

DLP®Technology for Spectroscopy

Pascal Nelson

1 What's New from Texas Instruments?

Texas Instruments DLP Products has launched the first ever near-infrared micro electromechanical system (MEMS) digital micromirror device (DMD), the DLP4500NIR. At the same time, the DLP NIRscan™ platform was introduced, enabling developers to design a new generation of high performance affordable spectroscopy solutions.

2 What is Spectroscopy?

Spectroscopy is a powerful non-contact technique for quickly recognizing and characterizing physical materials through the variations in absorption or emission of different wavelengths of light. Spectroscopy can be performed using visible, infrared (IR), or ultraviolet (UV) wavelengths.

Spectroscopy operates on the principle of spreading light out into a spatially distributed band of wavelengths – a rainbow of “colors” (even if the colors are not visible to the human eye). This allows the variation in light intensity versus wavelength to be measured and recorded. This recorded data can be analyzed to reveal many things about the materials through which the light passes, or from which it reflects or is emitted. The near-infrared (NIR) and short wave infrared (SWIR) regions are particularly rich in molecular vibrational mode information, making this wavelength range a target for molecular spectroscopy applications.

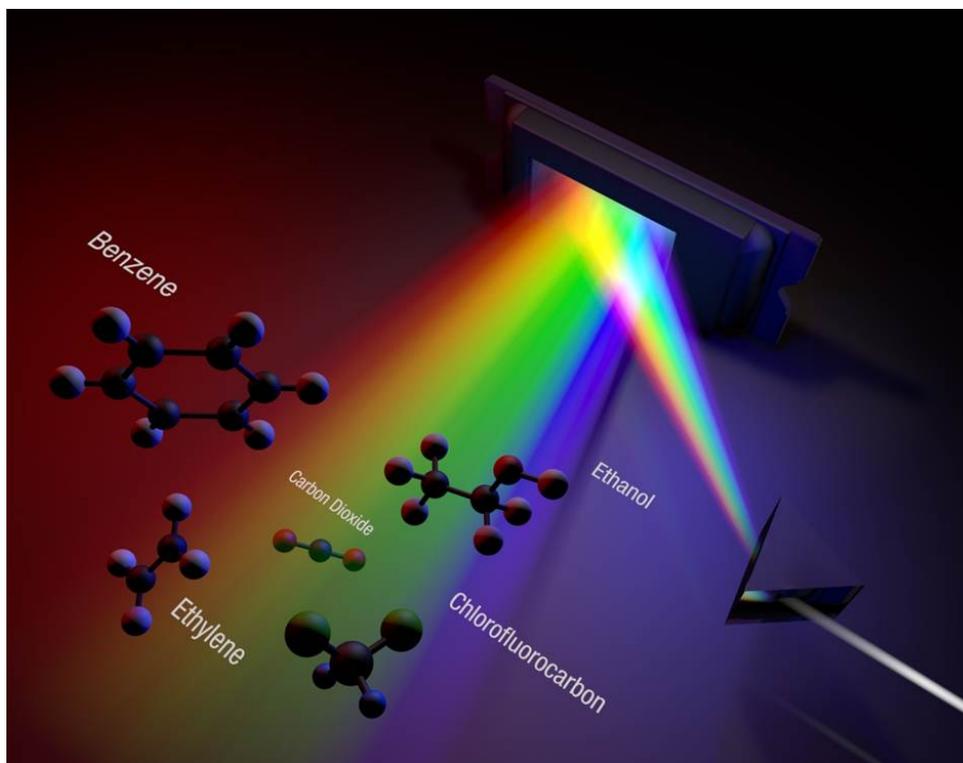


Figure 1. Spectroscopy Reveals the Properties of Materials Using Light

NIRscan is a trademark of Texas Instruments.
DLP is a registered trademark of Texas Instruments.

Figure 1 emphasizes the importance of spectroscopy as a tool for detecting and analyzing the properties of materials by measuring their differential interaction with various wavelengths of light. The figure also schematically illustrates the principle of spreading a spectrum across DLP DMD mirror array, which is used as a programmable wavelength selection filter to enable spectroscopy applications.

2.1 Where are Spectrometers Used?



Figure 2. Spectroscopy Uses

Figure 2 indicates the many industrial, medical, and scientific areas of application for spectroscopy. It is an incomplete list, because new applications are being enabled by the availability of lower cost, high performance, affordable spectrometers – especially those which use DLP technology.

- Pharmaceuticals
- Food and agriculture
- Petrochemicals
- Manufacturing (chemicals and plastics)
- Medical
- Security
- More...

Spectroscopy is used to:

- Identify an unknown material by comparison to a catalog of spectral characteristics
- Determine the presence of a substance of interest
- Inspect a quantity of material to determine concentration limits of certain substances
- Analyze the chemical composition of a sample using principal component analysis (PCA) and chemometrics

2.2 Existing Spectroscopy Solutions

There are a number of types of spectroscopy, which include:

- Emission (bright line) spectroscopy – used primarily for elemental analysis
- Direct absorbance or reflectance spectroscopy – used primarily for molecular analysis
- Raman spectroscopy – used for molecular analysis

In addition to the different types of spectroscopy (for example, Raman or direct), various optical and detection approaches are implemented. Spectrometer designs use both mirrors and lenses for the optical elements. Likewise, both transmissive and reflective diffraction gratings are used to disperse the light into its constituent wavelengths. However, choosing a sensor (detector) to record the intensity versus wavelength data presents a significant challenge.

One approach (shown in Figure 3) uses a single point (non-array) detector. For visible, and perhaps near UV wavelengths, the detector can be a silicon-based photodiode. For NIR and IR wavelengths, the detector may be a photonic device (based on an exotic semiconductor, such as InGaAs), or a thermal device (bolometer, thermocouple, pyroelectric). A single-point detector requires some physical movement to scan the spectrum produced by the diffraction grating, in order to sample all of the wavelengths. Often this requirement is met by rotating the diffraction grating, which is a demanding and potentially troublesome mechanical solution, particularly for portable systems.

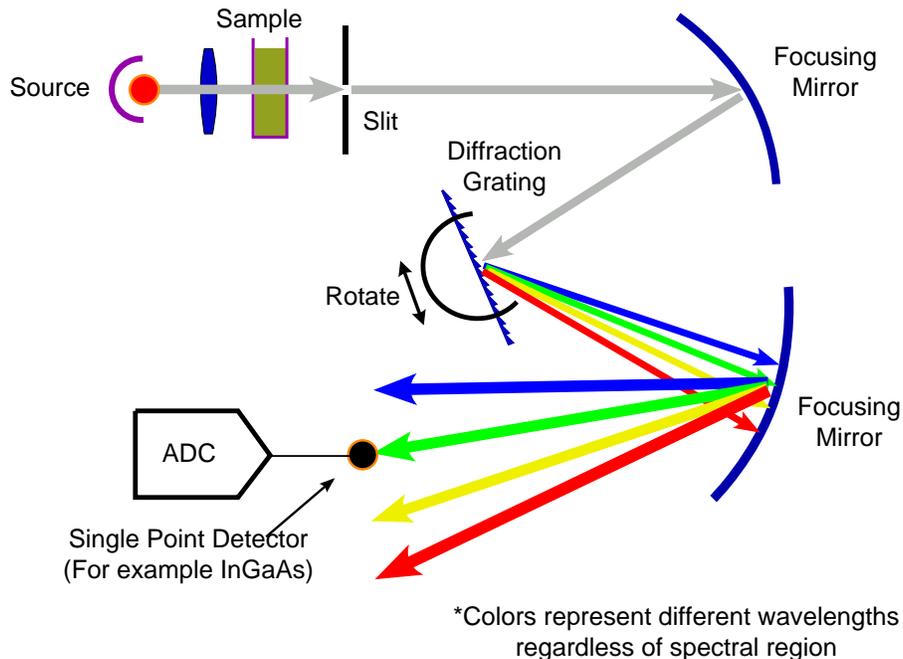


Figure 3. Spectrometer Using a Rotating Grating and Single Element Detector

In some wavelength ranges (visible, long wavelength UV, and NIR regions: about 350 to 900 nm) silicon-based CCD imaging arrays may be practical (see Figure 4). These imaging arrays are similar to those used in scientific cameras. Use of an array detector removes the requirement of a moving element in the optical chain, allowing simpler and more robust mechanical design. In addition, these sensors provide the advantage of data capture similar to image capture in cameras. Arrays for the visible wavelength region are available in high resolutions, and with excellent sensitivity, at a reasonable cost.

In the IR range, especially for wavelengths $> 1 \mu\text{m}$, more exotic semiconductors are required, and array detectors are either very expensive, low resolution, or are not available. In some cases, it is possible to allow dead pixels, or pixel-to-pixel non-uniformity, to bring down cost, but this may limit the achievable performance of the resulting spectrometer.

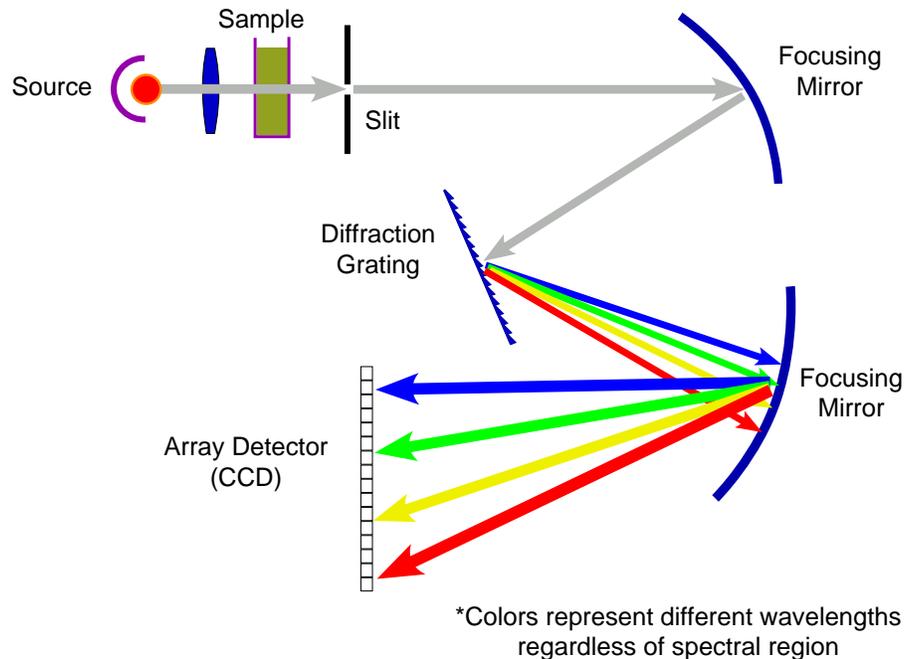


Figure 4. Spectrometer Using an Array Detector

In almost all NIR and IR spectroscopy solutions, especially beyond 1.7 μm , the detector must be aggressively cooled below ambient in order to reduce the effects of dark current, and to improve dynamic range. This is usually accomplished with a single- or multi-stage thermoelectric cooler (TEC).

Although excellent results can be obtained with array detectors in certain wavelength regions, the NIR and IR regions require expensive and low resolution exotic semiconductor detector arrays. This raises the price, and can limit the performance, of spectrometer solutions for NIR and IR based on array detectors.

3 DLP Technology for Spectroscopy Solutions

Considering the history of spectrometer design, the TI DLP DMD is well suited to provide an elegant solution to many of the problems noted.

The DMD (Figure 5) consists of an array of hundreds of thousands to millions of tiny micromirrors.

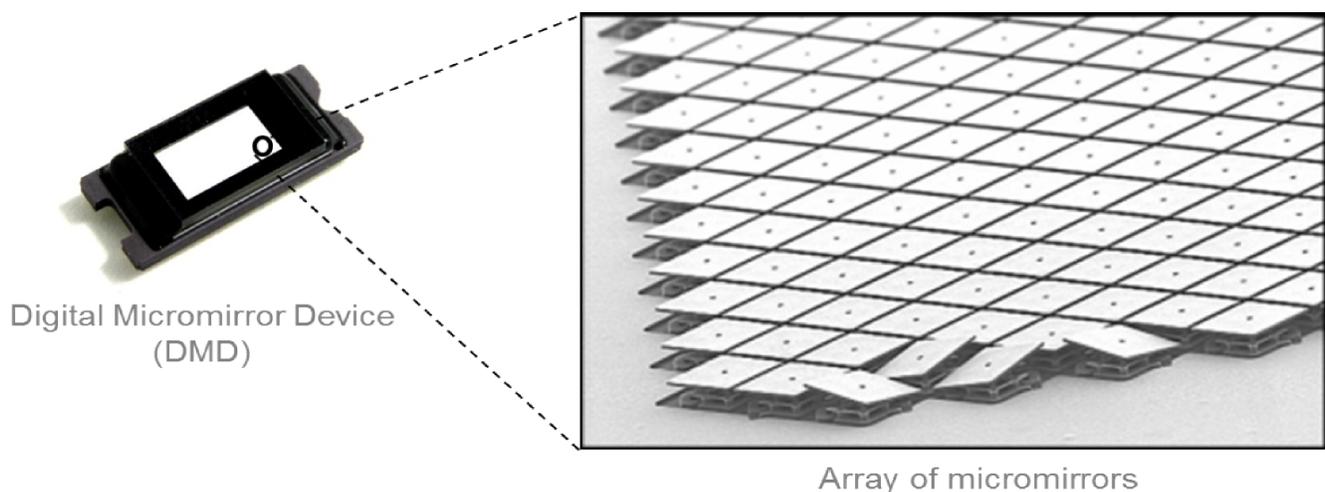


Figure 5. DLP DMD With Close-up of Mirror Array

The unique architecture of the DLP DMD facilitates a spectrometer architecture that uses a larger, single detector to displace an expensive array detector, while still allowing for a robust (no moving parts) optical platform.

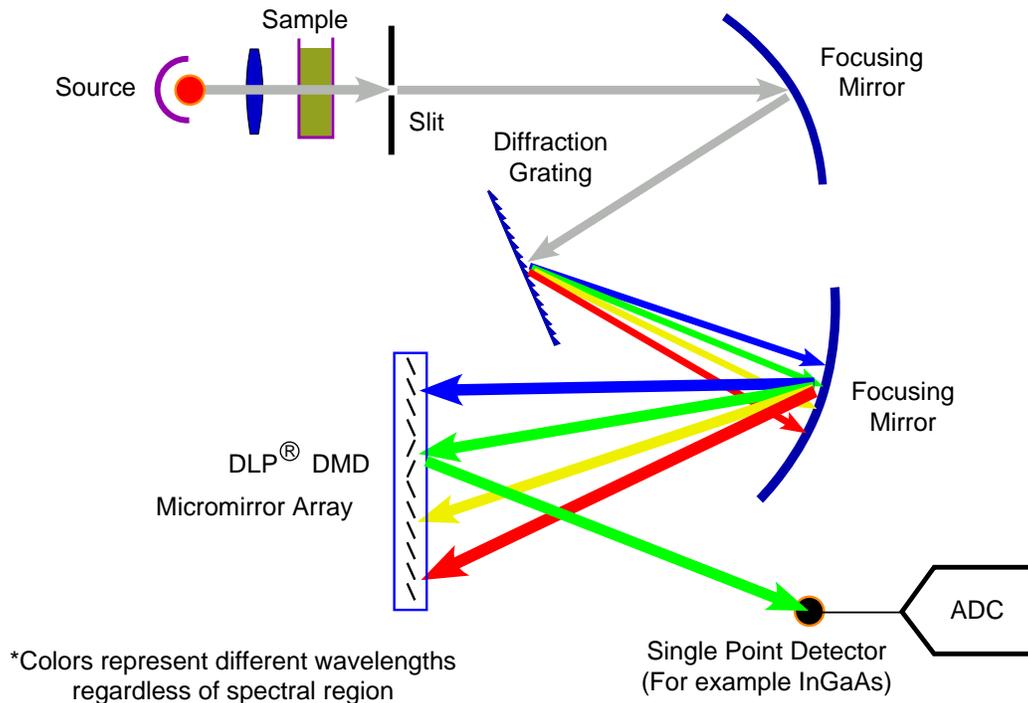


Figure 6. Spectrometer Using a DLP DMD and Single Element Detector

Figure 6 shows how the DMD is inserted into the optical path to select the specific wavelength regions for measurement by a single detector. The selection of individual wavelengths is accomplished by selectively turning columns of mirrors on or off, in order to reflect only the desired wavelengths to the detector. In the IR/NIR wavelength region, this allows the use of a high-performance, cost-effective single element detector, while providing wavelength selection agility, speed, and mechanical stability.

Figure 7 illustrates the optical layout of a DMD-based spectrometer. This powerful and programmable design architecture offers equipment makers the ability to analyze more near infrared substances with higher performance at lower price points, while using a small form factor suited for field analysis and inline manufacturing processes.

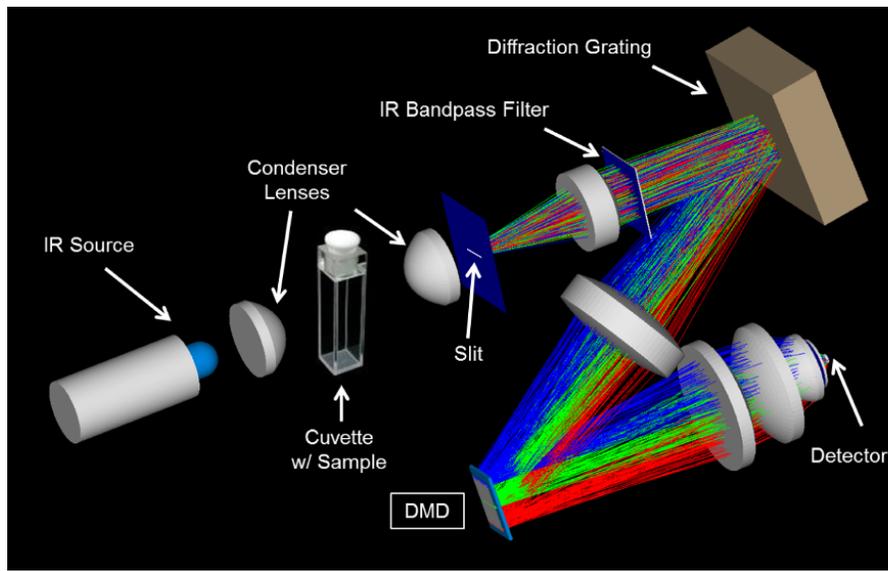


Figure 7. Illustration of Optical Path and Components of DLP NIRscan EVM

4 Why Choose DLP Technology for Spectroscopy?

4.1 Performance

The DLP DMD solution offers many advantages over existing spectrometer solutions, including:

- DMDs have more columns than are available in arrays, thereby offering higher wavelength resolution over array detectors.
- A DMD based spectrometer solution offers greater detector area and light capture efficiency than array detectors.
 - The DMD offers a larger spatial area (perpendicular to the spread out spectrum), and therefore can capture more light from a sample, as compared to a narrow array detector.
 - A DMD allows for the use of a much larger single pixel detector (1 to 3 mm), as compared with 30 to 50 μm pixel size for typical array detectors.
- DLP solutions make possible a better signal-to-noise ratio (SNR) over a given measurement time. This offers designers the ability to make more accurate measurements in less time, which allows for the measurement of new or harder to detect substances. Some array detectors often require 0.5 to 1 s (or even up to 10 s) integration times, even though they are advertised as having 10 ms acquisition time. With DLP, complete scans in < 0.5 s can provide the expected SNR.
- DMD based spectrometers offer ability to calibrate out the effects of stray light, allowing optimization at a lower cost than other non-DMD based systems.
- The single element detector approach offered by DLP technology eliminates scan errors due to pixel defects or non-uniformities which often accompany lower cost array-based solutions. Calibration of the DLP spectrometer is accomplished by software at time of assembly, and remains stable over temperature, aging, and mechanical vibration.
 - The mechanical simplicity and robustness of a DMD spectrometer simplifies manufacturing and alignment processes, with software-based calibration ensuring consistent unit-to-unit performance in volume production.

4.2 Programmability

- The programmable DLP DMD gives spectrometer designers more flexibility to program simple or complex scan patterns. This may expand the ability to measure more diverse substances with a single end equipment.

- The DLP architecture enables adaptive scanning techniques, which are not possible with array detectors or rotating grating designs. Furthermore, software can tailor scan methodologies based on previously measured results. This allows for a more “optimize as you go” analysis and gives more flexibility than simply increasing the scan time. Example methods may include:
 - Auto SNR adjust – constant SNR scan:
 - Can be accomplished by dynamically adjusting the scan rate, or dwell time, even within various sub-regions of the spectrum
 - Auto optical flux control:
 - Enabled by varying the number of mirrors in a column (height of column), thereby adjusting the magnitude of the reflected flux
 - “On the fly” control of resolution and wavelength ranges:
 - The width of scan columns can be changed, thereby varying the resolution as needed; sub-ranges of the spectrum can be scanned at higher resolution than surrounding, less interesting regions.
 - Chemometric methods with multiple patterns:
 - Calculated pattern sets can be applied sequentially to the DMD in order to look for characteristic spectral signatures of chemical substances.

4.3 Portable Form Factor

- The DMD enables a larger, single detector to displace an expensive array detector. This can dramatically decrease the cost of a spectrometer even while enhancing capability.
- The mechanical simplicity and robustness of a DMD-based spectrometer simplifies the manufacturing and alignment processes, with software-based calibration ensuring consistent unit-to-unit performance in volume production.

5 Next Steps

DLP technology offers a number of advantages in spectroscopy applications. Several shortcomings of existing spectrometer designs have been overcome through the use of DLP. It is now possible to design high performance, robust, flexible, and cost effective spectroscopy solutions using DLP technology. TI accelerates the adoption of DLP technology for spectrometry through IR optimized DMDs, spectroscopy development kits (NIRscan EVM), supporting software, and technical information.

Visit [TI DLP on the web](#) to learn more and keep up with the latest developments which are enabling advanced spectroscopy solutions.

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Original (February 2014) to A Revision	Page
• Updated title to DLP®Technology for Spectroscopy	1

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as "components") are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI's terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers' products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers' products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI's goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or "enhanced plastic" are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have **not** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Products

Audio	www.ti.com/audio
Amplifiers	amplifier.ti.com
Data Converters	dataconverter.ti.com
DLP® Products	www.dlp.com
DSP	dsp.ti.com
Clocks and Timers	www.ti.com/clocks
Interface	interface.ti.com
Logic	logic.ti.com
Power Mgmt	power.ti.com
Microcontrollers	microcontroller.ti.com
RFID	www.ti-rfid.com
OMAP Applications Processors	www.ti.com/omap
Wireless Connectivity	www.ti.com/wirelessconnectivity

Applications

Automotive and Transportation	www.ti.com/automotive
Communications and Telecom	www.ti.com/communications
Computers and Peripherals	www.ti.com/computers
Consumer Electronics	www.ti.com/consumer-apps
Energy and Lighting	www.ti.com/energy
Industrial	www.ti.com/industrial
Medical	www.ti.com/medical
Security	www.ti.com/security
Space, Avionics and Defense	www.ti.com/space-avionics-defense
Video and Imaging	www.ti.com/video

TI E2E Community

e2e.ti.com