DAVID

A Multi Spectral High Resolution Small Satellite

by

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Abstract

DAVID is a small satellite for advanced remote sensing purposes - designed to meet the specific requirements of today's and tomorrow's Earth observation users in the fields of environmental monitoring, hazard warning and damage assessment. The development is a joint German-Israeli co-operative project.

The satellite is designed to provide earth images with high spatial and spectral resolution and good radiometric sensitivity, despite its small size and low cost. It will have more spectral bands in the VIS/NIR range than sensors on most existing or planned multi-spectral high-resolution satellites and higher ground resolution than planned hyper-spectral space sensors like LEWIS or MODIS. DAVID will be able to meet the actual tendencies in Earth observation by delivering 12 narrow bands with a spatial resolution of about 5 m. By its slewing capability DAVID will get the important performance gain of short data delivery times due to short target revisit cycles of 3 days can be established. This is particularly important for the monitoring of dynamic processes.

Existing space-rated sub-systems will be used or adapted for this system, combined with new satellite and detector technologies, to achieve the low cost and high performance goals. The two principal companies involved, OHB-System in Germany and El-Op in Israel are both experienced in the design and construction of space systems, some of which have already been successfully launched. In addition, another German company, GAF, is actively involved in the parameter definition and image product distribution aspects of the system.

A feasibility study has been completed. This paper will describe the updated system concept.

1. Introduction

Remote sensing of the Earth from satellites is developing rapidly and there is a demand for more detailed information than that which the first systems, LANDSAT and SPOT, can presently provide. New commercial Earth observation systems which are scheduled to begin operations soon will offer higher spatial resolutions but the spectral resolution for multi-spectral images will be limited as with the existing systems to 3 or 4 broad bands. The spectral characteristics of the most common present and future VIS/NIR sensors are displayed in Table 1.

Table 1: Spectral characteristics of present and future spaceborne sensors and systems
(bands between 400 to 1100 nm)

Sensor	Spectral range (nm)	Spectral band width (nm)
NOAA-AVHRR	580-680	100
	730-1100	370
Landsat-MSS	500-600	100
	600-700	100
	700-800	100
	800-1100	300
Landsat-TM	450-520	70
	520-600	80
	630-690	60
	760-900	140
SPOT-HRV	500-590	90
	610-680	70
	790-890	100
IRS-LISS	520-590	70
	620-680	60
	770-860	90
RESURS	500-600	100
	600-700	100
	700-800	100
	800-1100	300
MOMS-2	440-505	65
	530-575	45
	650-680	30
	770-810	40
Earlybird MS	490-600	110
	615-670	55
	790-875	85
Quickbird MS	same as Landsat TM	
Orbview-3 MS	same as Landsat TM	
IKONOS-1 MS (SpaceImaging)	same as Landsat TM	

There is a need for images with many spectral bands but with high sensitivity and with ground resolution comparable to that of the next generation of MS imagers. It is this need that the MSRS sensor on DAVID is intended to fill.

2. Data Requirements

Operational observation systems and those, which are expected to become so in the near future, are aimed towards high (20m to 5m) and very high spatial resolution (>5m to 1m). It is clear that panchromatic data or 3 broad visible bands are given preference in their design. Examples are SPOT, IRS-1C, MOMS, Earthwatch, Space Imaging and others. Very few are emphasising a combination of a fairly high spatial resolution with a comprehensive multi-spectral component.

In our opinion, the multispectral component of earth observation is still, and most probably will be also in the future, an important basis for further market development. An example is the Landsat TM data which, even at a "coarse" 30 m resolution, count for a big share in the application market due to their better multispectral capabilities. In our view, current discussion is to some degree over-emphasizing the spatial component, which shifts satellite remote sensing very close to the classical aerial photo sensing.

Experimental hyperspectral systems, nearly all airborne, have been investigated for several years and new promising application fields have been identified. However, a lot of research probably has to be done before a commercial phase can be entered. Nevertheless one can draw conclusions on the completed research projects. Hyper-spectral sensors indeed provide much higher spectral resolution but only at the cost of lower spatial resolution and poorer sensitivity, especially for spaceborne systems. Hyperspectral data are highly redundant and effort has to be put on information "compression".

New detector technology allows improved signal/noise performance, and VIS/NIR atmospheric windows already offer excellent discrimination possibilities, especially when targeting vegetation. We have reason to believe that a sensor concept as presented in this paper, combining high spatial resolution with a "truly" multi-spectral number of bands in the VIS/NIR region, and also featuring a narrow bandwidth, will provide ideal data for all applications related to vegetation mapping and monitoring. The position of the bands as presented have been optimised for most vegetation types and also for some important soil-related spectral features. The compromise for the concept is well balanced and adapted to a number of application fields with growth expectations.

The MSRS sensor integrated in this "Smallsat" concept will be an extremely interesting system for the coming years. The particular areas of application for which the data is intended include ecological monitoring, vegetation classification and monitoring, hazard warning and damage assessment. And it could directly benefit from an increasing market driven by very high resolution pan-systems: it could be the standard provider of adequately resolved spectral information in combination with the pan data sources.

3. Data Applications

The visible and NIR regions of the electromagnetic spectrum are important for detecting different spectral features on the ground and in the atmosphere. These are used for better understanding of the physical, biological, and chemical status and dynamic processes of the environment. For the last 25 years, since the launch of the first Landsat satellite, all existing and planned spaceborne high resolution systems have sensors with a limited number of broad bands. The limited number of spectral bands as well as their broad width poses a problem in many remote sensing applications. Some of the expected advantages of the narrow band system over the current broad band system are briefly described in the following sections.

Vegetation

The main goal for most of satellites listed in Table 1 is vegetation remote sensing monitoring. However, refining the spectral band width and adding more bands will make it possible for more accurate detection of vegetation stress, species discrimination and mapping, and biomass estimation. The more critical wavebands for vegetation studies are: 440-500 nm for detecting chlorophyll/carotenoid ratios as a measure of plant stress; 630-690 nm is important due to its sensitivity to chlorophyll concentration and useful for initial stress detection; 660-680 nm is used for biomass estimation; 700-750 nm is useful for observing senescence in vegetation and detection of dead or dormant vegetation; 760-900 nm is essential for vegetation monitoring due to the maximum NIR reflectance; 800-840 nm is related to leaf anatomy and/or state of hydration; the height of feature around 865 nm may be useful for species discrimination; the shift in the 940-980 minor water absorption band may be useful in species discrimination and determination of hydration state; finally, shifts in the peaks of 1060-1100 nm may be related to leaf anatomy and/or morphology and may be useful for species discrimination.

Ocean and inland waters

The current remote sensing systems have had only a moderate success in studying water constituents such as chlorophyll concentration, suspended particles and yellow substance (Gelbstoff) in ocean and inland water bodies. The main reason is the limited number and distribution of the common spectral bands which were not optimized for the above features. A few of the optimal spectral regions which are currently not detectable are: 405-420 for yellow substance detection; 438-448; 500-520 and 660-670 nm for chlorophyll absorption; 483-493 nm for pigment concentration; and 546-565 nm suspended particles.

Atmosphere

In the visible and NIR regions the scattering and absorption of radiation by aerosol and gases are well known. The atmosphere can account for more than 50 percent of the detected radiance particularly in the shorter wavelengths. Consequently, for most (if not all) land and water remote sensing observations atmospheric parameters such as aerosol loading, absorptivity and cloud cover are used for correcting the above atmospheric effects. The most suitable spectral bands for such an applications are 660-680, 745-785, and 845-885 nm. In addition, determining the water vapor distribution areal variations as well as the amount of perceptible water in the atmosphere is also possible by using band ratio and/or curve fitting methods taking advantage of the main water absorption regions: 890-920, 931-941, 915-965, and 1020-1040 nm.

In summary, there is a considerable need for narrow and discrete spectral bands. The spectral product from such a system can be interpreted and analyzed in more quantitative way. As shown by different examples from the botany, oceanography, and atmospheric science disciplines, the subtle spectral features mostly occur over a relatively narrow range so they are not adequately measurable by the broad band sensors of the current satellite systems.

4. System Description

4.1 General

The DAVID system is based on a small (~180 kg) satellite bus with a light-weight electro-optic camera using a single mirror-type objective and a multiple detector system. On-board solid-state memory stores the images during recording, and these are transmitted to the ground when the satellite is within range of one of the data reception stations. Other components will include the satellite control and orientation system, the two-way data link, on-board means for radiometric calibration of the sensors and the solar panels for electrical energy supply.

With a sun synchronous orbit of 670 km, the ground pixel size is 5 x 5 m and the camera will cover a swath width of 30 km at nadir. In order to give coverage as frequently as possible, the sensor swath can be shifted to the maximum useful off-nadir angle of ±30°. In other satellite this is done by a tiltable mirror, but this adds weight and complexity. By using the DAVID control system to rotate the whole satellite accurately to the desired angle before recording begins, this mirror can be eliminated. In order to gain imaging performance, the scenes will be transmitted immediately after imaging with a 1-axis steerable antenna system, while the satellite slews towards a new imaging target.

The off-track and in-track slewing capability of the satellite enables very short hort revisit times (about 3 days, at least for latitudes < 30°) and in-track stereoscopic imaging.

To keep construction and launch costs at a low level, a low weight system was adopted, and to keep development costs low, suitable sub-systems that have already been developed will be used.

4.2 Satellite Platform

The satellite bus is based on existing, space qualified components which have been developed for BREMSAT and SAFIR. The satellite is 3-axis stabilised using an ACS subsystem, which consists of star sensor, sun sensor, gyros and wheels. This enables a high pointing accuracy of 0,02 deg. A GPS receiver on board will be used for orbit position determination and timing.

Considering the payload requirements, such as power needs, accommodation, and thermal aspects, the structure of the satellite bus is cube shaped and will be adaptable to several launchers.

Due to the power requirement of the payload and other subsystems DAVID can provide average 60 W power. During regeneration phase, where no imaging will be performed, the spacecraft will be sun pointed for optimal power generation.

4.3 Earth Observation Payload

Objective

The sensor objective is based on a telescope objective designed at El-Op for an astronomical space project in the UV region. The objective is of the Ritchey-Chretien type which uses two mirrors with refractive field- flattening elements. The primary mirror aperture is 200 mm in diameter with a focal length of 1600 mm. The field flattener was redesigned and a dichroic beam-splitting assembly installed to allow multi- spectral imaging in the visible region. This objective and its structure were designed for very low weight, using a light-weighted mirror, beryllium bezel and composite material structure and this enables the overall weight of the satellite to be kept low (See Fig. 1). Its high mechanical stability and dimensional insensitivity to temperature changes avoid the need for a focusing mechanism which helps to keep both weight and cost down.

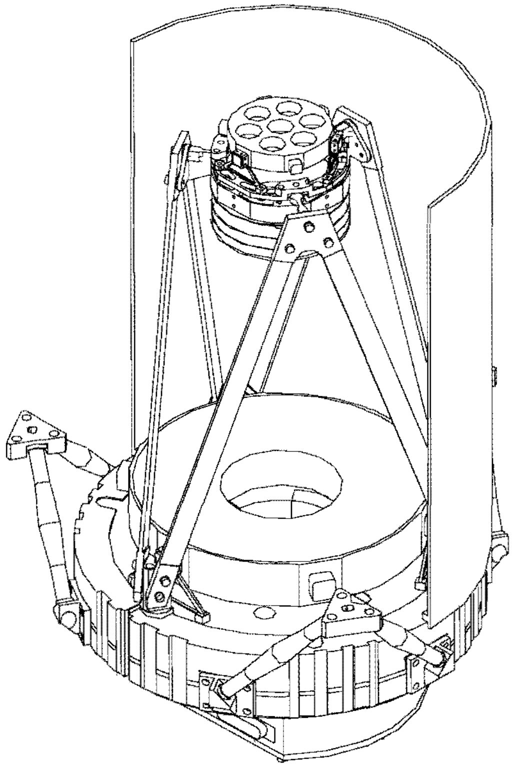

Fig. 1: Objective cutaway view

The performance is near diffraction-limited over the field of view of 2.6°. Although the F/# is 8.0, the high sensitivity is maintained by using a CCD-TDI (time delay integration) type detector array. The advantage of this design is that the overall weight and cost are much lower than would be the case with a larger diameter objective having a lower F/#.

Detectors

The camera will have 12 detector channels in its focal plane, each with a separate interference filter for wavelength band definition. In the TDI detector the signal from up to 32 rows is combined on each pixel. This results in an improvement of sensitivity by a factor of 5. Each of the TDI detector channels has 6000 pixels x 32 rows of TDI and three such units are fabricated on a single chip (see Fig. 2).

The number of used TDI rows can be selected in accordance with the amount of light collected to avoid saturation. The detectors are fitted before encapsulation with high-performance multi-layer interference filters, designed to transmit the desired pass-bands, coated on a thin transparent substrate. Each detector chip has three different filters, one for each of the three channels.

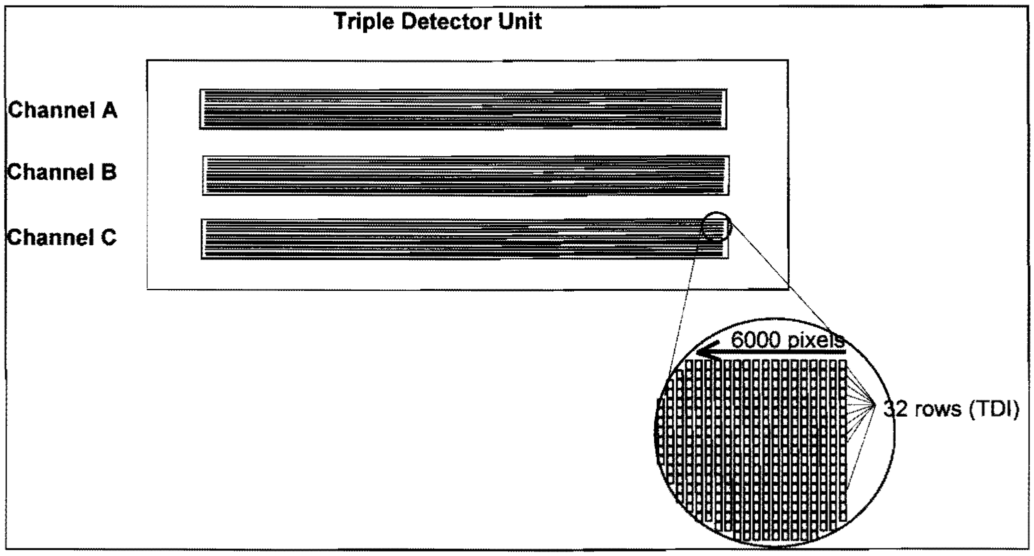

Fig. 2: Schematic layout of the Detector Unit

Three such chips are mounted on a dichroic beam splitter to provide nine of the channels. The other chip, carrying the remaining three channels, is mounted separately on its own glass block. This is illustrated in Figure 3.

The pixel size of 12 µm square in conjunction with the 1600 mm focal length of the objective give a ground resolution of 5 m at 670 km altitude.

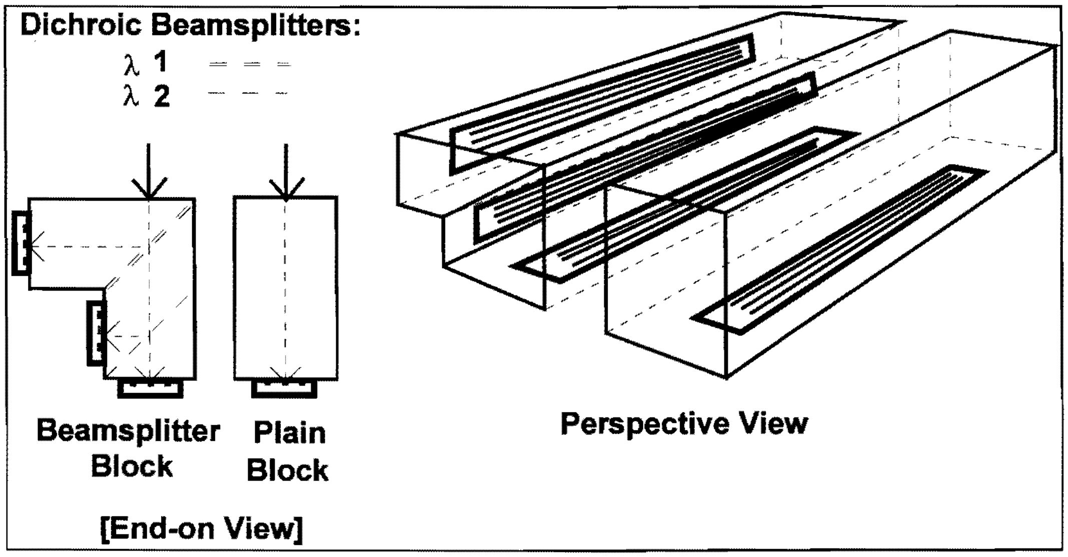

Fig. 3: Beam Combining Optics (schematic)

Spectral Resolution

In order to cover the whole visible/near-IR range from 0.435 to 1.0 µm, a total of 12 bands is provided. One option is to use a uniform bandwidth of 35 nm which provides contiguous coverage up to 750 nm with the three longest wavebands spread more widely up to 1000 nm (see Table 2 and Fig. 4 below). It would be desirable to have narrower bands, as indicated in Section 3 above, and the sensitivity does allow this, at least in the central part of the spectral region. This will be adopted, provided the considerable optical problems involved can be solved.

Region	Band	bandpasses	diagnostic features
Blue	1	435-470 nm	at 450 nm chlorophyll a absorption
	2	470-505 nm	
Green	3	505-540 nm	slope for senescent vegetation
	4	540-575 nm	at 560 nm green peak
	5	575-610 nm	
Red	6	610-645 nm	at 640 nm chlorophyll b absorption
	7	645-680 nm	at 670 nm chlorophyll a absorption
	8	680-715 nm	
NIR	9	715-750 nm	
	10	775-810 nm	near-infrared plateau
	11	855-890 nm	
	12	965-1000 nm	at 980 nm water absorption trough in healthy plants

Table 2: Wavelengthe bands (35 nm option)

The used 3-section dichroic beam-splitter which enables the maximum degree of registration to be attained. The three channels on each detector chip are in parallel but are spaced apart by some 400 µm, corresponding to a shift of about 150 m on the ground and hence to a delay of about 21 msec in the image. The signals will be combined in the image processing stage by introducing a digital delay to compensate for that in the recording. The signals from corresponding channels on the beam splitter are coincident and do not need any delay

The characteristics of the dichroic beam-splitter necessarily result in gaps between the spectral regions which each section covers. The problem is overcome by separating the fourth detector chip and providing it with the bands that are lost in between the regions passed by each beam-splitter. This chip will be in the same focal plane, being mounted on a glass block whose optical thickness is the same as the beam splitter. It is shifted in spatial position by about 20 mm, meaning a delay of about 1 second in the image relative to the other bands.

Fig 4 shows graphically the proposed bands for the DAVID MSRS as indicated in Table 2 compared to the bands of existing and planned spaceborne multispectral sensors, as listed in Table 1.

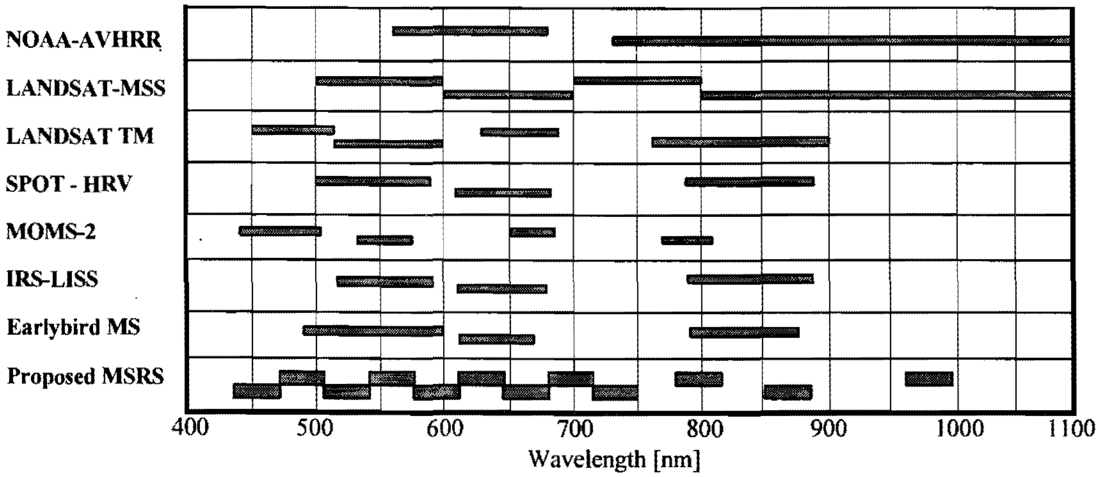

Fig. 4: Spectral bands for spaceborne MS sensors and for the DAVID MSRS (tentative).

Payload Electronics

The electronics includes clock generators to control the operation of the detectors and read out their signals, which are then amplified by low-noise preamplifiers and raised to the level needed for input to the 10-bit Analogue-to-Digital converters. Once the signals are in digital form, various operations can be performed, such as applying correction for non-uniformity of the sensitivity of the elements, which would severely affect image quality if not cancelled out.

Because of the limitations of data capacity in the recording system and the rate in the data down-link, lossless data compression is used to reduce the number of bits per pixel, without compromising radiometric accuracy. The compression ratio is 2.5:1. (Larger ratios are possible, but these introduce loss of data, which is may be unacceptable when quantitative measurements are required.)

On-Board Data Recording

A solid-state digital memory will be used to store the data obtained while imaging, until it can be relayed to the ground at a lower data rate, as determined by the capacity of the data link channel. The memory will store 33 GBit, and with a data compression ratio of 2.5:1, a typical 30 x 40 km scene would require 190 MBit of memory per channel. If all 12 channels operate at full resolution, the memory will be filled after about 14 such scenes. Other modes are envisioned which would allow recording more scenes between ground contacts. In one of these, three channels only would be selected to record at full resolution, which would allow 60 scenes to be stored. Another mode records all 12 channels, but at 10 m resolution, which is achieved by combining adjacent pixels; this also allows 60 scenes to be captured.

Data Down-Link

An X-Band transmitter with a directional antenna that is kept oriented towards the ground station will allow the data to be transmitted at 50 MBit/sec that requires 12 minutes of contact with the ground receiver. A higher rate option is being considered to reduce this time.

On-Board Calibration

In a multi-spectral system such as this, the relative sensitivity of the individual channels and of the pixels within them is of great importance. Since the sensitivity of detectors may change over time, and since other components such as optics, amplifiers, etc. may be affected by radiation in the space environment, a reliable means of calibration is necessary. In some satellite optical systems, this is based on a built-in light source and often calibrated photocells, but since these may change themselves, a constant reference such as the sun is used to calibrate them in turn. In DAVID, the sun light will be used directly. A small mirror, whose size will control the required level of attenuation will reflect a defocused image of the sun onto the telescope and thence to the detectors. To activate the system, the satellite will be oriented so that the sun rays fall on the mirror. Two different mirrors may be installed to provide two intensity levels for the calibration.

5. Performance

Values of NE$\Delta\rho$ have been calculated for typical atmospheric conditions and solar zenith angles. The values for 20% ground albedo at 45 deg sun zenith angle are shown in Fig. 5.
The values are higher for the shorter wavebands, due to the higher level of path-scattered sunlight and the lower sensitivity of the detector at these wavelengths. The latter is also the case at the longest wavelength. The performance is good in spite of the narrow bandwidth.

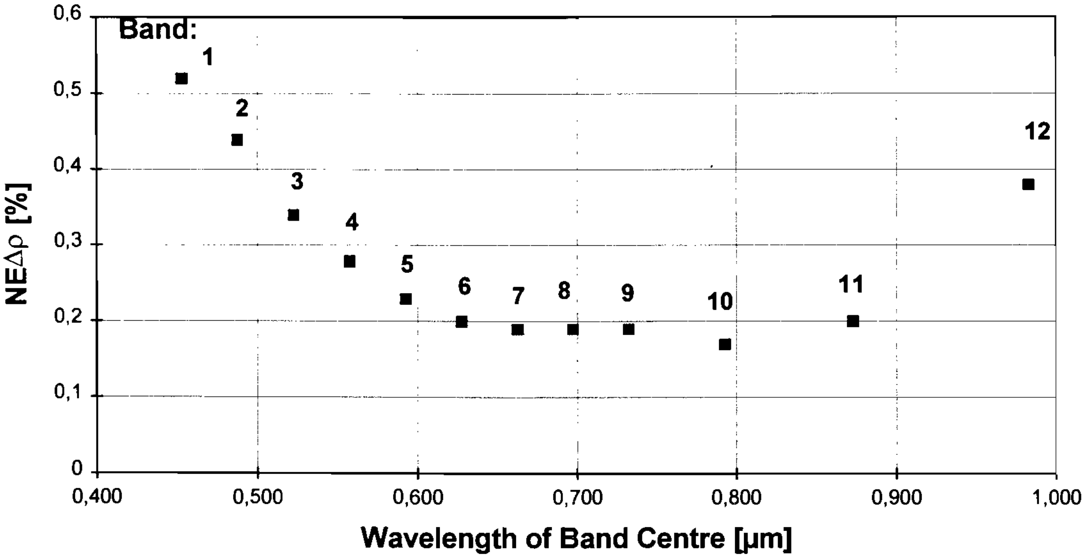

Fig. 5: Typical NEΔρ for 35 nm DAVID Bands

6. Conclusions

The MSRS camera for remote sensing on the DAVID satellite, as described above, offers a combination of high spatial and spectral resolution, high sensitivity and short revisit cycles. The clearly established need for this combination is not being met by existing or other planned satellites and therefore the MSRS payload will make a significant contribution to the Remote Sensing market.