PROGRESS OF THE MARS ARRAY TECHNOLOGY EXPERIMENT (MATE) ON THE 2001 LANDER

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ABSTRACT

NASA is planning missions to Mars every two years until 2010, these missions will rely on solar power. Sunlight on the surface of Mars is altered by airborne dust and fluctuates from day to day. The MATE flight experiment was designed to evaluate solar cell performance and will fly on the Mars 2001 Surveyor Lander as part of the Mars In-Situ Propellant Production Precursor (MIP) package. MATE will measure several solar cell technologies and characterize the Martian environment's solar power. This will be done by measuring full IV curves on solar cells, direct and global insolation, temperature, and spectral content. The Lander is is scheduled to launch in April 2001 and arrive on Mars in January of 2002. The site location has not been identified but will be near the equator, is a powered landing, and is baselined for90 sols. The intent of this paper is to provide a brief overview of the MATE experiment and progress to date. The MATE Development Unit (DU) hardware has been built and has completed testing, work is beginning in the Qualification Unit which will start testing later this year, Flight Hardware is to be delivered next spring .

1. INTRODUCTION

This flight experiment is one of five experiments that make up the MIP package. MIP is designed to demonstrate the conversion of atmosphere CO_2 into propellant (O_2), which can be used to return to earth. One of the most important resources required to produce propellant on Mars is energy. Power is required for all phases of propellant production, from the initial collection and compression of atmospheric carbon dioxide to the liquification and storage of the cryogenic propellants produced. In many propellant production systems, the power system is the single largest and most massive component.

The four other experiments on MIP are; Mars Atmosphere Acquisition and Compression (MAAC), Oxygen Generating System (OGS), Mars Thermal Environment Radiator Characterization (MTERC), and Dust Accumulation and Removal Technology (DART). The MIP experiment control and main structure is being built and operated by NASA Johnson Space Center, as is OGS. MAAC and MTERC are being built at the NASA Jet Propulsion Laboratory, and DART is being built at NASA Glenn Research Center as well. The MATE and DART experiments share a 26 cm. x 24 cm. honeycomb substrate.

2. MATE DESCRIPTION

MATE is Mars Array Technology Experiment and its primary goal is to determine the optimum solar cell type for future missions. To do this it will measure the performance of solar cells, the solar spectrum, solar insolation, and temperature. MATE has several components and electronics, they are:

10 solar cells (5 pairs) Note: 9 on DU
2 solar cell strings

2 radiometers, direct and global
6 temperature sensors
1 dual spectrometer, 300 –1700 nm

2.1 Component Description

Each component is described briefly. Figure 1 shows a layout of the MATE DU experiment, the outlines represent components under the plate and the empty space is for the DART experiment which shares the same plate. The Qualification and Flight units will have slightly different component locations and configurations. This experiment has no moving parts. The diagram in figure 2 shows the general concept of the experiment and its interfaces.

MATE has a dedicated 4" x 6" circuit board in the MIP warm electronics box (WEB). This board is instructed what test scenario to perform and can run IV curves, sense temperatures, read insolations, run the spectrometers, then sorts the data, repeats any measurements, and sends the data back to MIP, which it sends to the Lander. The Lander stores the data until it is ready to be transmitted to an orbitting satellite and then back to Earth.

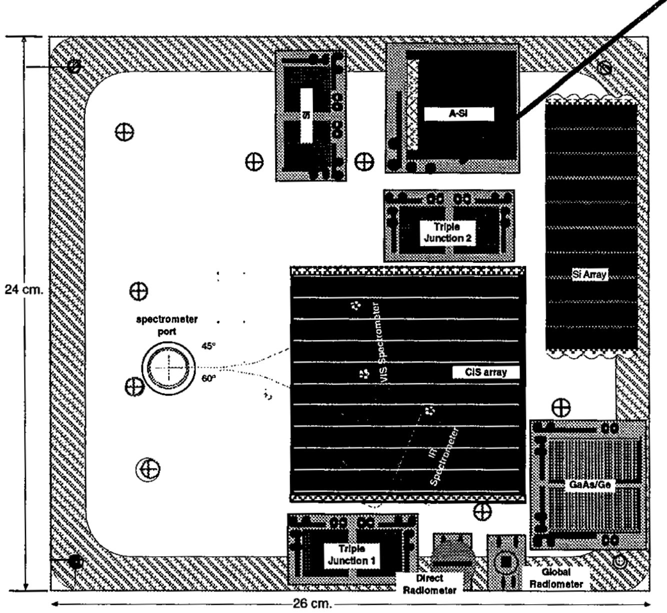

Figure 0: MATE DU Layout

Solar Cells (10): The solar cells will be made from a variety of materials and sizes. There are 5 pairs of different cell types. The space available, 80 mA maximum current, and 6 V maximum voltage limit the sizes of the cells. Cell selection was based on state-of-the-art viable cell technologies which will be suitable for the Mars environment. The cell types selected include; high efficiency Si from Sharp, Amorphous Si form United Solar Systems, two types of GaInP/GaAs/Ge triple junction cells from Spectrolab and Tecstar (these are p/n and n/p designs), and GaAs/Ge from Tecstar which are similar to those used on pathfinder [1,2].

Cells must perform at a lower temperature intensity then is common to most space cells [3]. The solar intensity on Mars is approximately one third of earth's AM0 or 45 mW/cm^2. Preliminary spectral data from Mars pathfinder and Viking have shown that the sunlight on Mars varies with dust content and tends to scatter the red part of the spectrum.

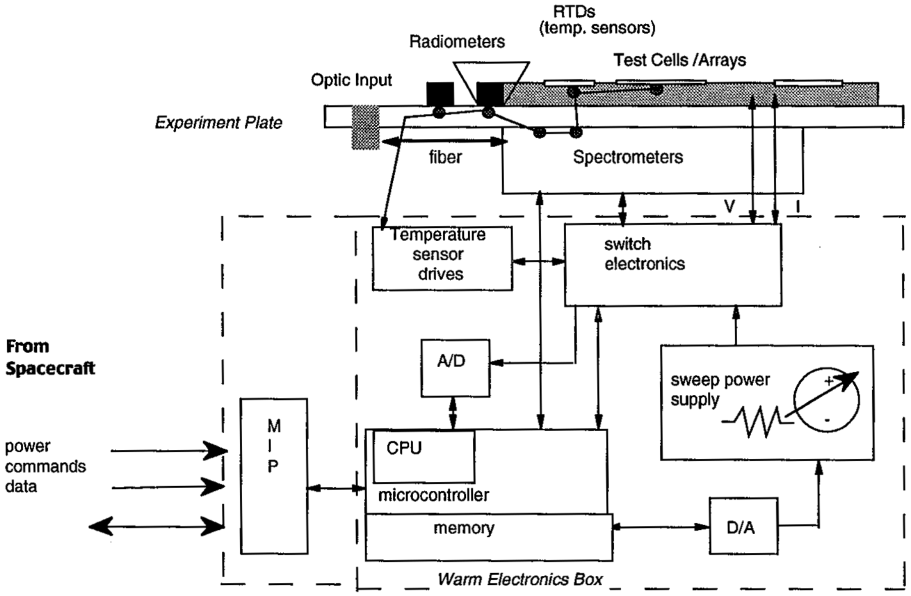

Figure 2 : Functional Diagram

Studies show that large area roll out thin film arrays prove very useful for many Mars missions. Thin films include CIS and Amorphous Si, both of which are being considered in the space community. Mobile manned missions will require large portable arrays that can be easily moved.

Solar Cell Strings (2): Two series strings will be flown on this mission. One string will be standard solar cells; the other will be a thin film. These strings are intended to test new technology as well as identify any problems with array designs. A string of Si cells from Sunpower and a CIS string from Global Solar are planned. Both of these strings demonstrate new unproven space technologies, the Si string has interdigitated front and back contacts, the CIS string contains fully integrated processing for cells and interconnects.

Radiometers (2): The radiometers are thermocpile devices that contain 20 thin film thermocouple junctions.. They are in an Argon filled TO-5 can with a Sapphire window and carbon black absorber as shown Figure 3. These devices generate a voltage proportional to the solar intensity and are 1-10 mV at Mars with a -.4%/°C temperature correction. They are being made by Dexter Research and have typically been used for measuring laser power.

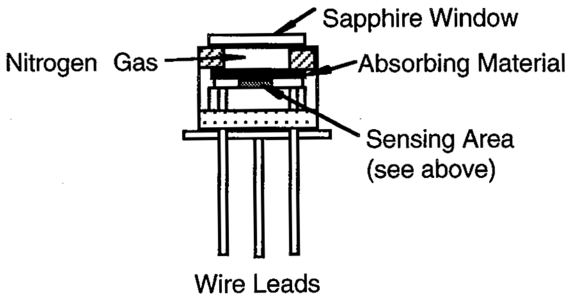

Figure 3 : Radiometer Design

There are two radiometers, one measuring global and the other measuring direct radiation or solar insolation. The global measurement is done with a radiometer that has approximately 130° field of view. This field of view is considered adequate based on the limitations of the device and the expected amount of scattered light. A second radiometer will have a cylindrical shell placed over it with baffles and a slit; this will measure direct radiation with the sun overhead. The direct radiometer can only be read when the sun is directly over the slit, this will consist of a timed measurement in 20 second intervals for 20 minutes around its optimum sun sensing. A precision landing allows for proper orientation of the slit prior to launch (within 15°).

Temperature Sensors (6): Six temperature sensors from Wahl will be scattered around the MATE experiment, two will be attached to the radiometers, two will be on the photodiode arrays of the spectrometers, and the rest will be under solar cells. The temperature sensors are platinum devices known as RTD (resistance temperature dependence). They have a well-characterized linear change in resistance with temperature (.385 %/°C) and a 0° C resistance of 1000 Ω. They are in a small ceramic case with two wires. Measurement accuracy will be 1 degree C. The temperature will be measured using a 3-wire technique and constant 100 µA current source.

Dual Spectrometer (2): The dual spectrometer consists of an input optic and two spectrometers, both having optical fiber inputs. This will span the solar spectrum from .3µm to 1.7 µm with a nominal resolution of 10 nm. This range was selected based on the bandwidth of solar cells and the AM0 spectrum, covering 86% of the total energy.

The input optic converts incident radiation into a diffuse light source. It consists of a tube, thin diffusing element made of Spectralon, a folding prism, and a fiber output. Light enters this diffusing element and is scattered uniformly and therefore each fiber will see the same amount of light. This diffuser extends the capability to look at the sky at any time of the day. Figure 4 shows a sketch of the input optics and figure 7 shows the

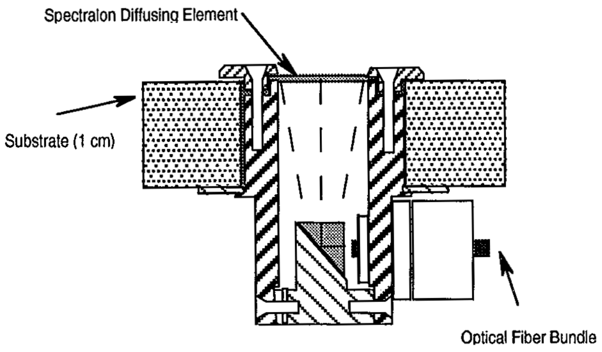

Figure 4: Spectrometer Input Optic Design

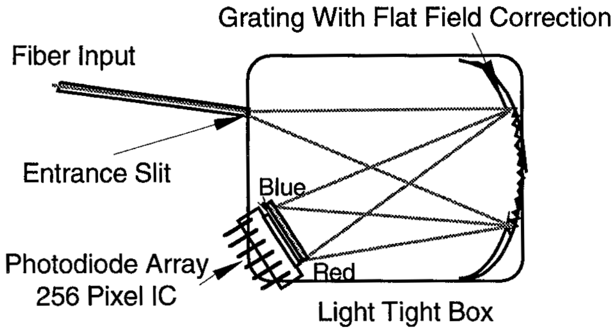

Figure 5: Fixed Grating Spectrometer

individual components.

The spectrometers are two separate devices with the same basic design except for the wavelength range they are designed for. Traditional spectrometers have used a rotating grating with a single detector, measurements for each wavelength range had to be made sequentially by turning the grating and reading the detector. These spectrometers have a fixed grating with multiple detectors where the entire spectral range is read simultaneously (figure 5). The multiple detectors are a photodiode array (PDA), each of these spectrometers has a PDA with 256 elements or detectors. These are very compact devices, but have a fixed resolution based on the detector response, grating, slit size, pixel size, and number of pixels. One spectrometer is made by Zeiss and has a Si PDA (Hamamatsu) covering 300-1100 nm, and the other is made by Control Development with an InGaAs PDA (Sensors Unlimitied) covering 900-1700 nm.

The sensitivity of the spectrometers is adjusted by one of two ways, by a gain adjustment or a change in the integration time. These spectrometers will have a fixed gain amplifier with a variable integration time to optimize the signal for the A/D. With the gain fixed, the integration time is proportional to the signal level and can be divided out to compare readings over different days. The resolution of this spectrometer is much higher then any current or planned measurements and should be able to resolve many narrow absorption bands over a wide range of environmental conditions [4,5].

Electronics : The operation of the electronics is based on an 8-bit CPU, session programmed into ROM which is dumped into RAM, and an 8-bit D/A and A/D. There are 65 wires that connect to the experiment and 25 wires that connect to the MIP Main Controller Board. The board is a multi-layer 4" x 6" and gets ±15V from MIP and has a 5V regulator on board. All of the A/D is converted using optimized 8-bit setup which guarantees <1% resolution over the range being measured. All of the data is passed to MIP as it is generated in a 256 byte packet system.

2.2 MATE specifications

The MATE/DART plate is 24 cm. x 26 cm and rests on the top horizontal surface of MIP. MATE is 500 cm^2 and will be operated from a single 4 x 6" electronics board in the MIP Warm Electronics Box. It requires 7.5 W of power and operates for less then 1 minute per session. The board will receive power and instructions from the MIP main controller board and transfer data for storage to MIP. The MIP main controller board will store data and transmit data to the lander. The total mass of MATE including the electronics is 510 g.

3. MATE Operation

The MATE operation currently has five different measurement scenarios, a sixth will be added for the flight unit, and a seventh is a ground test. Three of the measurement scenarios are identical and only vary by the time(s) of day, a fourth scenario is for the direct radiometer, and the fifth is a health check. MATE is scheduled to run once per day at solar noon, once per hour throughout the day one day per week, and once per week at night. MATE is operated 19 times per week unless power limitations or Lander priorities prevent it.

The three operation scenarios will measure full IV curves on all cells and strings, the radiometers, temperatures, and spectrometers. This sequence will run about 1 minute, use 7.5 W nominally, and take about 60 Kbits of data. All of the data will be in 8-bit format with the A/D scaled to optimize resolution. An IV curve will have 256 points and clearly identify open circuit voltage, short circuit current, and maximum power. The temperature will be within 1 degree C. Solar Insolation will be a converted voltage and temperature measurement The spectrometers will first be reset, read once to adjust the A/D scaling, and then read a second time. The

The direct radiometer measurement can only be done when the sun is passing over the slit. The radiometer will be measured every 20 seconds over a 20 minute interval centered around solar noon. A plot of this data will result in a peak measurement under direct illumination. Comparison of the other data is necessary to interpolate the direct insolation. Health checks will consist of a quick scan of all the instruments and cells. Data will be cell open and shirt circuit conditions, temperatures, and radiometer data.

A sixth session will be added to measure the spectral effectt of the dust directly. This will be coordinated with the DART Material Adherence Experiment (MAE) which has a moving glass window. MATE and DART experiments will be operated simultaneously and do not share any common communication so timing is critical to obtain this data. Dust will accumulate on the MAE window which can be rotated over the spectrometer input optics. Taking the spectrum with and without the dust laden window and subtracting the two spectrums will result in a spectrum of just the effect of the dust.

4. DESIGN COMMENTS

The DU Unit has been built and has completed all testing and is shown in Figure 6. This unit included all the components of MATE except with lower fidelity, alternate but representative cell types were used. The testing included functional test, communication protocol, Mars chamber thermal tests (hot, cold, and nominal sols at 6 torr), cruise in hard vacuum, vibration, electromagnetic interference, and pyroshock.. All tests were considered successful with two mechanical failures during vibration and pyroshock. The conical slit resting on the direct radiometer caused a lead wire to break on the temperature sensor during vibration and the InGaAs PDA pulled away from the optic during pyroshock. Both of these failures have been resolved with design modifications which will be implemented in the qualification and flight hardware.

The flight unit will differ from the DU with some minor design modifications. The locations of the components will be changed to improve the field of view for many of the solar cells, all the high components to one side, and allowing for shorter wire runs on the top plate. The direct radiometer will be cylindrical and have additional baffling to improve its response. The dual spectrometer input optics will be raised slightly to rest just under the MAE window when it is opened to avoid stray light and it will have a light pie feed inside the optics. MIP is located in close proximity to the Additional changes include the use of ferrite beads and mesh to reduce EMI. MIP

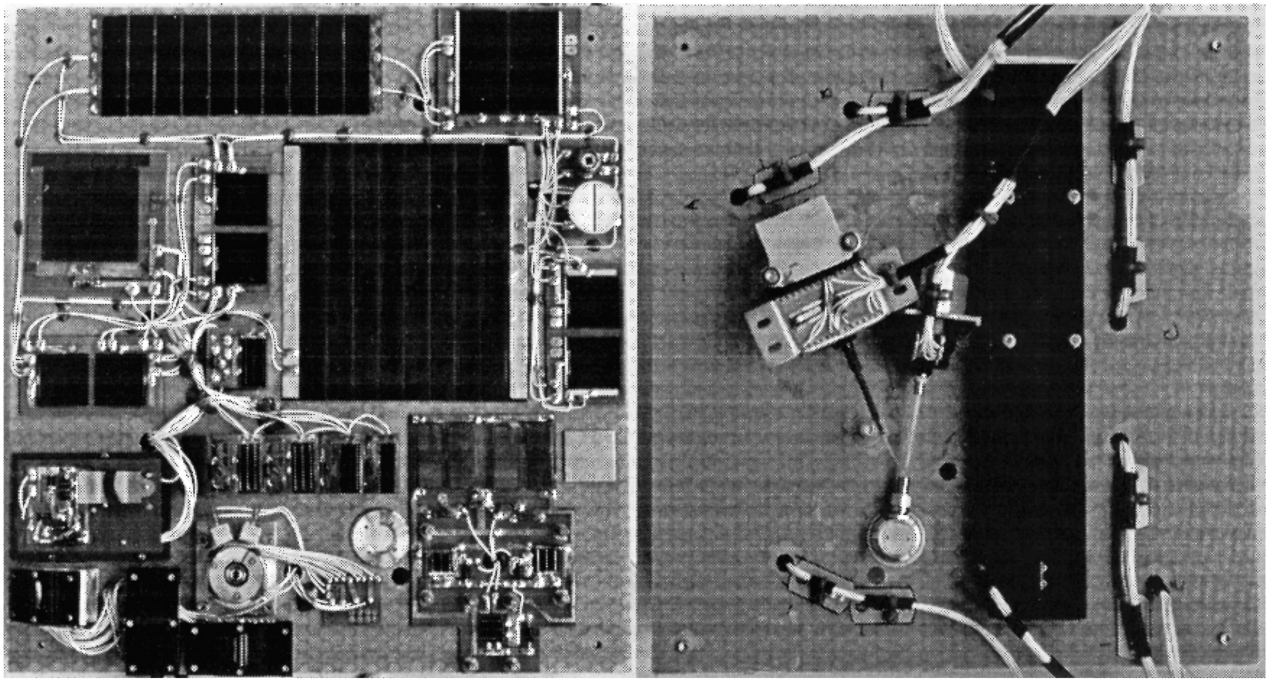

Figure 6 : MATE/DART DU (top and bottom views)

5. CONCLUSIONS

Both MATE and DART are ready toi proceed toi the Qual and Flight hardware build with confidence in the survivability of their experiments. The data obtained form MATE will be both beneficial in assessing the performance of solar cells and arrays on Mars as well as characterizing the Mars environmnet for modelling of future solar cell materials. The mission is baselined for 90 days depending on site location and power. MATE main objectives .are to:

- Measure solar cell performance in-situ
- Evaluate different types of solar cells

- Study long term effects of the Martian environment, particularly dust, on solar cells [6].
- Characterize the Martian environment by measuring the spectral content, solar insolation, and cell temperature

The MATE experiment is teamed up with the DART experiment [7]. With these two experiments, many of the concerns related to providing solar power on Mars will be studied.

Successful operation of the MATE experiment is dependent on several factors. Complete calibration of the radiometers, spectrometerrs, and temperature sensors will be performed on the flight hardware. One important test condition is a dust free baseline measurement on the surface of Mars. MIP will have a dust cover which will be opened after the landing dust has settled and the rover and pan cam have been deployed. A second issue is the field of view of the solar cells and sensors; Lander equipment may shadow some of the experiment. The orientation and location of the Lander will be known; the site and the location of the sun must be identified. These are critical elements in interpreting the data. The DART experiment also contains a sun sensor which will locate the sun and help to determine the optimum times to measure the direct radiometer. These two elements will aid in data analysis and measurement timing.

6. REFERENCES

More information can be found on the NASA Glenn Research Center PVSE branch web page at http://powerweb.lerc.nasa.gov/pvsee/publications/wcpec2/mate2001.html or NASA JPL Mars Missions web page at http://mars.jpl.nasa.gov/2001/lander/index.html

[1] G.A. Landis, “Solar Cell Selection for Mars,” 2nd World Conference on Photovoltaic Energy Conversion, Vienna, Austria, July 1998

[2] G.A. Landis and J. Appelbaum, "Design Considerations for Mars PV Power Systems," *Proceedings of the 21st IEEE Photovoltaic Specialists Conference, Vol. 2,* pp. 1263-1270, May 1990.

[3] D. Scheiman, P. Jenkins, D. Brinker, and J. Appelbaum,” Low-Intensity, Low-Temperature (LILT) Measurements and Coefficients on New Photovotaic Structures.” Progress in Photovoltaics, Vol. 4, pp. 117-127 (1996)

[4] G.A. Landis, "Dust Obscuration of Mars Photovoltaic Arrays," *Acta Astronautica, Vol. 38, No.* 11. pp. 885-891 (1996). Presented as paper IAF-94-380, 45th International Astronautical Federation Congress, Jerusalem, Oct. 9-14 1994.

[5] E.A. Guiness, C.E. Leff and R.E. Arvidson, “Two Mars Years of Surface Changes Seen at the Viking Landing Sites,” *J. Geophys. Res, Vol 87,* B12, pp. 10051-10058 (1982).

[6] G.A. Landis and P. Jenkins, “Dust on Mars: Materials Adherence Experiment Results from Mars Pathfinder,” *Proceedings of the 26th IEEE Photovoltaic Specialists Conference,* Anaheim CA, pp. 865-869, Sept. 29-Oct. 3 1997.

[7] G.A. Landis, P. Jenkins, C. Baraona, D. Wilt, M. Krasowski, and L.Greer, “Dust Accumulation and Removal Technology (DART) Experiment on Mars 2001 Lander,” 2nd World Conference on Photovoltaic Energy Conversion, Vienna, Austria, July 1998