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Optical Properties of Nanosatellite Hardware

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LIST OF ACRONYMS

ASTM	American Society for Testing and Materials
COTS	commerical off-the-shelf (components)
EDSN	Edison Demonstration of Smallsat Networks
GPS	Global Positioning System
ISS	International Space Station
JEM	Japanese Experiment Module
J-SSOD	JEM Small Satellite Orbital Deployer
LDEF	Long Duration Exposure Facility
LPSR	Laboratory Portable Spectroreflectometer
MISSE	Materials on International Space Station Experiment
SMDC-ONE	Space Missile Defense Command-Operational Nanosatellite Effect

TECHNICAL MEMORANDUM

OPTICAL PROPERTIES OF NANOSATELLITE HARDWARE

1. INTRODUCTION

Over the last decade, a number of very small satellites have been launched into space. These have been called nanosatellites (generally of a weight between 1 and 10 kg) or picosatellites (weight <1 kg). This also includes CubeSats, which are based on 10-cm cube units. With the addition of the Japanese Experiment Module (JEM) Small Satellite Orbital Deployer (J-SSOD) to the International Space Station (ISS), CubeSats are easily cycled through the JEM airlock and deployed into space (fig. 1). The number of CubeSats launched since 2003 was approaching 100 at the time of publication, and the authors expect this trend in research to continue, particularly for high school and college flight experiments.

Figure 1. CubeSats deployed from the J-SSOD and photographed against an ISS solar array background.

Because these spacecraft are so small, there is usually no allowance for shielding or active heating or cooling of the avionics and other hardware. Parts that are usually ignored in the thermal analysis of larger spacecraft may contribute significantly to the heat load of a tiny satellite. In addition, many small satellites have commercial-off-the-shelf (COTS) components. To reduce costs, many providers of COTS components do not include the optical and physical parameters necessary for accurate thermal analysis.

Marshall Space Flight Center participated in the development and analysis of the Space Missile Defense Command-Operational Nanosatellite Effect (SMDC-ONE) and the Edison Demonstration of Smallsat Networks (EDSN) nanosatellites. These optical property measurements are documented here in hopes that they may benefit future nanosatellite and picosatellite programs and aid thermal analysis to ensure project goals are met, with the understanding that material properties may vary by vendor, batch, manufacturing process, and preflight handling. Where possible, complementary data are provided from ground simulations of the space environment and flight experiments, such as the Materials on International Space Station Experiment (MISSE) series. NASA gives no recommendation, endorsement, or preference, either expressed or implied, concerning materials and vendors used.

Solar absorptance (α_s) was calculated from spectral reflectance measurements made from 250 to 2,800 nm with an AZ Technology Laboratory Portable Spectroreflectometer (LPSR) model 300. ASTM E-903 was the test method used under normal laboratory conditions,[1] and ASTM E-490 was the solar spectral irradiance data used to calculate α_s.[2] Most of the samples were flat, but stray light was minimized as much as possible with either a blackbody or black cloth as sample background. The LPSR has repeatability of approximately ±1%, where α_s is given as range, that is, from actual measurements taken across the sample.

Infrared emittance (ε_{IR}) measurements were made with an AZ Technology TEMP 2000A infrared reflectometer. This instrument measures the total hemispheric reflectance averaged over 3–35 μm wavelengths. ASTM E-408 was the test method used under normal laboratory conditions.[3] Stray light was minimized as much as possible. The TEMP 2000A has repeatability of approximately ±0.5%, where ε_{IR} is given as a range, that is, from actual measurements taken across the sample.

2. ANTENNAS

The antenna for the SMDC-ONE satellite had exposed 301 stainless steel and Kapton®. The antenna for the EDSN satellite was a Digi-Key 1575.42 MHz ceramic patch, part number 931-1141-ND for Global Positioning System communication. Two EDSN antennas indicated quite different results, which was unexpected given the lack of visual differences. Data for these can be found in table 1. Also included are preflight optical properties of an antenna consisting of direct-write copper on Tedlar® film that was flown on the MISSE-8 experiment.

Table 1. Optical property measurements of antenna parts.

Sample		Solar Absorptance	Infrared Emittance
SMDC-ONE antenna	301 stainless steel	0.41	0.14
	Kapton	0.58	0.84
EDSN GPS antenna	No. 1	0.20	0.13–0.15
	No. 2	0.24	0.28–0.31
Direct-write on Tedlar	Copper	0.61	0.32

3. PRINTED CIRCUIT BOARDS

The printed circuit boards for this study are as-built rather than blank. Some were conformal coated, and some were left uncoated. Measurements were taken of areas with the fewest connections and areas with many connections to allow the thermal designer to calculate an overall average for their particular surface.

3.1 Uncoated Circuit Boards

Figure 2 shows the uncoated G115-SP1.5_v1 board for EDSN, grooved side up. Solar absorptance and infrared emittance are given for each area of the board in table 2. The reverse side was mostly sections of solder for attaching solar cells, so only typical properties are presented here.

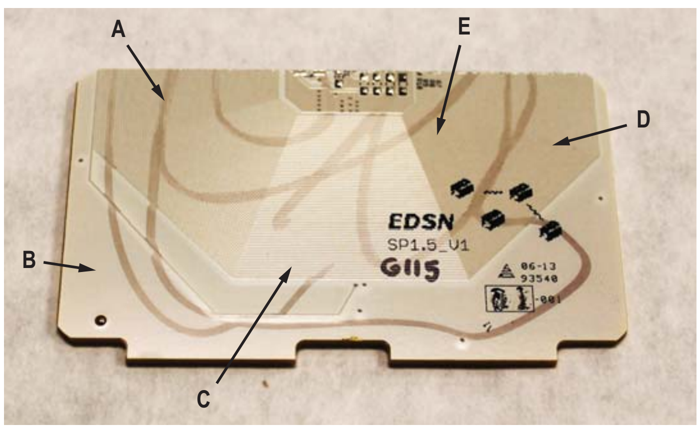

Figure 2. Uncoated EDSN white circuit board G115.

Table 2. Optical properties of uncoated EDSN G115 white circuit board.

Area	Solar Absorptance	Infrared Emittance
Obverse A	0.45	0.88
Obverse B	0.49	0.90
Obverse C	0.47	0.88
Obverse D	0.46	0.89
Obverse E	0.45	0.89
Reverse	0.31	0.05

Figures 3 and 4 are of an uncoated green circuit board for EDSN. Solar absorptance and infrared emittance are given for each area of the board in table 3. Three measurements were made around the center of the obverse side that were identical in solar absorptance and infrared emittance.

Figure 3. Uncoated EDSN G116 green circuit board, numbered side.

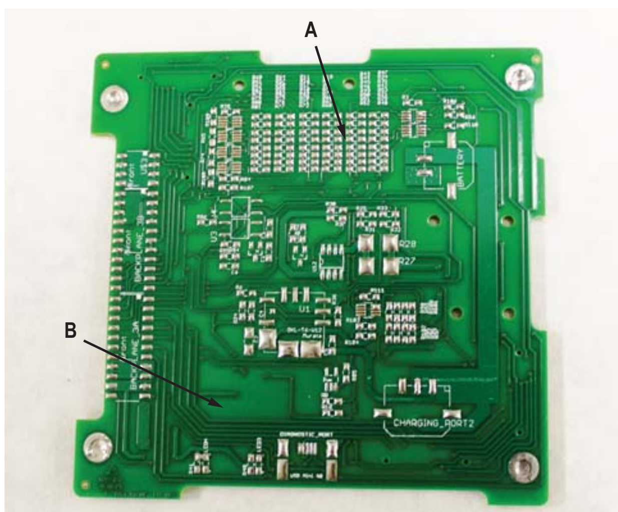

Figure 4. Reverse side of G116-B3_v1 board.

Table 3. Optical properties of uncoated EDSN G116 green circuit board.

Area	Solar Absorptance	Infrared Emittance
G116 obverse	0.65	0.86
G116 reverse –A	0.77	0.89
G116 reverse –B	0.81	0.90

3.2 Coated Circuit Boards

Four coated EDSN circuit boards were measured. The only white board was G114 (figs. 5 and 6). The Arathene 5750-A/B (LV) urethane conformal coating varied by the amount of thinner added, but this did not appear to have any impact on the optical properties. For completeness, the coating for the G111 board for 18 g of part A, 100 g of part B, and 20 g thinner (figs. 7 and 8); G112 was 18 g of part A, 100 g of part B, and 30.5 g thinner (figs. 9 and 10); G113 and G114 were 18g of part A, 100 g of part B, and 45 g thinner (figs. 11 and 12). Optical properties for the white and green coated circuit boards are in tables 4 and 5, respectively.

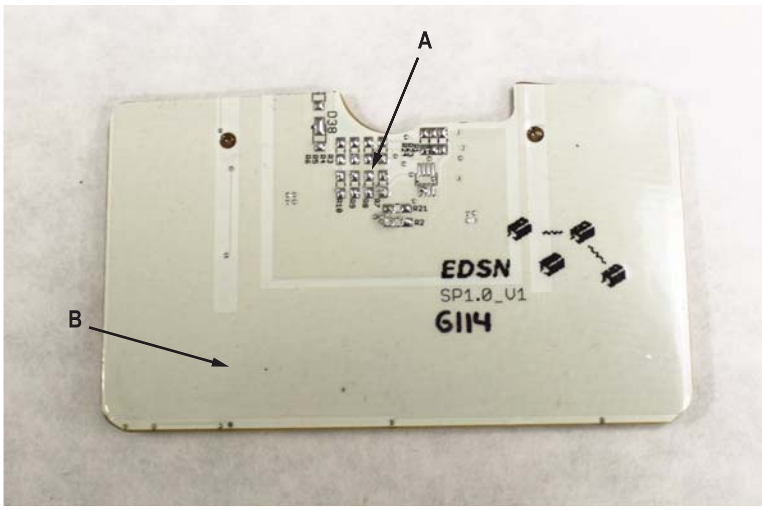

Figure 5. Coated EDSN white circuit board, numbered side.

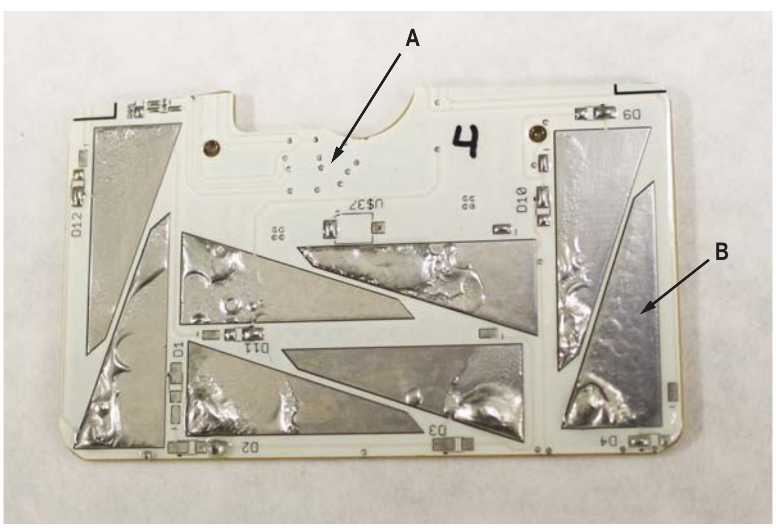

Figure 6. Reverse side of G114 circuit board.

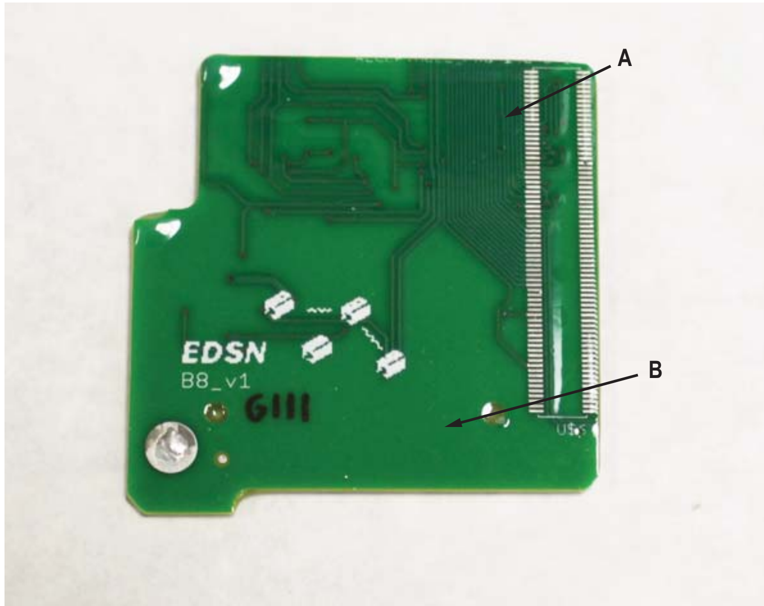

Figure 7. Coated EDSN green circuit board G111, numbered side.

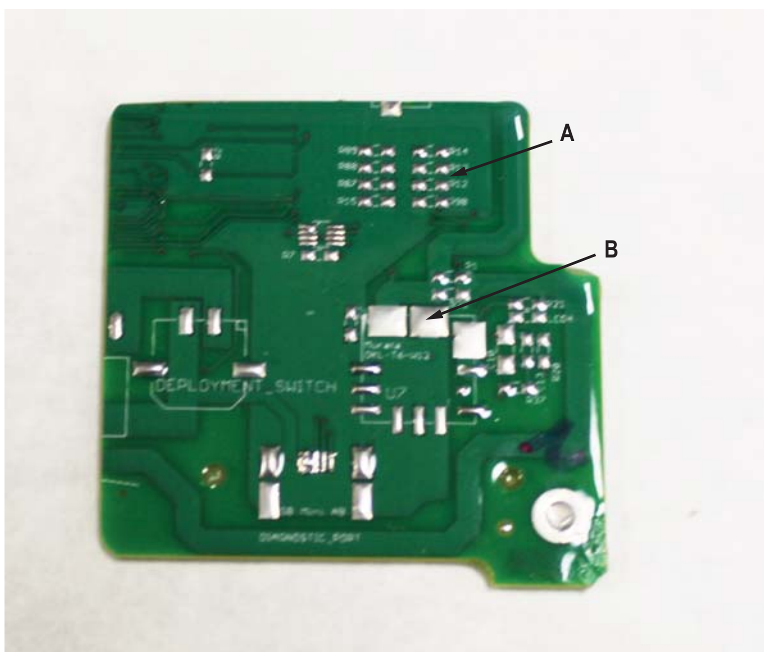

Figure 8. Reverse side of G111 circuit board.

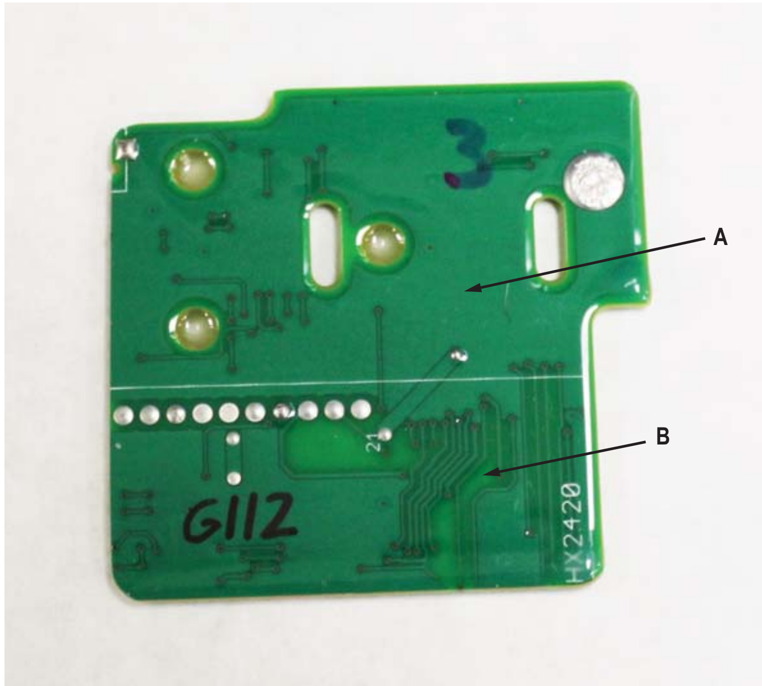

Figure 9. Coated EDSN green circuit board G112, numbered side.

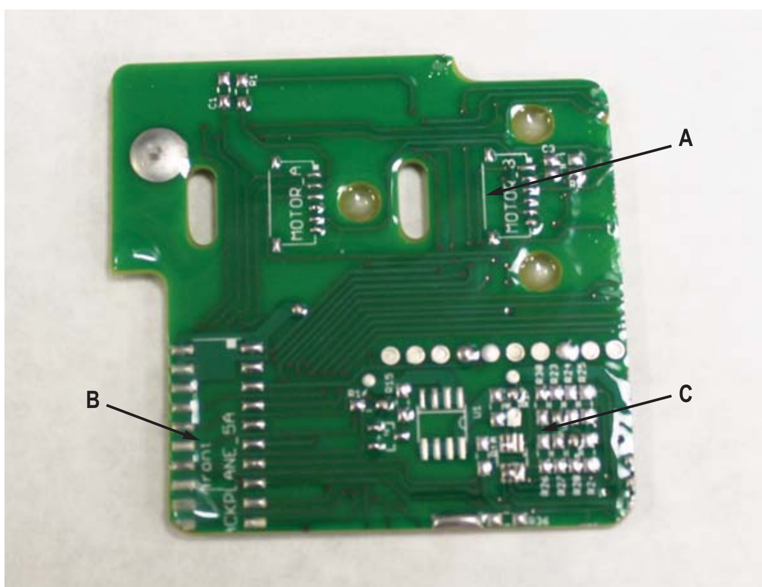

Figure 10. Reverse side of G112 circuit board.

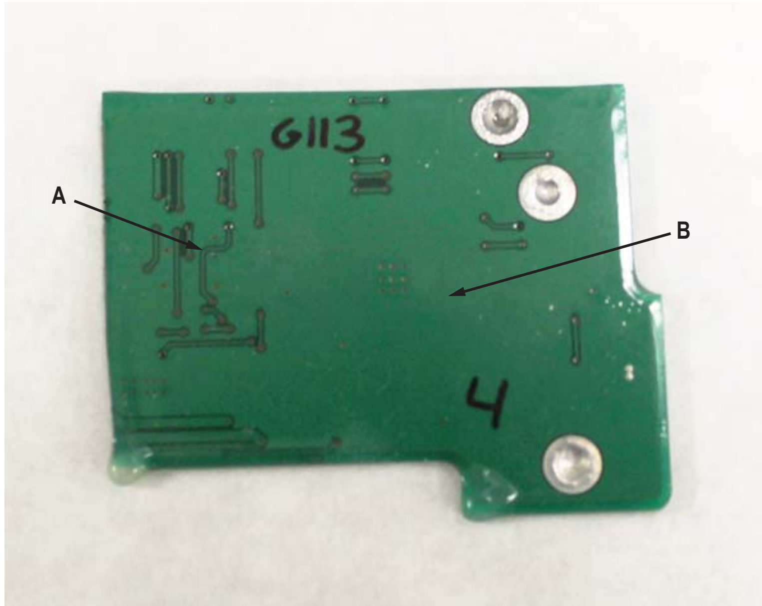

Figure 11. Coated EDSN green circuit board G113, numbered side.

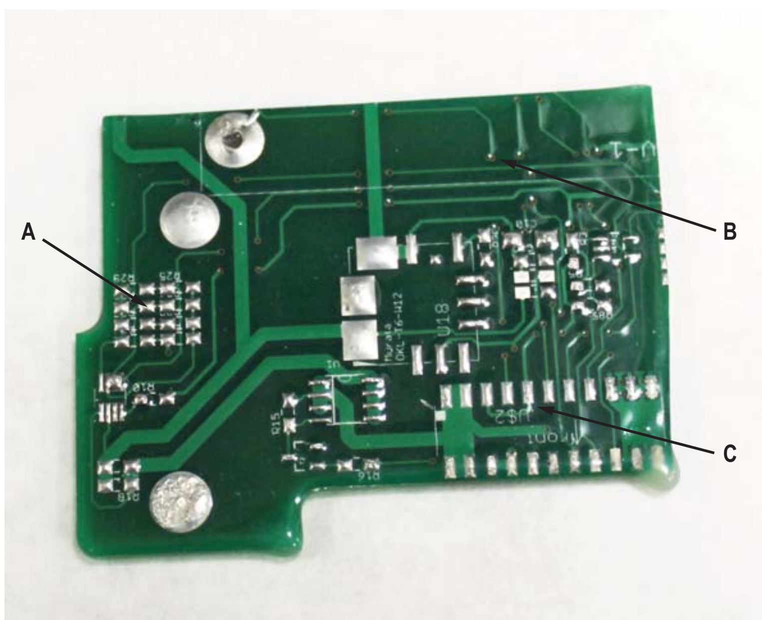

Figure 12. Reverse side of G113 circuit board.

Table 4. Optical properties of coated EDSN white circuit board.

Area	Solar Absorptance	Infrared Emittance
G114 obverse A	0.48	0.89
G114 obverse B	0.44	0.91
G114 reverse A	0.36	0.89
G114 reverse B	0.50	0.77

Table 5. Optical properties of coated EDSN green circuit board.

Area	Solar Absorptance	Infrared Emittance
G111 obverse A	0.71	0.89
G111 obverse B	0.74	0.90
G111 reverse A	0.69	0.86
G111 reverse B	0.61	0.77
G112 obverse A	0.59	0.89
G112 obverse B	0.70	0.90
G112 reverse A	0.60	0.84
G112 reverse B	0.67	0.82
G112 reverse C	0.51	0.80
G113 obverse A	0.61	0.88
G113 obverse B	0.68	0.88
G113 reverse A	0.68	0.81
G113 reverse B	0.70	0.64
G113 reverse C	0.72	0.85

4. SOLAR CELLS

Solar cells by their very nature absorb sunlight. As the efficiency of solar cells has improved over the years, the solar absorptance has increased. Table 6 contains the data for the SMDC-ONE nanosatellite triple-junction, high-efficiency solar cells. Optical properties are included for older, less efficient silicon solar cells after exposure on the Long Duration Exposure Facility for 5.8 years. Other single-junction and multi-junction solar cells should fall between these two extremes; thin film photovoltaics under development at the time of publication may have very different properties.

Table 6. Optical properties of solar cells.

Sample	Solar Absorptance	Infrared Emittance
SMDC-ONE triple junction	0.93	0.85
LDEF silicon	0.74–0.75	0.83–0.84

5. BATTERIES

An EDSN lithium-ion battery with the plastic wrapping removed had infrared emittance of 0.11. This is typical of bare metal. A battery with intact plastic wrapping (fig. 13) had infrared emittance of 0.85.

Figure 13. EDSN battery with green plastic wrapping.

6. MISCELLANEOUS MATERIALS

Other materials measured in support of SMDC-ONE and EDSN can be found in table 7. It should be noted that chemical conversion coatings such as Alodine have highly variable optical properties dependent on the substrate metal, surface finish, and application method.

Table 7. Optical properties of miscellaneous nanosatellite materials.

Area	Solar Absorptance	Infrared Emittance
Copper tape	0.48	0.80
Tin plate	0.49–0.51	0.15–0.20
Alodine on 6061-T6 aluminum	0.33	0.07

7. DISCUSSION AND CONCLUSIONS

The information presented here was gathered to support nanosatellite and picosatellite missions that may not be able to perform their own thermal property measurements. Some margin should be included in a design for unexpected degradation or contamination events. The specific conditions for the spacecraft must be considered when choosing materials.

The authors would also like to note the concurrent development of "Spacecraft Surface Charging Analysis of a CubeSat," a document on NASA Charging Analyzer Program (NASCAP) analysis for EDSN by Emily Willis that may be useful for other nanosatellite developers.

REFERENCES

1. ASTM E-903, Standard Test Method for Solar Absorptance, Reflectance, and Transmittance of Materials Using Integrating Spheres, Book of Standards, Vol. 12.02, December 1, 2012.

2. ASTM E-490-00a, Standard Solar Constant and Zero Air Mass Solar Spectral Irradiance Tables, Book of Standards, Vol. 15.03, 2014.

3. ASTM E-408, Standard Test Methods for Total Normal Emittance of Surfaces Using Inspection-Meter Techniques, Book of Standards, Vol. 15.03, June 1, 2013.

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