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 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 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](image)

*Colors represent different wavelengths regardless of spectral region

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 μm, 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.
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.

*Colors represent different wavelengths regardless of spectral region

**Figure 4. Spectrometer Using an Array Detector**

**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 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.
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](http://www.ti.com) to learn more and keep up with the latest developments which are enabling advanced spectroscopy solutions.
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