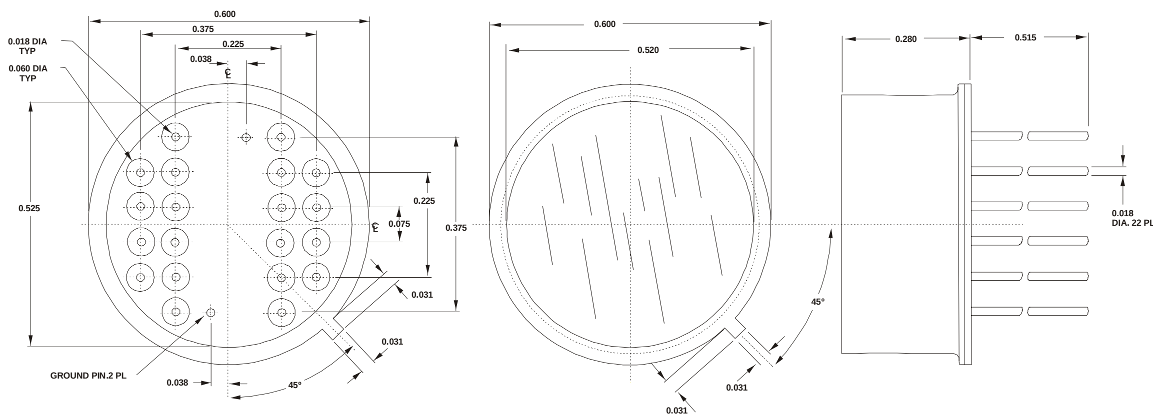
Pin Layout (Bottom View)



H1, L1	BIT 3
H2, L2	REFERENCE CHANNEL 1
H3, L3	BIT 4
H4, L4	BIT 6
H5, L5	REFERENCE CHANNEL 2
H6, L6	BIT 5
H7, L7	BIT 1
L8	LOW SENSITIVITY REFERENCE CHANNEL 3
H8	HIGH SENSITIVITY InGaAs REFERENCE CHANNEL 3[1]
H9, L9	BIT 2
H10	HIGH SENSITIVITY SILICON REFERENCE CHANNEL 3[1]
+VE	COMMON BIAS VOLTAGE
GND & GR	CASE GROUND AND GUARD RING[2]

1) Separate pins are used to make available the high sensitivity InGaAs and silicon reference channel 3 and perform coarse wavelength identification. If both detectors respond, the wavelength is likely to be in the transition region, specifically 1064 nm.
2) The guard rings for the two detector arrays are bounded directly to the package.

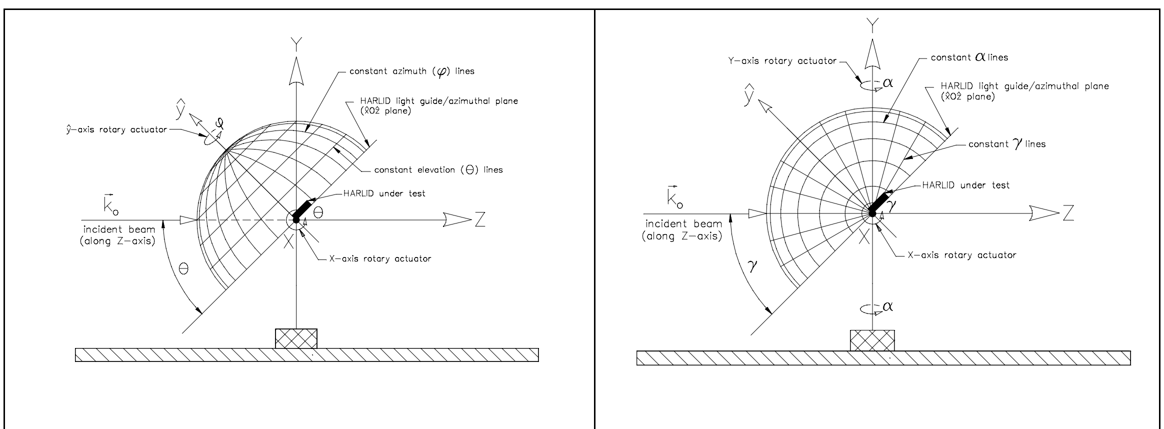
Mechanical Structure (Top View)



HARLID™ Coordinate System

When testing the HARLID™ module, it is very important to use an experimental setup that references the module to an orthogonal set of spherical coordinates. Such a reference system is shown on the left-hand side of the figure below. In that situation, the HARLID™ front window faces the laser radiation and the module's light channels are aligned parallel to the $\hat{x}O\hat{z}$ plane. In other words, the module's header tab is located down and to the right (i.e. 4:30 o'clock position) when looking at it from the front. In this configuration, azimuth angles are defined by φ (rotation around $\hat{y}$) and elevation angles are given by θ (rotation around the X-axis).

The use of any other reference system, such as the one shown on the right-hand part of the figure, should be used with caution, as it results in a non-orthogonal configuration and requires coordinate transform to recover the azimuth and elevation angles from the angular displacement made. In the case depicted below, the module is rotated around the X and Y-axes leading to angular displacements (α and γ) instead of the true elevation and azimuth angles (θ and φ).



Correct coordinate system | Wrong coordinate system

Azimuth angle sign convention: Assuming the correct coordinate system shown above, positive azimuth angles are defined to the right and negative angles are to the left when viewing the module from the front. Zero azimuth angle corresponds to the normal to the base of the module.

Angle codes: The 6-bit HARLID™ module divides the field of view into 64 intervals that are fairly evenly spaced within the design range of angles for the module, which is approximately 100.8° or ±50.4°. The following table relates the bit readout codes to the azimuth angle. 1's meaning that an element is illuminated for a particular angle and 0's meaning it is not.

Transition angles: Between each of the 64 angular intervals, there is a transition in which one of the HARLID™ elements changes from a "1" to a "0" or vice versa. This angle occurs midway between the two angles on either side, defining the centers of the angular range for the two corresponding bit codes. There are in total 63 transition angles, located at intervals of about 1.6°. Therefore, each angle quoted in the following table represents the center of an angular interval of approximately ±0.8°.

High and low sensitivity offset: Because there is a spatial separation of the two rows of detector elements for the high and low sensitivity channels and a single Gray code aperture mask defines the angles, there is an offset between the high and low sensitivity angles and the readout codes for the two detector arrays are different.

Field of view: The geometry of the design limits the field of view of each array of detectors. Angles higher than +46.5° are beyond the field of view of the high sensitivity channel, while negative angles higher than –46.5° fall outside the field of view of the low sensitivity channel. Therefore, the HARLID™ field of view is quoted to be ±46.5°.

It should be noted that the transition of BIT 1 does NOT occur at zero azimuth angle but at +6.25° for the high sensitivity channel and -6.25° for the low sensitivity channel.

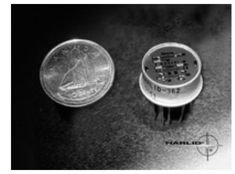
High Sensitivity	Low Sensitivity	ANGLE CODE						High Sensitivity	Low Sensitivity	ANGLE CODE					
Angle (°)	Angle (°)	BIT 1	BIT 2	BIT 3	BIT 4	BIT 5	BIT 6	Angle (°)	Angle (°)	BIT 1	BIT 2	BIT 3	BIT 4	BIT 5	BIT 6
52.1	46.8	1	0	0	0	0	0	5.5	-7	0	1	0	0	0	0
50.7	45.1	1	0	0	0	0	1	3.9	-8.6	0	1	0	0	0	1
49.3	43.3	1	0	0	0	1	1	2.3	-10.1	0	1	0	0	1	1
47.9	41.6	1	0	0	0	1	0	0.7	-11.6	0	1	0	0	1	0
46.5	39.8	1	0	0	1	1	0	-0.8	-13.2	0	1	0	1	1	0
45	38	1	0	0	1	1	1	-2.5	-14.7	0	1	0	1	1	1
43.6	36.3	1	0	0	1	0	1	-4.1	-16.2	0	1	0	1	0	1
42.2	34.5	1	0	0	1	0	0	-5.7	-17.7	0	1	0	1	0	0
40.8	32.8	1	0	1	1	0	0	-7.3	-19.2	0	1	1	1	0	0
39.4	31.1	1	0	1	1	0	1	-9	-20.6	0	1	1	1	0	1
38	29.3	1	0	1	1	1	1	-10.6	-22.1	0	1	1	1	1	1
36.6	27.6	1	0	1	1	1	0	-12.3	-23.6	0	1	1	1	1	0
35.1	25.8	1	0	1	0	1	0	-13.9	-25	0	1	1	0	1	0
33.7	24.1	1	0	1	0	1	1	-15.6	-26.5	0	1	1	0	1	1
32.3	22.4	1	0	1	0	0	1	-17.3	-28	0	1	1	0	0	1
30.8	20.7	1	0	1	0	0	0	-19	-29.4	0	1	1	0	0	0
29.4	19	1	1	1	0	0	0	-20.7	-30.8	0	0	1	0	0	0
28	17.3	1	1	1	0	0	1	-22.4	-32.3	0	0	1	0	0	1
26.5	15.6	1	1	1	0	1	1	-24.1	-33.7	0	0	1	0	1	1
25	13.9	1	1	1	0	1	0	-25.8	-35.1	0	0	1	0	1	0
23.6	12.3	1	1	1	1	1	0	-27.6	-36.6	0	0	1	1	1	0
22.1	10.6	1	1	1	1	1	1	-29.3	-38	0	0	1	1	1	1
20.6	9	1	1	1	1	0	1	-31.1	-39.4	0	0	1	1	0	1
19.2	7.3	1	1	1	1	0	0	-32.8	-40.8	0	0	1	1	0	0
17.7	5.7	1	1	0	1	0	0	-34.5	-42.2	0	0	0	1	0	0
16.2	4.1	1	1	0	1	0	1	-36.3	-43.6	0	0	0	1	0	1
14.7	2.5	1	1	0	1	1	1	-38	-45	0	0	0	1	1	1
13.2	0.8	1	1	0	1	1	0	-39.8	-46.5	0	0	0	1	1	0
11.6	-0.7	1	1	0	0	1	0	-41.6	-47.9	0	0	0	0	1	0
10.1	-2.3	1	1	0	0	1	1	-43.3	-49.3	0	0	0	0	1	1
8.6	-3.9	1	1	0	0	0	1	-45.1	-50.7	0	0	0	0	0	1
7	-5.5	1	1	0	0	0	0	-46.8	-52.1	0	0	0	0	0	0

Notes:

1) All angles are with respect to the package axis.
2) The specified angle in each case is at the center of a ±0.8° range.
3) Shaded angles are outside the nominal field of view.

HARLID ™

Detailed Data Sheet



PRINCIPLE OF OPERATION

The HARLID™ module consists of four basic components. These are 1) an aperture mask (referred to as the Gray code mask), having an appropriate number of channels, in which the rows of apertures are arranged into a digital configuration, 2) a light-guide system in which optical isolation is maintained between the signals in the various channels, 3) a secondary aperture mask array, which works in conjunction with the digital (Gray code) mask to define the angle of incidence of the incoming light, and 4) a linear detector array having a number of elements that matches that of channels in the Gray code mask.

The basic operation of the HARLID™ is illustrated in Figure 1. As the figure shows, the incident illumination passes through the digitally arranged apertures of the Gray code mask to illuminate the elements of the detector array located below. The elements of the detector array are either illuminated or dark, depending on the channel and angle of incidence of the light passing through the Gray code aperture mask. Clearly, the angular resolution achievable depends on the number of channels or “bits” in the module, and the design field of view. For example, in a simplistic version of a 6-bit (channel) module, a 90º field of view can be divided into 64 discrete angular intervals, making each interval 1.4º wide, for an angular resolution of ± 0.7º. As the figure shows, the coding operates in only one axis at a time, so that a second similar module would be required to obtain angular resolution in the other axis. In a practical device, reference channels must be included in the module in order to establish signal levels for determining whether the signal in a detector element is a “1” or a “0”.

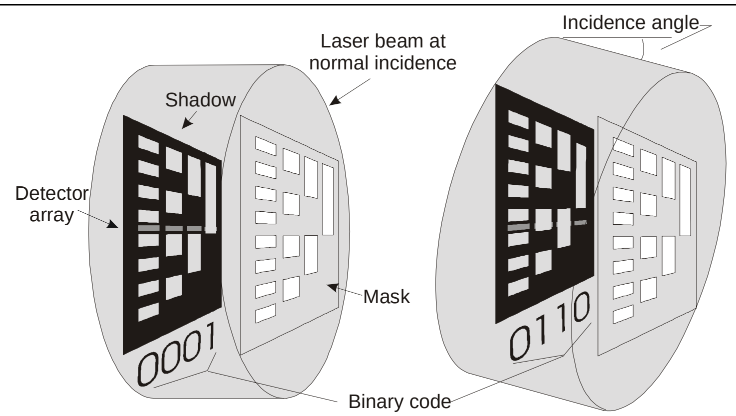


Figure 1: HARLID™'s principle of operation

The light guide in the HARLID™ module is an array of optical channels bounded on each side by highly reflecting mirrors, to confine the light to a particular channel and prevent illumination of adjacent elements of the detector array. For a module positioned to achieve angular resolution in the azimuth direction, the reflecting mirrors bounding the optical channel may have minimal function when the elevation component of the optical signal is zero. However, for light incident at large elevation angles, the mirrors bounding the sides of the optical channel are essential, not only to prevent the light from illuminating adjacent detector elements, but to ensure that light reaching the detector element has minimal loss of signal after several reflections.

DETAILED DESCRIPTION

The HARLID™ module's principle of operation has been described in the previous section. It was noted that reference channels are required in the module in order to establish signal levels to decide whether a signal is a "1" or a "0". The reference channels are designed to be illuminated over the full field of view of the module. Field experiments have shown that it is highly desirable to have a reference channel positioned adjacent to each digital-signal channel where each signal bit is compared with the closest reference to determine whether it is illuminated or not. In order to achieve this in a 6-bit module, 3 reference channels are required. Thus, the 6-bit module described herein has been designed to have 9 channels. Figure 2 shows the pattern of the Gray code aperture mask. The long apertures in the 2nd, 5th, and 8th positions are the reference channel apertures, while the other six rows on the mask are the six digital aperture patterns. The Gray code aperture mask is a thin metal sheet, and is made using photolithographic and chemical etching processes. The mask has a total thickness of 0.003 inches, but makes use of a nickel-cladding layer of 0.0005 inches in which the apertures are defined. The Gray code has been chosen as the digital pattern to make sure that a single bit varies at a time when the incident angle is varied. The dimensions of the apertures are controllable to within approximately ± 0.0001 inches, which represents an error of less than 0.1°. The 6-bit digital pattern has been designed to achieve – as nearly as possible – equal angular steps for the 64 intervals. Moreover, the sizes of the apertures have been designed to take into account the angle of the incident light.

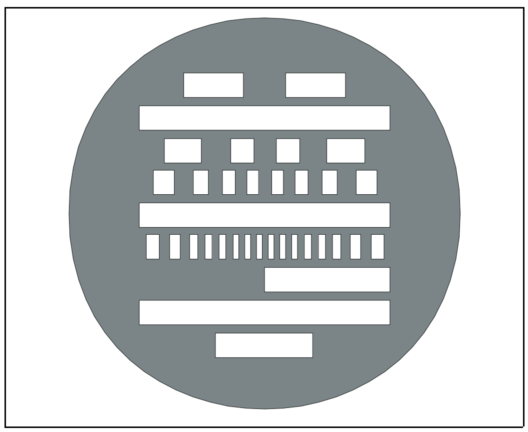


Figure 2: 6-bit gray code mask

In order to achieve an optical dynamic range of 60 db or more – as required by most laser warning receivers – two detector arrays have been included in the design. The arrays are positioned side by side on the same detector chip, but are separated to avoid any significant crosstalk. One of the arrays receives direct radiation through the mask apertures, while the other is attenuated by approximately 15 db. This architecture was chosen to reduce the requirement on the electronic amplifying circuits. Since there is a spatial separation between the two rows of 9 detector elements – high and low sensitivity – and both arrays are illuminated through the same Gray code aperture mask, then, it is clear that the bit readout codes for the two arrays are different at a given angle.

In the HARLID™ module, each detector is made of layers of silicon and InGaAs assembled in a "sandwich" configuration. The spacing of the elements of the two detector arrays has been designed to match each other precisely. Both detector arrays are fabricated using n-type substrates so that the common surfaces are soldered together with thin solder preforms and used to apply a unique bias voltage (15V). The junction surface of the elements of the InGaAs array are mounted down to the main ceramic of the assembly using small solder preforms and the elements of the silicon array – positioned on the top – are bonded to the metal traces connecting the corresponding InGaAs elements. Light is incident on the junction surface of the silicon detector elements. In this assembly, short wavelength light incident on the (upper) silicon detector is absorbed in the silicon while longer wavelength light passes through the silicon to be absorbed in the InGaAs. In the spectral transition region, light is absorbed by both detectors. Both the front and back surfaces of the silicon detector elements are coated in order to minimize reflective losses, as is the front surface of the InGaAs detector elements.

Every detector element is assembled according to the procedure stated above but the high-sensitivity reference channel 3. In this case, the signal from the silicon and the InGaAs detector elements are brought to separate pins to provide a means of performing coarse wavelength identification. Roughly, the silicon detectors respond to wavelength shorter than 1 um, whilst the InGaAs detectors respond to wavelength longer than 1 um. Both detectors respond equally to radiation around 1 um.

Figure 3 shows a schematic diagram of the detector sandwich assembly. The secondary aperture mask, as defined previously, is essentially a metallization layer placed on top of the silicon detector elements to confine the light sensitive area.

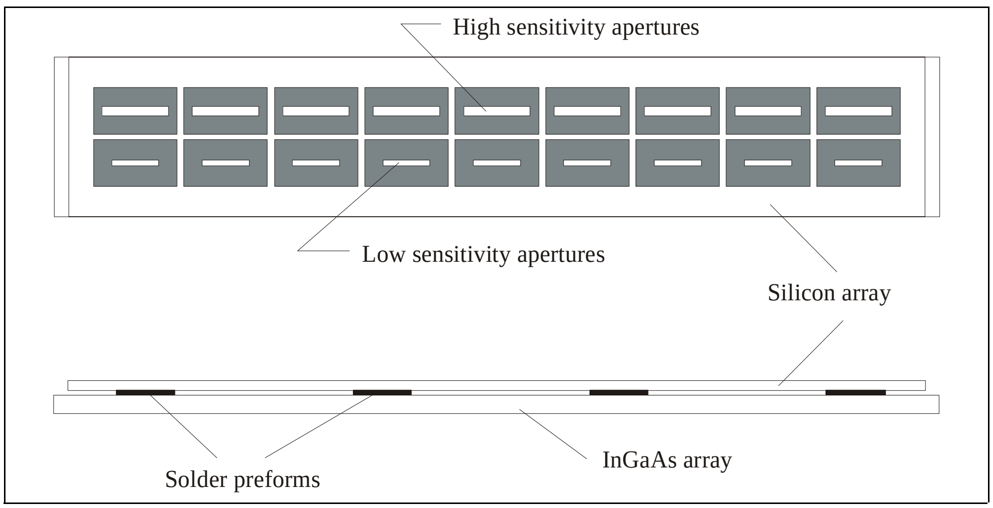


Figure 3: Sandwich detector array assembly

Light incident on the top edge of the module front window is guided down to the elements of the detector array located at the bottom by air light guides. The air light guide consists of a series of highly reflecting spacers assembled on a grooved or slotted ceramic base, somewhat as shown in Figure 4. The large opening in the central region of the ceramic support is intended to provide clearance for the detector array assembly. The smaller circular holes in the ceramic are required to clear the pins of the header. In the light guide assembly process, jigging is required to hold the spacer/reflectors in a vertical orientation while they are tacked in place with the use of a black epoxy. The addition of black metal cover tabs epoxied over the ends of the light guide channels strengthens the assembly and blocks the entry of stray light from the ends of the guide.

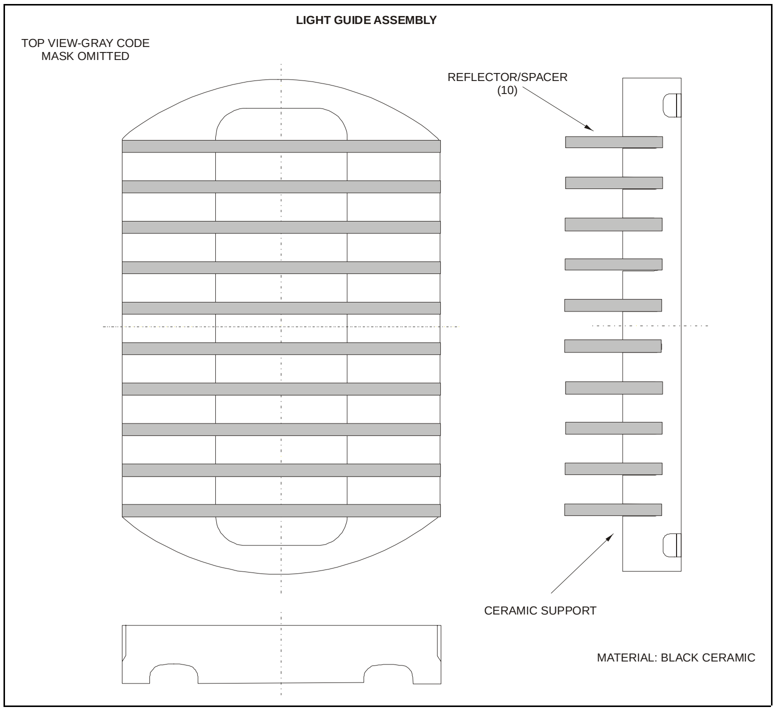


Figure 4: Drawing, hollow light guide

The miniaturized HARLID™ module described herein was designed to fit into a standard TO-8 package. Thus, the optical design and therefore the design of the various individual components of the module described in previous paragraphs has taken into consideration the package size and field of view requirement (e.g. mask aperture size vs reference to bit signal contrast and diffraction). A photograph of the fully assembled 6-bit HARLID™ module is shown in figure 5.

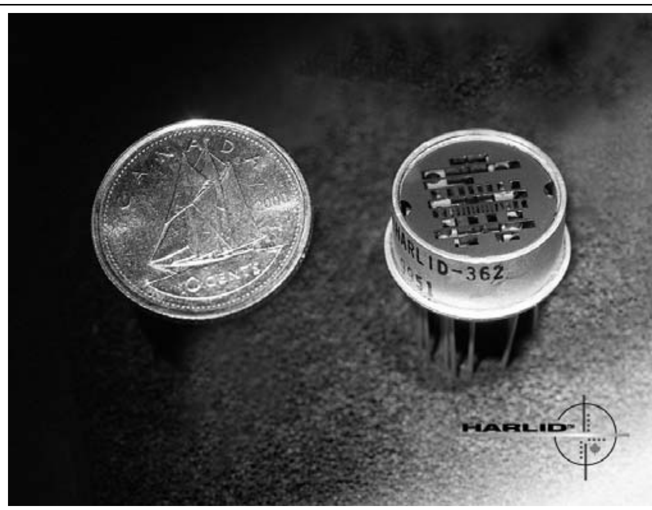


Figure 5: The HARLID™ module

PERFORMANCE CHARACTERISTICS

With the detector sandwich assembly described above, the spectral range of the module includes the outputs from both silicon and InGaAs. Since the respective elements of the two detector elements in each channel are connected together, then a single output from the combined elements is obtained. In the short wavelength range, the output is entirely from the silicon, while the long wavelength response is from the InGaAs. As noted previously, output from both detector elements is obtained in the transition region between about 900 and 1100 nm. The measured spectral response of one HARLID™ module is shown in Figure 6. It is noted that a fairly smooth transition of signal from silicon to InGaAs occurs around 1000 nm near the band edge of silicon. The dip in response of about 10% in this region represents a loss of quantum efficiency in the sandwich assembly, believed to be due mainly to non-ideal anti-reflective coating of the back surface of the silicon detector and "front" surface of the InGaAs detector.

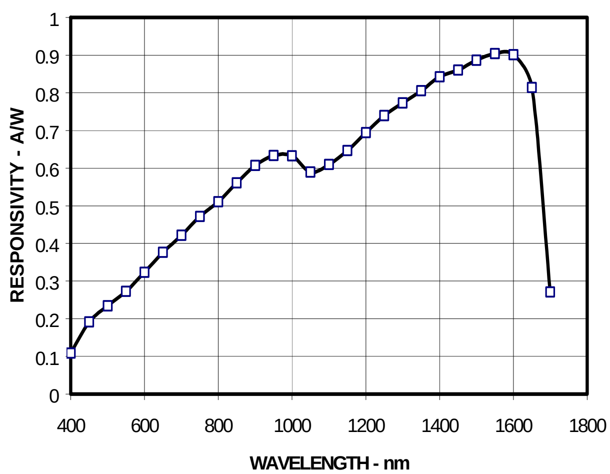


Figure 6: HARLID™ - spectral response

Verification of the accuracy of the azimuth angle readout can be achieved in a number of ways. Since there are in total 64 angular bit intervals in a 6-bit HARLID™ module, or 63 angles representing the transitions between the bit intervals, the measurement of all of them is too time consuming for verification. Since all bit-intervals are defined by a highly accurate Gray code mask, then the measurement of a small fraction of the angles is considered sufficient to qualify the angular performance of the module. Therefore, the measurement of the 15 transitions of bit 5 (from "1"s to "0"s) are measured and compared with the design or calculated values. (A transition angle is determined when the signal channel output is 50% of the output from the adjacent reference channel. All angles are measured with respect to the plane of the base of the header and measurement accuracy of the test bench is considered to be about ± 0.2º). In addition to the transition angles for bit 5, the single transition of bit 1 is measured to define the pointing accuracy of the module. Table 1 shows typical results measured at 7 elevation angles comprised between –45º and +45º. The measured values of the 15 transition angles and the deviation from the calculated values are recorded in each case. We note from the measurement of bit 1 that there is a pointing accuracy for this module of about –0.6º. If this deviation is taken into consideration, then it is seen that most of the 5th bit angles are correct to within a few tenths of a degree when the elevation angle is zero or ± 15º. At elevation angles of plus and minus 30º, the error is slightly larger but typically less than about 1º. The error goes up to 2 degrees at extreme elevation angles (i.e. ±45º).

Table 1: Electro-Optical Tests (high-sensitivity channel)

		EL = -45°		**EL = -30°**		**EL = -15°**		**EL = 0°**		**EL = +15°**		**EL = +30°**		**EL = +45°**	
AZ (°)	bit	AZ (°)	dev. (°)	AZ (°)	dev. (°)	AZ (°)	dev. (°)	AZ (°)	dev. (°)	AZ (°)	dev. (°)	AZ (°)	dev. (°)	AZ (°)	dev.
6.25	1	6.1	-0.2	5.8	-0.5	5.7	-0.6	5.7	-0.6	5.6	-0.7	5.6	-0.7	5.8	-0.5
44.3	5	42.1	-2.2	43.3	-1.0	43.7	-0.6	43.9	-0.4	43.7	-0.6	43.1	-1.2	41.8	-2.5
38.7	5	36.5	-2.2	37.6	-1.1	38.1	-0.6	38.1	-0.6	37.9	-0.8	37.4	-1.3	36.2	-2.5
33	5	31.5	-1.5	32.0	-1.0	32.3	-0.7	32.4	-0.6	32.2	-0.8	31.9	-1.1	31.1	-1.9
27.2	5	25.5	-1.7	26.3	-0.9	26.6	-0.6	26.7	-0.5	26.5	-0.7	26.2	-1.0	25.2	-2.0
21.4	5	20.1	-1.3	20.5	-0.9	20.7	-0.7	20.7	-0.7	20.6	-0.8	20.4	-1.0	19.8	-1.6
15.4	5	14.2	-1.2	14.6	-0.8	13.9	-1.5	14.8	-0.6	14.7	-0.7	14.5	-0.9	14.0	-1.4
9.3	5	8.5	-0.8	8.7	-0.6	8.7	-0.6	8.6	-0.7	8.6	-0.7	8.5	-0.8	8.2	-1.1
3.1	5	2.4	-0.7	2.3	-0.8	2.5	-0.6	2.5	-0.6	2.4	-0.7	2.3	-0.8	2.1	-1.0
-3.3	5	-3.7	-0.4	-3.8	-0.5	-3.9	-0.6	-4.0	-0.7	-4.0	-0.7	-4.0	-0.7	-3.9	-0.6
-9.8	5	-10.1	-0.3	-10.4	-0.6	-10.5	-0.7	-10.5	-0.7	-10.5	-0.7	-10.5	-0.7	-10.3	-0.5
-16.5	5	-16.5	0.0	-17.0	-0.5	-17.2	-0.7	-17.3	-0.8	-17.2	-0.7	-17.1	-0.6	-16.7	-0.2
-23.3	5	-23.1	0.2	-23.7	-0.4	-24.0	-0.7	-24.0	-0.7	-24.0	-0.7	-23.7	-0.4	-23.2	0.1
-30.2	5	-29.5	0.7	-30.5	-0.3	-30.9	-0.7	-31.0	-0.8	-31.0	-0.8	-30.6	-0.4	-29.5	0.7
-37.2	5	-36.4	0.8	-37.5	-0.3	-37.9	-0.7	-38.0	-0.8	-37.9	-0.7	-37.5	-0.3	-36.5	0.7
-44.2	5	-41.0	3.2	-43.8	0.4	-44.8	-0.6	-45.0	-0.8	-44.7	-0.5	-44.2	0.0	-42.6	1.6

The angle measurements noted in the previous paragraph are obtained by scanning the output of a particular bit between the azimuth extremes of ±45º. The signal outputs for bits 4, and 5, and reference channels 1 and 2 are shown in Fig. 7. The corresponding scans for -45º are shown in Fig. 8. The peaks in the outputs of the reference channels are believed to be due to a small amount of scattered light in the module at certain extreme angles, and may be responsible in part for the degraded angular accuracy at the very high elevation angles.

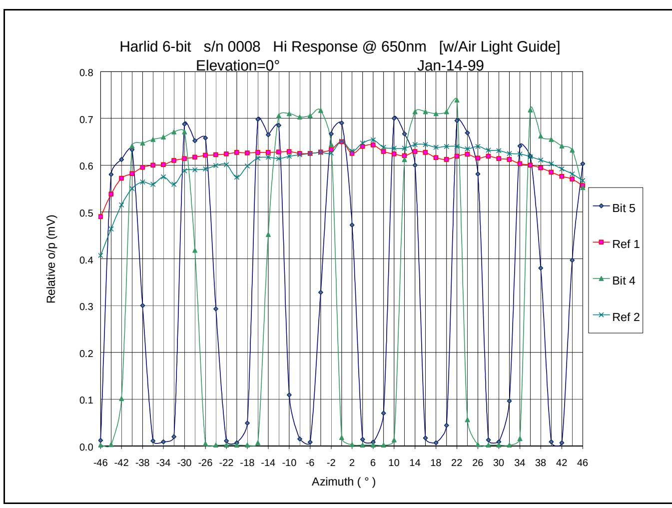


Figure 7: Signal output measured at 0° elevation

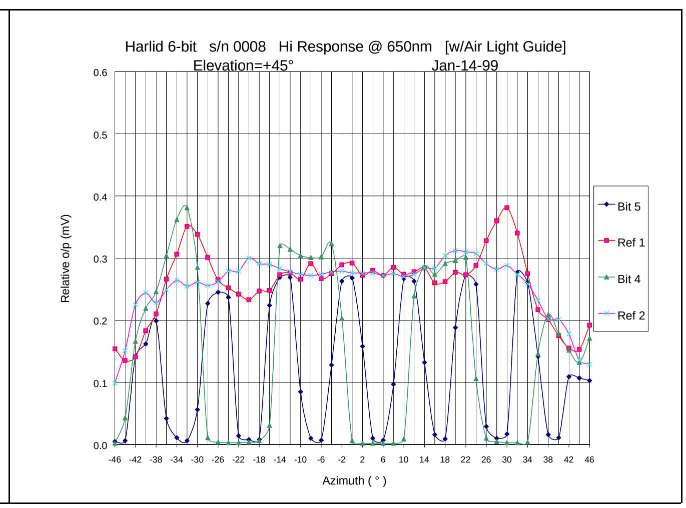


Figure 8: Signal output measured at 45° elevation

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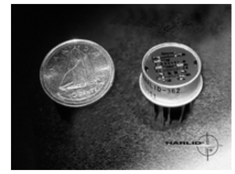
Application Notes



Since its introduction on the market, the HARLID™ module has often been mistaken for a full laser warning receiver (LWR). The reason is simple and comes from the fact that the module by itself does an encoding of the angle of arrival (AOA) of a laser beam. This is the essence of a LWR. However, a designer must realize that, in order to obtain a reliable answer, several steps still need to be developed. Moreover, the design must take into account the various effects of the laser light on the battlefield. Sensor location is also a critical parameter determining LWR performance. Air, maritime and land environments pose very different challenges. For example, LWRs installed on land platforms are much more vulnerable to the light scattered by the surroundings than similar equipments mounted on airborne platforms.

The circuit proposed in this application note is far from a commercial HARLID™-based LWR. It states the basic principles required to take advantage of the main characteristics of the HARLID™ sensor considering typical laser found on a battlefield (range finder/target designators). Figure 1 shows a block diagram of the application proposed.

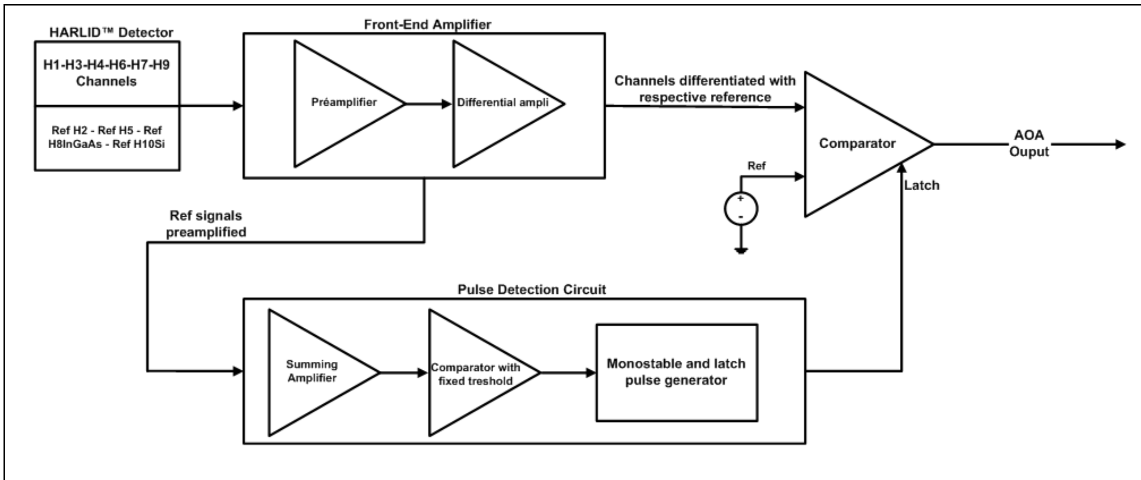


Figure 1) Block diagram of the HARLID™ circuit

Basically, the circuit consists of four parts namely, a HARLID™ module, a front-end amplifier, a comparator circuit and a pulse detection circuit. The front-end amplifier essentially converts the currents generated by the HARLID™ sensors into manageable signals. The comparator circuit converts the analog pulses into the digital world. The pulse detection circuit is the key of the system. It synchronizes the output of the system with the arrival of each laser pulse. Each circuit will be briefly described hereafter.

Figure 2 shows the basic concept of the front-end amplifier for one signal bit (H4) and one reference channel (ref H5). The signal from bit H4 is high-pass filtered by the combination R8/C1. The cutoff frequency is chosen to maintain good signal transfer even in high background environments. This signal is then amplified by U1B whose gain has been set approximately to 150. The output of U1B is high-pass filtered to remove any DC component and to attenuate the effect of non-laser sources (slow varying signals).

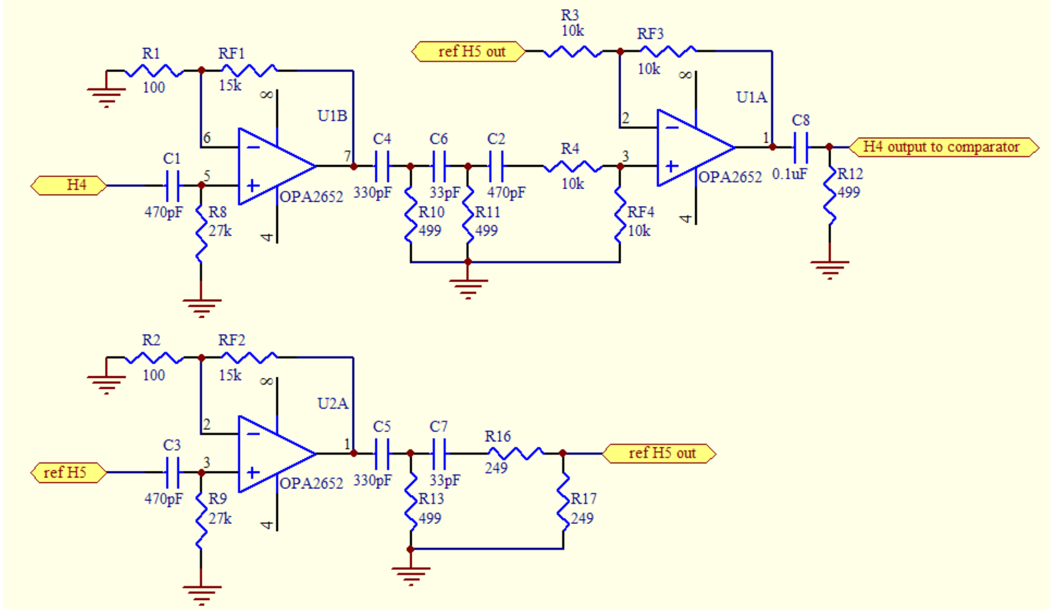
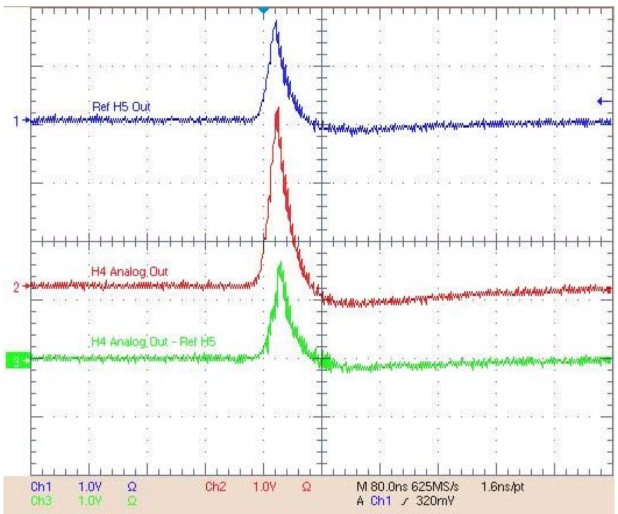


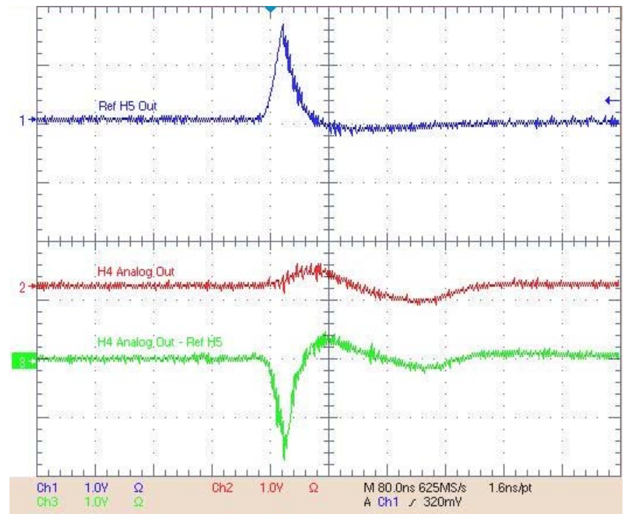
Figure 2) Front-end amplifier

A similar amplification stage is used to process the signal from the closest reference (ref H5) available on the HARLID™ module. It is very important to compare each signal bit with the closest reference channel to compensate for any non-uniformity that can be found in laser beams when operated at long ranges. The reference signal is also high-pass filtered but the output is halved by the combination R16/R17 to produce a good discrimination between the signal bit and the reference channel.

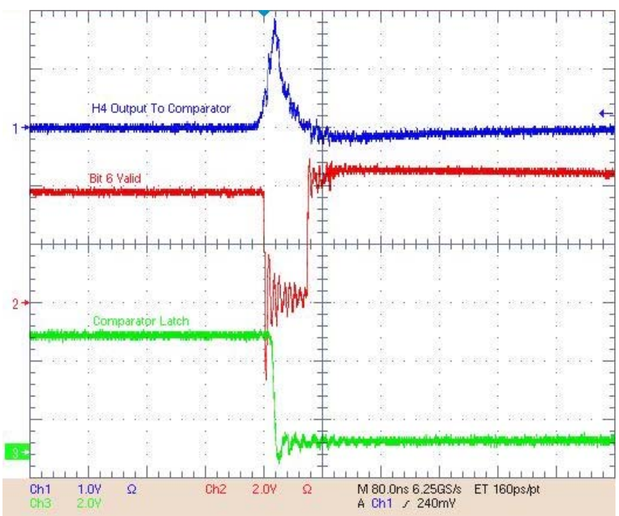
Following amplification, the reference output signal (ref H5 out) is subtracted from the signal bit in order to produce a positive pulse when both the bit channel and the reference channel are illuminated (Figure 3A) and a negative pulse when the bit channel is masked (Figure 3B). Figure 3A and 3B clearly demonstrate the uniformity of the reference channel signal for the two angles tested. They also show the relative amplitude measured on the reference channel and the signal bit.



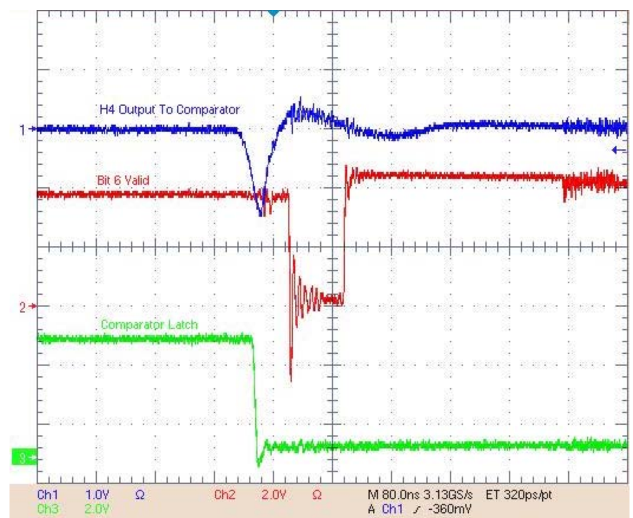
A) Reference and bit illuminated



B) Reference illuminated / bit masked



C) Analog to digital conversion (bit low)



D) Analog to digital conversion (bit high)

Figure 3) HARLID™ laser to angle timing diagram

The comparator circuit shown on Figure 4 converts the output signal (H4 Output to Comparator) into digital format. The comparison level is determined by potentiometer R18 which is adjusted just above zero volt to minimize unwanted oscillations when both inputs are close to zero. The middle curves in Figure 3C and 3D give a representation of the comparator output (Bit 6 valid) for the two cases discussed above. In Figure 3C, the comparator flips low on the rising edge of the input (H4 output to comparator), while it remains high in the other case (Figure 3D). Please note that the negative going pulse seen on the middle curve of Figure 3D (Bit 6 valid) is due to parasitic effects in the amplification stage. This does not affect the results it occurs after the detection process. In brief, a low logic level is obtained when a signal channel is unmasked and a high level is obtained when it is masked.

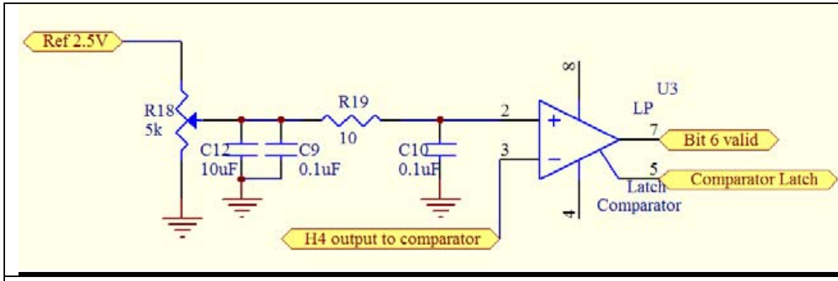


Figure 4) Comparator circuit

The next step in the process consists in determining the exact time where the comparator output must be latched. The pulse detection circuit shown in Figure 5 achieves function.

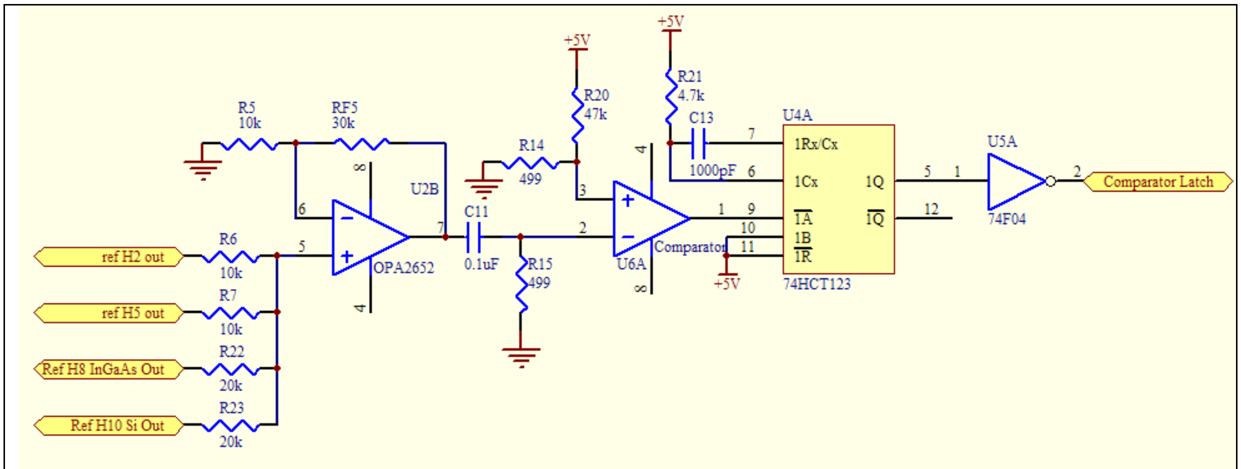


Figure 5) Pulse detection circuit

The pulse detection circuit essentially consists of a summing amplifier (U2B) where the signal from every reference channel is averaged to produce a detection pulse. Averaging all the reference signals is important as it increases the equivalent sensing surface area and improves noise immunity. The average signal is then applied to the input of a comparator whose threshold has been set above the noise. This setting is very important as it determines the false alarm rate of the LWR.

The last stage in the pulse detection circuit consists of a pulse generator. Each time the comparator goes low, U4A generates a fixed duration pulse that freezes the information on a bus. The bottom curve of Figures 3C and 3D shows the output of the pulse detection circuit in the cases discussed. It is important to realize the tight tolerance existing on the timing of the latch signal (Comparator Latch). In the best case, this signal should occur in synchronism with the peak of a laser pulse (typically within a few nsec).

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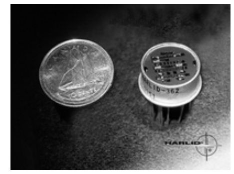
Evaluation Board



The HARLID™ evaluation board (EVB) comes fully assembled in a ruggedized enclosure suitable for transportation by any carriers. When unpacking, please make sure that the kit includes the following components:

1 HARLID™ EVB	The EVB is made of 1 analog and 1 digital printed circuit board (PCB). Upon delivery, the analog board is inserted onto the digital board and is ready for operation. The analog board features a high-precision HARLID™ socket designed for easy insertion and removal. When inserting the module, please make sure that all the pins are properly lined-up and that the header tab is aligned with the notch engraved in the socket. Gently press on the module and screw the socket reference nut until the module sits firmly in place.
1 16-pin Samtec flat cable	This cable is provided to users who want to operate the analog board remotely from the digital board. When doing so, the analog board must be unplugged from the digital board and the flat cable must be used to connect both components. Please make sure that the cable is properly connected (i.e. pin 1 in the analog board to pin 1 of the digital board) or damage could occur.
1 LED flashlight	The LED flashlight is used to stimulate the HARLID™. It operates on two standard AA cells provided with the kit. Please note that this source is sufficient for demonstration purposes only and is intended to be used at a maximum distance of 30 cm from the HARLID™ front window. High reliability testing requires a uniform laser source generating a large-area well-collimated beam.
1 9VDC battery 1 9V AC/DC adaptor	The HARLID™ EVB can be powered either by one standard 9 V DC battery or one 9 V AC/DC adaptor. Both equipments are provided with the kit. An autonomy of 4 hours is expected when operating from a 9 V DC battery with the LCD backlight OFF. Operating with the LCD backlight ON reduces the operation time to about 2 hours. The board can operate with both the 9 V DC battery and the AC/DC adaptor connected, however, the design has been made in such a way that whenever a plug is inserted in the power jack then the power is drawn from the AC/DC adaptor only. No provision is made for battery charging.
1 CDROM 1 9-pin (male/female) serial	The CD-ROM includes all the files required to install the HARLID™ GUI. This software gives a graphical representation of the HARLID™ results. To operate properly, the software must be installed on a PC compatible

cable	computer running on Windows 2000 as the operating system. The computer and EVB must be connected together using the 9-pin serial communication cable provided with the kit. The CD-ROM also includes all the schematics and source code of the EVB as well as the source code of the HARLID™ GUI.
1 HARLID™ socket reference holder	This bracket is provided as an option to users who want to perform extensive testing of the HARLID™ module using the EVB as a test platform. In this case, the analog board must be removed from the digital board and the HARLID™ reference holder must be screwed behind the HARLID™ reference socket using the screws provided with the kit. The HARLID™ reference holder can then be used in conjunction with any standard ¼-20 optical mount to develop a custom test platform. Please note that the center of the screw provided with HARLID™ reference holder is precisely aligned with the HARLID™ detector plane and can be used as a reference point to measure angles.

As stated above, the HARLID™ EVB is made of analog and digital boards. Figures 1 and 2 give a block diagram of the combination. The analog board includes all the components required to amplify the currents generated by the HARLID™ module and to convert them into TTL compatible signals. In order to do so, each amplified signal bit is compared with the closest reference channel available on the module. The comparators are wired in order to produce a low level when the signal from a bit channel is lower than the signal from a reference channel and a high level otherwise. The full schematics of the EVB are included on the CD-ROM provided with the kit.

Similar circuits have been used to process the high- and low-sensitivity channels of the HARLID™ module and a wavelength discrimination comparator has been installed on reference channel 3 to determine whether the Si or the InGaAs detector responded to the stimulation.

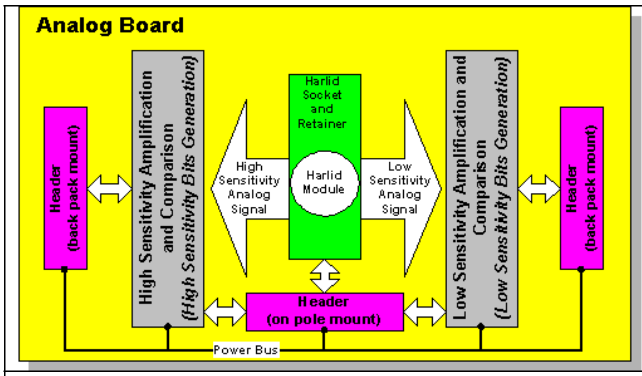


Figure 1) Analog board

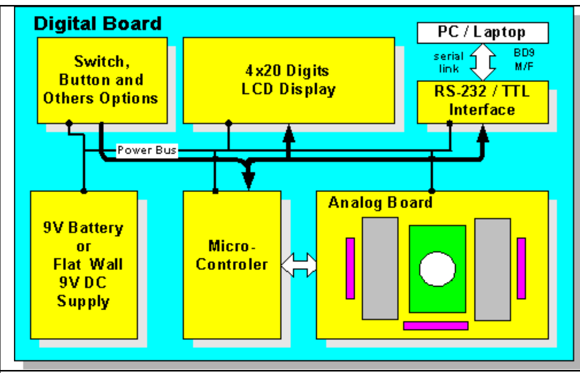


Figure 2) Digital board

The information from the analog board is sent to the digital board via two 10-pin header rows installed on each side of the board. The signals from the low-sensitivity channels are brought to the right-hand side of the board while the signals from the high-sensitivity channels are brought to the left-hand side. The two header rows are used to fit the analog board onto the digital board using mating connectors. When inserting the analog board onto the digital board, please make sure that all the pins are aligned and that the board sits in the appropriate direction (see the UP labels on both boards) or damage could occur.

PRIOR TO REMOVING THE ANALOG BOARD FROM THE DIGITAL BOARD OR INSERTING IT BACK, MAKE SURE THAT THE POWER IS TURNED TURN OFF OR PERMANENT DAMAGE COULD OCCUR.

A third header is available in the bottom part of the analog board. This header conveys a combination of the high- and low-sensitivity signals and is used to operate the analog board remotely from the digital board. In this case, a miniature 16-pin flat cable must be used to interconnect the boards.

As shown in Figure 2, the digital board essentially includes a microcontroller (ATMEGA128) and a LCD display. The microcontroller periodically reads the information produced by the analog board, applies a look-up-table for bit-to-angle code conversion and sends formatted information to the display using an appropriate communication protocol. The microcontroller also features a serial port for communication using a standard RS-232 link.

Before operating the HARLID™ EVB, the user must first power the unit using either the 9 V DC battery or the AC/DC adaptor provided with the kit. The user can then access the introduction menu by toggling the power switch. Figure 3 shows a view of the HARLID™ EVB Introduction menu.

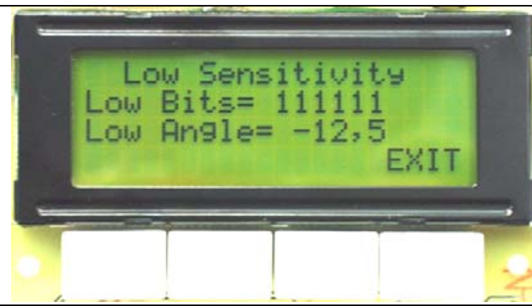
3) HARLID™ EVB Introduction menu

4) HARLID™ EVB Main menu

To continue, the user must press the button placed underneath the **START** string. The LCD display then shows the HARLID™ EVB Main menu (Figure 4). At this time, four options are available namely **HIGH**, **LOW**, **ALL** and **EXIT**.

The user can select **HIGH** to obtain a reading of the high-sensitivity channel or **LOW** to obtain a reading of the low-sensitivity channel. Selecting **ALL** gives a simultaneous reading of the high- and low-sensitivity channels. The **EXIT** button brings the user back to the Introduction menu. Figures 5 and 6 show a representation of the LCD display whenever **HIGH** and **LOW** options are selected.

5) HARLID™ EVB High-Sensitivity screen



6) HARLID™ EVB Low-Sensitivity screen

In the high-sensitivity screen, the angle code as read from the analog board is shown as well as the corresponding angle (in degrees) obtained after table look-up conversion. This mode also gives an indication whether the silicon or the InGaAs detector detected the radiation. The information shown on the display in updated in quasi real time as the user changes the angle of arrival of the light on the HARLID™ module.

The low-sensitivity screen shows very similar information but for the low-sensitivity channel. It has to be remembered that the beam intensity produced by the LED flashlight is somewhat close to the minimum threshold of the low-sensitivity channel therefore, it is possible that the information shown in this mode is not as reliable as in high-sensitivity mode.

In high- and low-sensitivity modes, it is possible to connect the HARLID™ EVB to a computer using a standard serial communication link and reproduce the results via the HARLID™ GUI software. In order to do so, the HARLID™ GUI must be installed by running the installation file (setup.exe) available on the CD-ROM provided with the kit. To install the software properly, the user must follow the instructions given on screen. Then the computer and the HARLID™ EVB must be connected together using the serial communication cable provided with the kit.

If installed and configured properly, then the HARLID™ GUI will give a representation of the measured angle as shown in Figure 7. If the serial communication fails to operate properly then it is possible to reconfigure the serial port by accessing the “Port Setting” item of the “Options” menu. Correct setting are as following: 9600 bps (Baud rate), 8 db (8 data bits), paNone (No parity), 1 sb (1 stop bits), fcNone (No flow control).

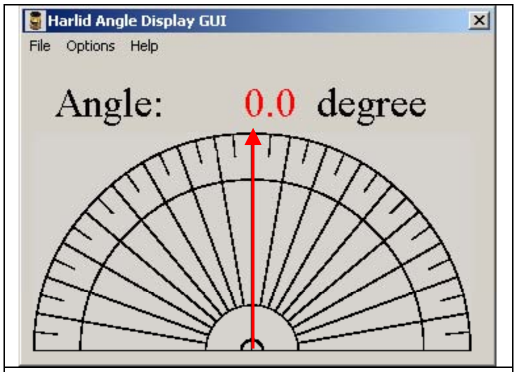


Figure 7) HARLID™ GUI

The "File" menu of the HARLID™ GUI gives access to two interesting options. Firstly, by selecting the "View Live" option, a new window showing the raw information data is displayed. The user can resume to normal operation at any time by unselecting the "View Live" option. Secondly, the "Save Log…" item of the "File" creates a log file including all the information generated by the EVB. The format is standard ASCII and the file can be accessed using any text processor.

Whenever a user selects the **ALL** button from the HARLID™ EVB Main menu then the LCD display shows a combination of the information produced by the high- and low-sensitivity channels (see Figure 8). It has to be remembered that the serial communication is not enabled in this mode.

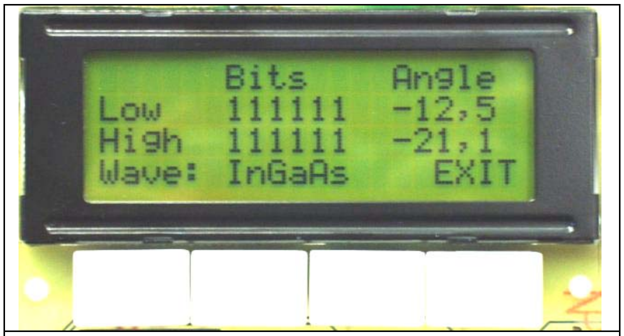


Figure 8) HARLID™ EVB All Channels Menu

In case of malfunction, a user might want to reset the microcontroller to original state by pressing the reset switch available on board. This situation is likely to occur as the microcontroller includes an internal watchdog timer that resets automatically if operation becomes erratic for period of time longer than one second.

The LCD display installed on the HARLID™ EVB also features a backlight and a contrast potentiometer. The backlight can be switched on and off by toggling the small switch located near the display. One must remember that operating with the backlight on will considerably shorten the battery's lifetime. The contrast potentiometer is factory adjusted for optimum performance at time of delivery. However, it is possible to change the setting to adapt to specific conditions. Turning the potentiometer clockwise will increase contrast and vice versa.

Conclusion

This contract report collects in a single document the latest documentation about the HARLID™ technology. This work was done to help current and future customers to understand the technology and ease the development of HARLID™-based products. The information presented herein includes a data sheet of the HARLID™ sensor, a detailed data sheet, an application note and a user's manual for an evaluation board. Each document serves specific purposes and tries to answer precise questions. The HARLID™ data sheet includes most of the electrical, mechanical and optical information required to develop a HARLID™-based design. The detailed data sheet focuses on the operating principle and the internal components. Performance data is shown for comparison purposes. The application note was written to help the designer understand the steps required to extract angular information and the tight timing requirements. Finally, the evaluation board and accompanying user's manual were developed as a eans to give rapid access to the technology.

It is believed that this document will broaden the use of the HARLID™ and will help to develop better business relations with the customers.

Annexes

Item No.	Name	Description	FootPrint	Price	Quantity	Manufacturer	Dealer	Part ID (Of Dealer)
1	Microcontroller	ATmega128	64-TQFP	$27.63	1	Atmel	Digi-Key	ATMEGA128-16AC-ND
2	Interface TTL/RS-232	MAX232	16-SOIC	$5.52	1	Maxim	Digi-Key	MAX232ACSE-ND
3	4x20 Char LCD Display	LCD Display	Custom	$50.39	1	Optrex	Digi-Key	73-1095-ND
4	Quad Op-Amp SMT	Quad Op-Amp	16-SOIC	$0.82	10	Texas Instrument	Digi-Key	296-9540-1-ND
5	Capacitor SMD 0.1 uF	SMD Capacitor	0805	$0.70/10	9	Panasonic-ECG	Digi-Key	PCC1788CT-ND
6	Capacitor SMD 0.33 uF	SMD Capacitor	0805	$0.70/10	2	Panasonic-ECG	Digi-Key	PCC1817CT-ND
7	Battery Holder	Battery Holder(9V)	Custom	$1.50	1	MPD	Digi-Key	BH9V-PC-ND
8	5 V Regulator	Regulator 78M05 Type	D-Pack	$0.92	1	Texas Instrument	Digi-Key	296-11135-1-ND
9	9 V Regulator	Regulator 78M09 Type	D-Pack	$0.92	1	Texas Instrument	Digi-Key	296-11138-1-ND
10	DC Power Jack	2.1mm Power Jack	Custom	$1.07	1	CUI Inc	Digi-Key	CP-002-APJ-ND
11	12 V DC Power Adaptor	Power Adaptor (500mA)	None	$7.45	1	CUI Inc	Digi-Key	T413-P5P-ND
12	Right Angle DB9	DB9 Female Connector	Custom	$3.50	1	AMP	Digi-Key	A23305-ND
13	Serial Cable (M/F)	6' Cable (DB9M/DB9F)	None	$3.95	1	?	Maddison	130057
14	Resistor 1K	1K SMD Resistor 1%	0805	$8.22/200	19	Panasonic-ECG	Digi-Key	P1.00KCCT-ND
15	Resistor 10K	10K SMD Resistor 1%	0805	$8.22/200	30	Panasonic-ECG	Digi-Key	P10.0KCCT-ND
16	Resistor 49.9K	49.9K SMD Resistor 1%	0805	$8.22/200	7	Panasonic-ECG	Digi-Key	P49.90KCCT-ND
17	Resistor 100K	100K SMD Resistor 1%	0805	$8.22/200	31	Panasonic-ECG	Digi-Key	P100KCCT-ND
18	Resistor 220	22 Ohm SMD Resistor 1%	1206	$8.22/200	1	Panasonic-ECG	Digi-Key	P22.1FCT-ND
19	Resistor 8K	8K SMD Resistor 1%	1206	$8.22/200	1	Panasonic-ECG	Digi-Key	P8.06KFCT-ND
20	Resistor 10K	10K SMD Resistor 1%	1206	$8.22/200	6	Panasonic-ECG	Digi-Key	P10.0KFCT-ND
21	Connector	Programming Conn.	IDC06	$1.40	1	AMP-TycoElec.	Digi-Key	A26715-ND
22	Low Prof. Pin Header	Strip of 64 Pin	SIP	$10.83/64pins	24 pins	Mill-Max	Digi-Key	ED7564-ND
23	Low Prof. Pin Socket	Strip of 36 Pin	SIP	$6.67/36pins	24 pins	Mill-Max	Digi-Key	ED7536-ND
24	High Prof. Pin Socket	Strip of 50 Pin(Harlid Socket)	SIP	$9.63/50pins	22 pins	Mill-Max	Digi-Key	ED7150-ND
25	Double Header Strip	BreakAway Type Header	IDC04	$3.38/80	4	AMP-TycoElec.	Digi-Key	A26524-ND
26	Single Header Strip	Header Strip for LCD	SIP	$1.76/40	16	AMP-TycoElec.	Digi-Key	A26520-ND

27	SMD Potentiometer	2K Potentiometer SMD	Custom	$1.62	1	Bourns Inc.	Digi-Key	3361P-202GCT-ND
28	Push Button SMD	Reset Push Button SMD	Custom	$1.18	1	Omron Elect.	Digi-Key	SW262CT-ND
29	DPDT off-on Switch	Strait SMD Switch	Custom	$14.62	1	ITT Industries	Digi-Key	CKN1102CT-ND
30	SPST off-on Switch	Right Angle SMD Switch	Custom	$12.41	1	ITT Industries	Digi-Key	CKN1097CT-ND
31	Momentary Push Button	Black MBPL PB Switch	Custom	$3.03	6	ITT Industries	Digi-Key	401-1182-ND
32	SMD Header 2x8	2x8 Header SMD	Custom	$1.77	2	SamTec	Utech	FTS-108-01-L-DV
33	Cable Strip 2x8	Cable Strip 12" Double F	None	$16.95	1	SamTec	Utech	FFSD-08-D-12-01-N
34	PCB Fabrication	Analog and Digital Board	None	$60	1	CIC	---	---
35	Hexagonal Nut	Screw Nut 2-56	None	$8.10/100	7	Spaenaur	Cantin&Fils	HN-5000
36	Round Head Screw (1/2)	Screw Round Head 2-56	None	$7.91/100	7	Spaenaur	Cantin&Fils	445-052
37	Hexagonal Nut	Screw Nut 4-40	None	$8.10/100	8	Spaenaur	Cantin&Fils	HN-5001
38	Round Head Screw (3/8)	Screw Round Head 4-40	None	$8.90/100	8	Spaenaur	Cantin&Fils	MS-5007
39	Nylon Washer 2-56	Washer for 2-56 Screw	None	$2.80/100	4	Spaenaur	Cantin&Fils	654-001
40	Nylon Washer 4-40	Washer for 4-40 Screw	None	$2.80/100	4	Spaenaur	Cantin&Fils	654-002
41	9 V Battery	9 V Square Battery	None	$2	1	Anywere	---	---
42	Jumper (Shunt)	Shunt for Prog. Enable	None	$1.62/10	1	AMP-TycoElec.	Digi-Key	A26242-ND
43	Rubber Feet	Rubber Bumper/Feet	None	$0.33	4	H. H. Smith	Electrosonic	2197
44	Flash Light (4 LEDs)	Model: LightWave 2000 red	None	$35.60	1	Lightwave	Glow-Bug	www.glow-bug.com
45	HARLID Socket	Round Socket for HARLID	Custom	$85.00	1	RDDC-Valcartier	---	---
46	HARLID PCB Holder	Attach HARLID on PCB	None	$250.32	1	RDDC-Valcartier	---	---
47	HARLID Rotary Bracket	HARLID Board on Pole	None	$217.44	1	RDDC-Valcartier	---	---
48	HARLID Test Software	HARLID Test Software CD	None	$2.00	1	RDDC-Valcartier	---	---
49	HARLID Board Manual	Board Manual	None	???	1	RDDC-Valcartier	---	---
50	Stuffing/ PCB Assembly	Reflect Time to Assemble	None	$200	1	RDDC-Valcartier	---	---

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List of symbols/abbreviations/acronyms/initialisms

DND	Department of National Defence
HARLID	High Angular Resolution Laser Irradiance Detector

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DOCUMENT CONTROL DATA

1. ORIGINATOR (name and address) DRDC-Valcartier 2459, Pie XI Blvd. North Val-Belair, Qc, G3J 1X5 CANADA	2. SECURITY CLASSIFICATION (Including special warning terms if applicable) Unclassified

3. TITLE (Its classification should be indicated by the appropriate abbreviation (S, C, R or U)
HARLID™(Data sheet, application note and evaluation board) (U)

4. AUTHORS (Last name, first name, middle initial. If military, show rank, e.g. Doe, Maj. John E.)
J. Fortin, J. Dubois, D. Comeau and J. Delisle

5. DATE OF PUBLICATION (month and year) December 2004	6a. NO. OF PAGES 26	6b .NO. OF REFERENCES 4

7. DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum. Give the inclusive dates when a specific reporting period is covered.)
Revenue generation report

8. SPONSORING ACTIVITY (name and address)

9a. PROJECT OR GRANT NO. (Please specify whether project or grant)	9b. CONTRACT NO. CIEE 3-022
10a. ORIGINATOR'S DOCUMENT NUMBER ECR-2004-300	10b. OTHER DOCUMENT NOS N/A

11. DOCUMENT AVAILABILITY (any limitations on further dissemination of the document, other than those imposed by security classification)

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HARLID, laser warning receiver, laser detector, angle of arrival

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