Power System Design for Earth Orbiting Satellites

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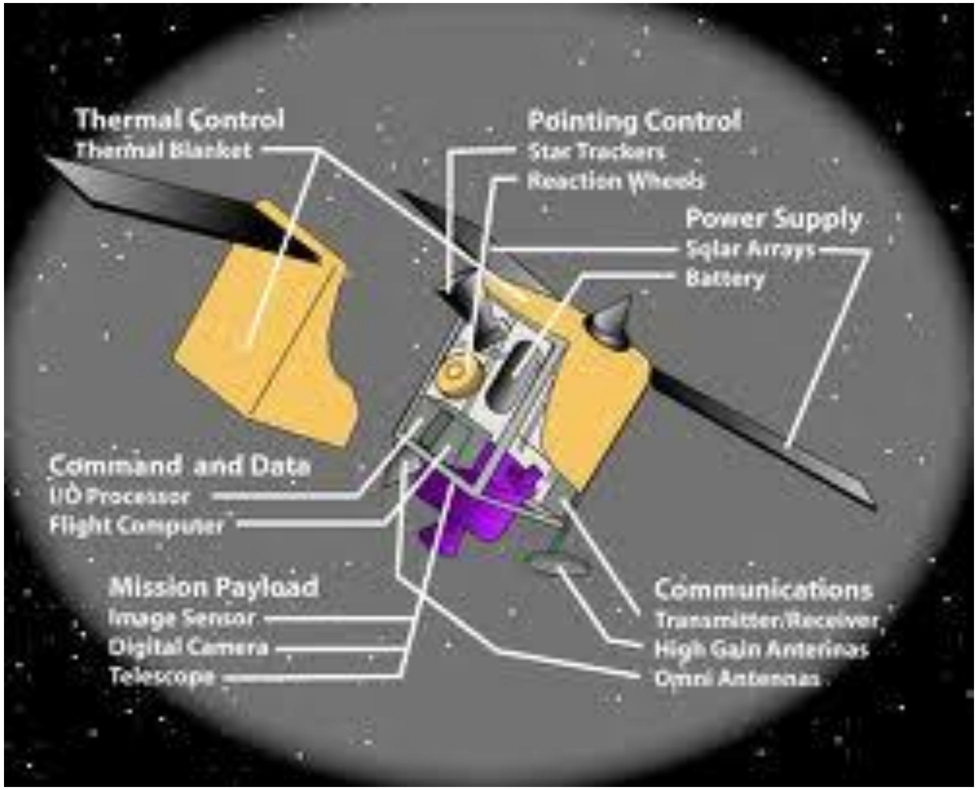
Satellite Subsystems (Overview)

- Satellite systems consist of propulsion, attitude control, onboard data handling, telecommunications, payload control, thermal control and power systems etc.

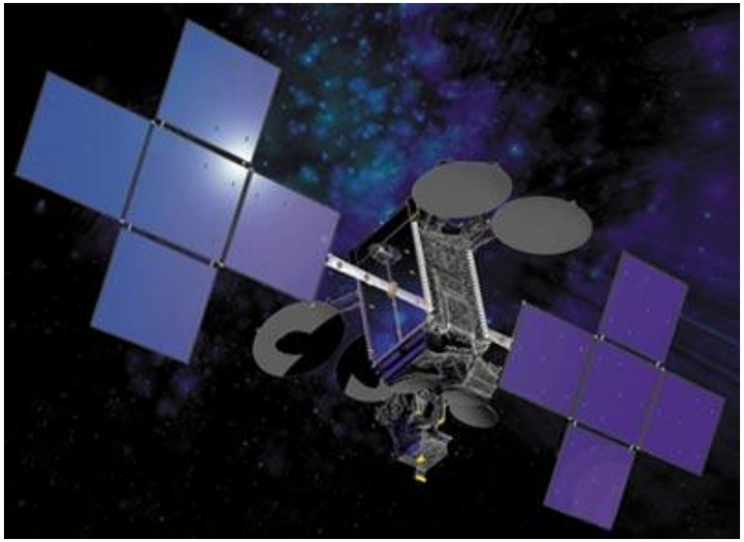


Satellites and Power

- Since the launch of Sputnik, thousands of satellites have been launched for variety of purposes.
- However, keeping a satellite in orbit is a challenging prospect, since it involves spending energy to push against Earth's gravity well, to spend energy to adjust its attitude, energy to cool/warm its interior, energy for its navigation / telemetry systems and most importantly energy for its communication systems.

Power Used by Satellites

- Early satellites had over 8,500 solar cells mounted on the surface of the satellite, which supplied about 42 watts of power. No battery backup was provided in these satellites.
- Newer communications satellites have about 32,000 solar cells mounted on the surface of the satellite, and they supply about 520 watts. A nickel cadmium battery is used for backup power during eclipses.
- Some satellites such as Intelsat 8 use 4.8 kW of power.



Power Systems and Satellites

- Reliable and continuous operation of the power systems is essential to the successful fulfillment of the satellite’s mission.

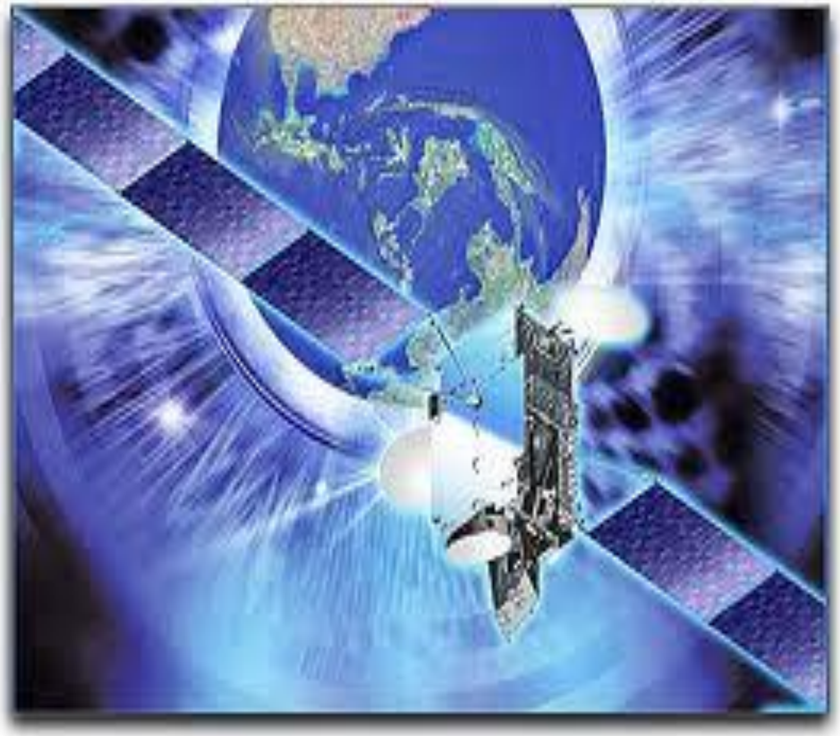
- A failure and even a very brief interruption in the source of power can cause catasrophic consequences for the satellite’s attitude control sytems as well as to its temperature control and its electrical systems. This can be more important in LEO satellites.

Power Sytem Failures on Satellites

- In October 1997, trading on Bombay's National Stock Exchange in India was halted for four days after the Insat-2D satellite lost attitude control and began spinning in space. The problem was blamed on a power failure and cost the exchange around US$2 billion in losses
- In September 2003, Loral Space & Communications declared the Telstar 4 satellite a total loss after it experienced a short circuit on the primary power bus on March 26,
- 1996, a solar panel on Canada's Anik-E1 satellite was disconnected, causing a power shortage and safety shutdown of the satellite. The satellite was restarted and was able to transmit a reduced number of television programs

Power System Design for Satellites

- Hence, in order to make sure that the continuous operation of the satellite is maintained, it is essential to design and fabricate its power systems to meet various requirements. Otherwise, the satellite's systems can stop functioning and this can cause a catastrophic failure of the satellite as well.



Power System Design for Satellites

- Fundamental criteria that must be met for proper power system design for satellites include:

  - Reliability (most important criteria)

  - Low Weight/Volume – High Power Density

  - Lower Costs

  - Compatible with the mission/payload of the satellite

  - Safety

  - Availability in a short time scale

  - Easy serviceability

Power System Design Preliminaries

- When designing a power system for the satellite, the following information needs to be analyzed before the design process can begin:

  - The altitude of the satellite and its precise orbit

  - Calculation of exposure of the satellite

  - Amount of power needed by primary / telemetry operational systems

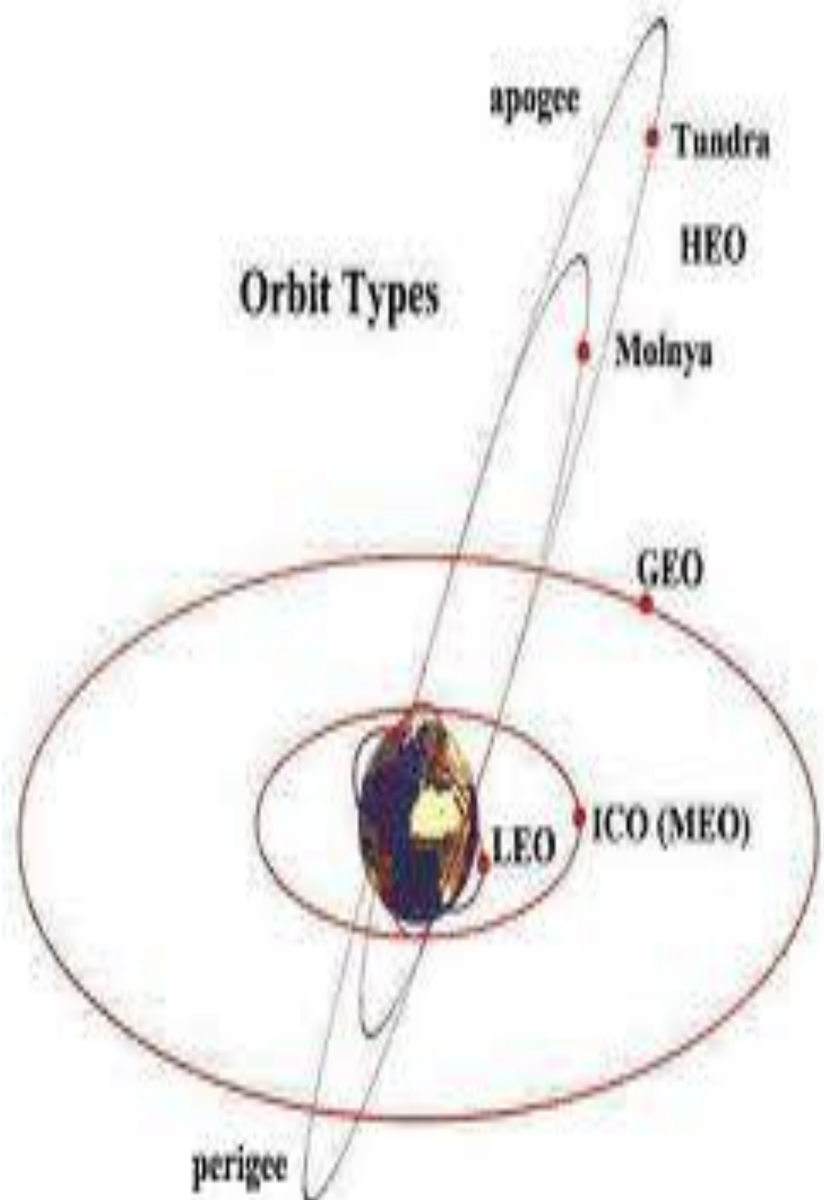
  - Amount of power needed for communications

  - Power Needed for any External Payload

  - Projected Lifeterm of the satellite

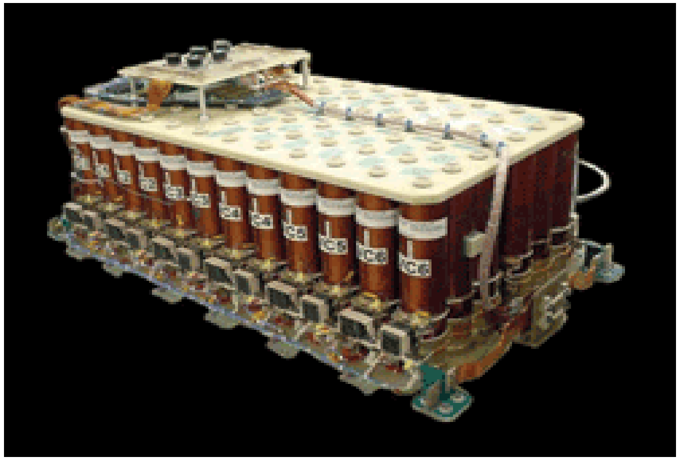
Effects of Orbit on Power Requirements of a Satellite

- The orbit of the satellite will be an important determining factor for the power requirements of a satellite.
- In LEO, the satellite will interact with the decreasing density of the atmosphere, atomic oxygen corrosion, ionespheric plasma, solar electromagnetic radiation and increased exposure to charged particles around South Atlantic Anomaly.
- MEO will deal with solar UV rad.
- GEO will deal with outer electrom belts,Solar UV and cosmic radiation.
- Molniya faces Van Allen Belts



Types of Power Sources for Satellites

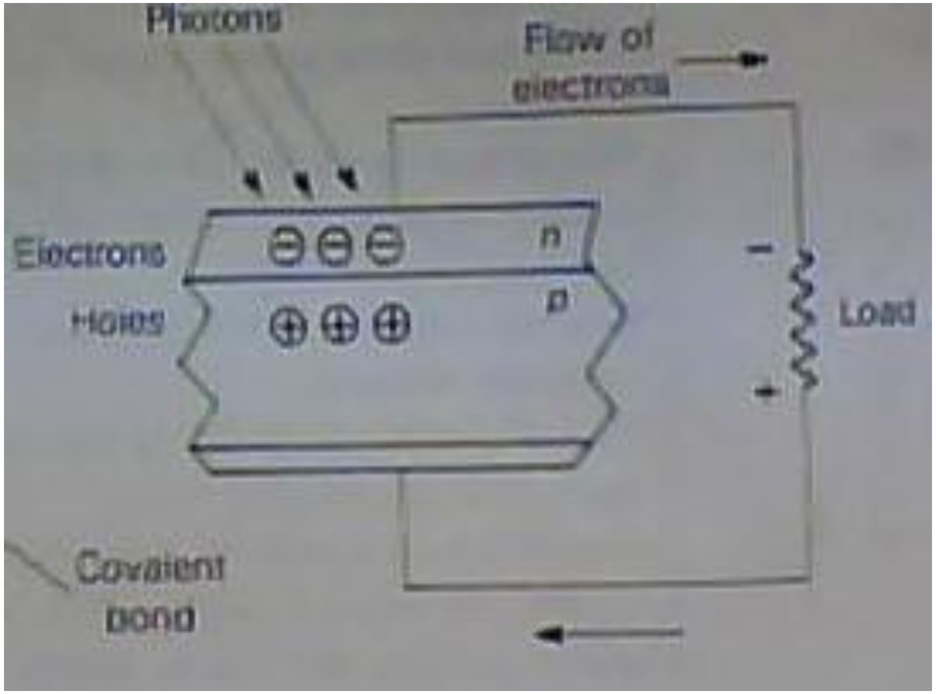
- Solar Power (Photovoltaic)
- Primary Battery
- Secondary Battery
- Radioisotope Thermoelectric Generators

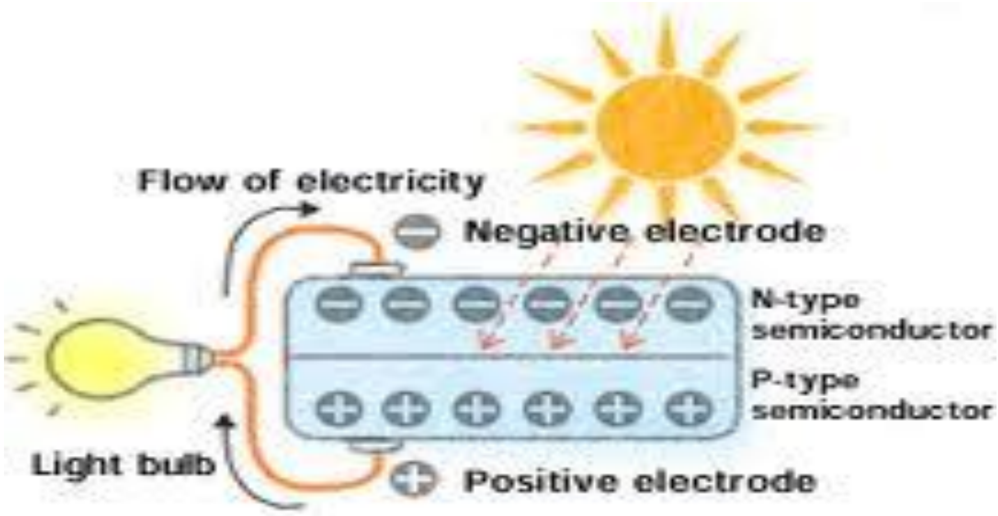


Solar Power Systems (Photovoltaic)

- In essence, the usage of solar power systems onboard satellites uses photovoltaic systems . Photovoltaic system is when the production of power across the junction of two dissimilar materials (n and p doped semiconductors) take place when exposed to light or electromagnetic radiation.

Photovoltaic Effect





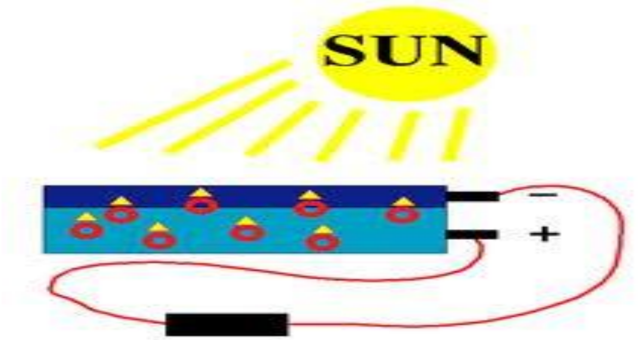
Solar Power Production Basics

- Each solar cell assembly has a semiconductor p-n junction. When silicon is typically used, it is infused with boron for p type material (electron deficient) and with phosphorus for n type (electron excess)
- The p-n junction is at equilibrium when no illumination is present. When appropriate EM radiation hits, photons with sufficent energy will create electron-hole pairs and the radiation is converted to a potential across the relevant cell which has usable electrical power. Individual cells will produce voltage of 0.5 V.
- However, photons with excess energy will dissipate it as heat and the efficinecy will drop. Moreover, there will be a rapid fall when optimum voltage is received.
- Usually, Silicon and Gallium Arsenide (GaAs) are used.

Solar Panels for Satellites

- The fuel for photovoltaic conversion comes from the photons captured in the solar panels of the spacecraft/satellite.
- Solar panels that are properly oriented toward the Sun can provide about 130 W/m2 and 50W/kg of power. Because solar cells mounted on the satellite's body will not, in general, be optimally oriented, they can typically provide 30 to 35 W/m2 and 8 to 12 W/kg of power.

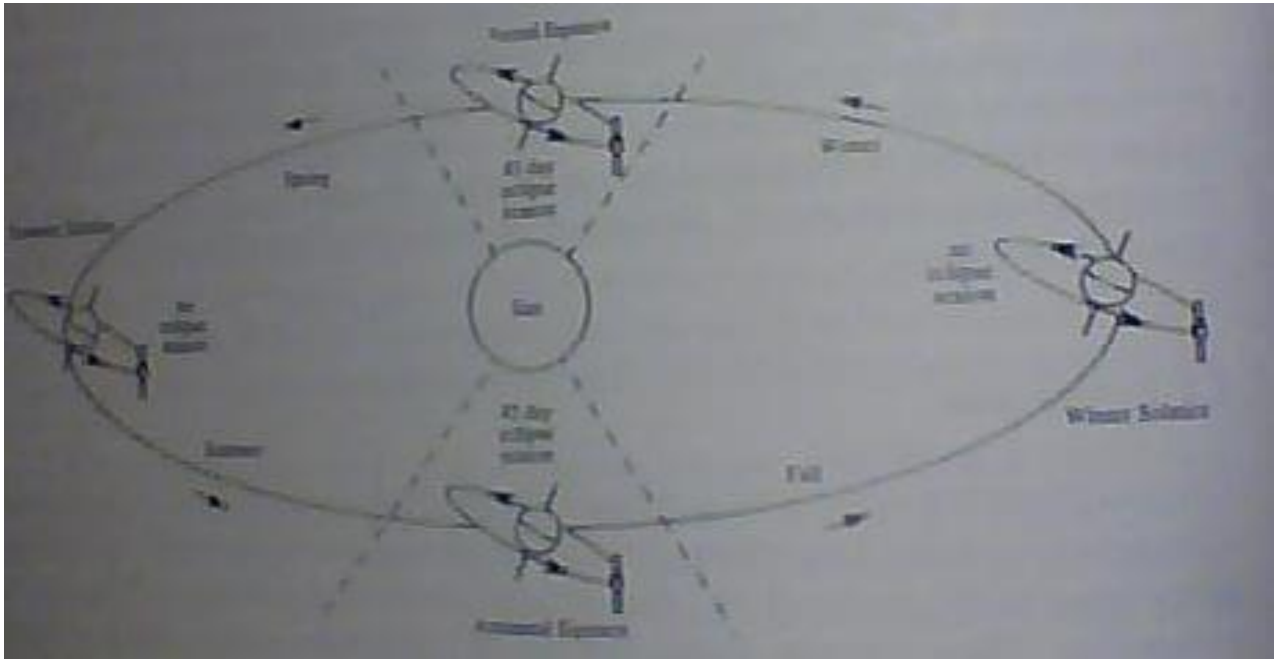
Optimal Photovoltaic Design for Satellites



- To improve cell efficiency, the cell's spectral response has been shifted toward blue wavelengths (they are shorter) to take advantage of the peak output of the sun.
- Thus,shallower diffusion depths have been used with the n layer (excessive electrons) more thinner then the p layer (deficient of electrons)
- N on P cells are more radiation resistant
- Optimization requires locating the p-n junction as close as possible to the surface in order to maximize the collection of current generated by photons near the blue end of the spectrum.

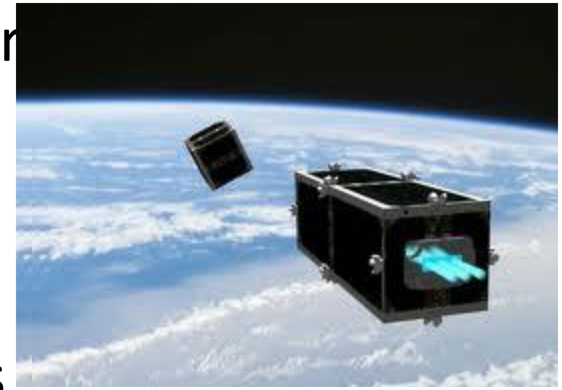
Eclipses in Satellites

- Depending upon the position and the orbit of the satellite, it will be subjected to eclipses in which the solar panels will not be able to receive sufficent photons for electric production.
- Especially for satellites in LEO, there will be regular eclipses throughout the day and around 40% battery power may need to be used for each orbit. Each eclipse can last as long as 35 minutes.
- In GEO orbits, an eclipse can occur in certain seasons and it can last for about 72 minutes.



Problems with Solar Electric Conversion in Satellites

- Radiation damage is an important problem with solar cells in space. Especially, it is known from the data gathered that cells having p type material in the upper region suffer more form radiation exposure. Moreover, thin cells suffer less then thicker ones, but they have a lower conversion efficiency.



- Moroever, vibration at initial launch, stress at vacuum conditions, micrometeorites,atomic oxygen effects and general fatigue, as well as thermal load cycles will effect the solar panels and the solar cells. Generally, 10% of solar cells will deteriorate per year.
- Changing of the attitude for optimal communications can effect efficiency as panels may not be at right angle

Performance Parameters for Solar Array

- There are two figures which can be used to measure the performance of a space solar array.
- Power per unit mass (W/kg)
- Power per unit area (W/m2)
- Typical values are

  - BOL 30-40 W/kg and 90-110 W/m2

  - EOL (End of Life) can vary in space conditions

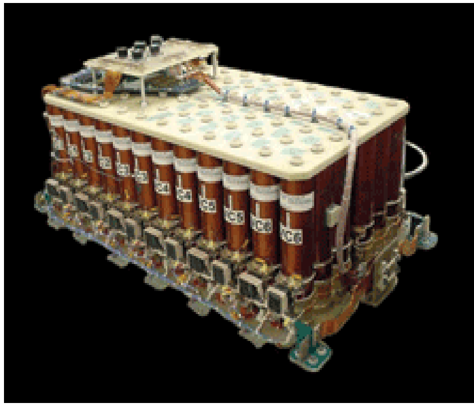
Satellite Power System Elements

- Satellite power systems consists of primary and secondary energy sources and a power control network which regulates the distribution of power.
- Primary Energy Soruce converts fuel into electrical power. (or photons to electricity)
- Secondary enegy source is required to store enery and deliver electrical power to the satellite system and the payloads when the primary system is not available.
- Power control network is required to deliver appropriate voltage-current levels to all spacecraft loads as and when required.

Primary Power Systems

- For majority of the satellites, the primary power system consists of using solar power systems (photovoltaic) through the means of a solar array in order to achieve that objective.
- A solar array is an assembly of thousands of solar cells connected in way to provide appropriate power levels as needed for the particular operation of the satellite.
- Solar systems will power the satellite’s payload and subsystems. Also, extra power needs to be produced for charging.

Secondary Power Systems



- Secondary power systems are those systems which are used for providing power when the primary power is not available.
- Especially for satellites with solar arrays this means that the batteries must provide power during eclipses and that the array must recharge the batteries in sunlight. (more frequently in LEO)

Batteries in Secondary Power Systems

- The main function of a battery operation in satellites is the way in which the reliability and charge efficency are related to charge control.
- Parameters of importance for batteries include:

  - Charge / Discharge rate (cycles)

  - Depth of Discharge (percentage of the battery capacity discharged during the eclipse)

  - Extent of overcharging

  - Thermal Sensitivity

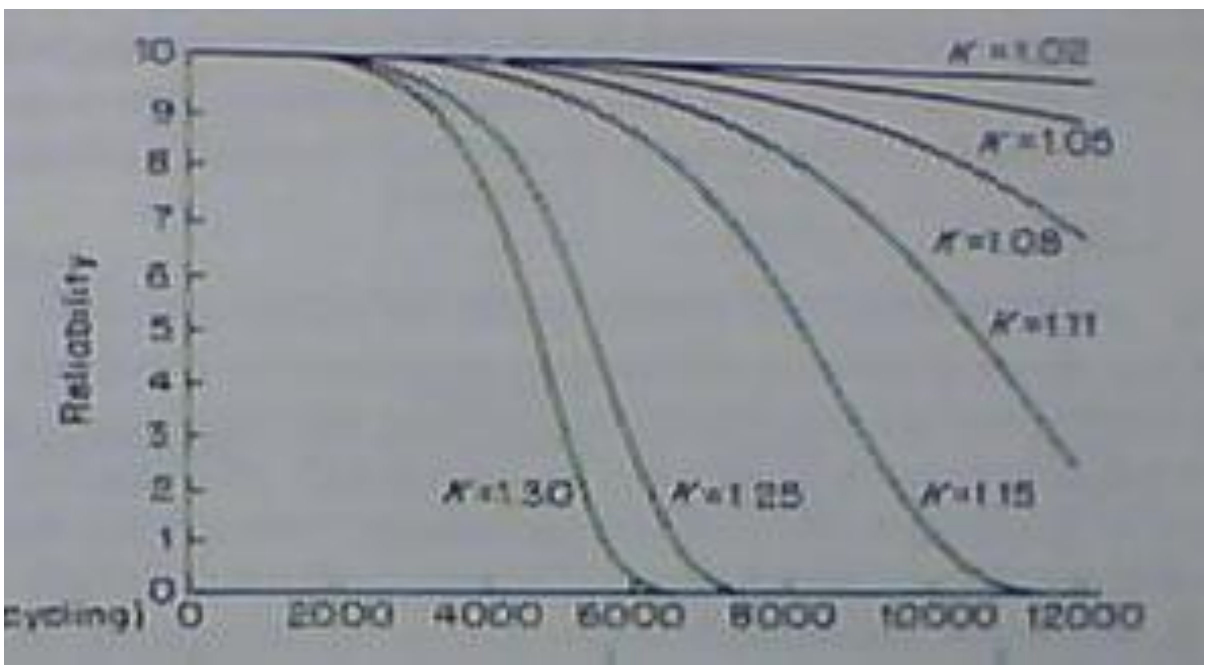
  - Temperature Gradients

Battery Types in Satellites

- In the 1960s, nickel-cadmium (NiCd) was the primary technology used for satellites, and it is still used to some extent today for LEO satellites that require lower levels of power. NiCd batteries are reliable, simple to manage, have a low self-discharge, and a strong heritage in space.
- In the 1990s, nickel-hydrogen (Ni-H2) batteries began to replace NiCd, especially in GEO satellite because of their high energy over mass ratio.
- Now Lithium ion batteries are becoming the new standard, Combined with higher energy and better charge efficiency, this lets the satellite maker reduce the size of the satellites’ solar panels.

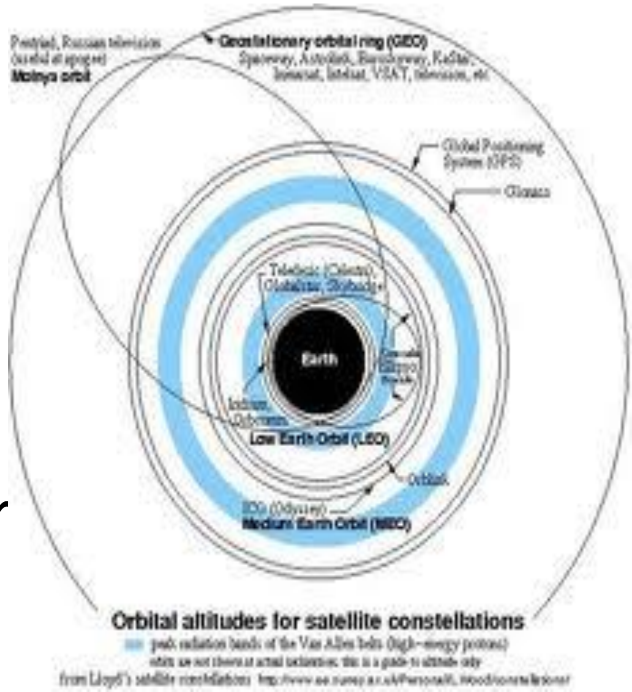
Battery Types and Properties

Type	Specific energy (W h/kg)
Ni–Cd	39
Ni–H_2	52
Ag–Zn	60
Ni–MH	60
Li–Ion	80
Li–TiS_2	125
Na–S	150

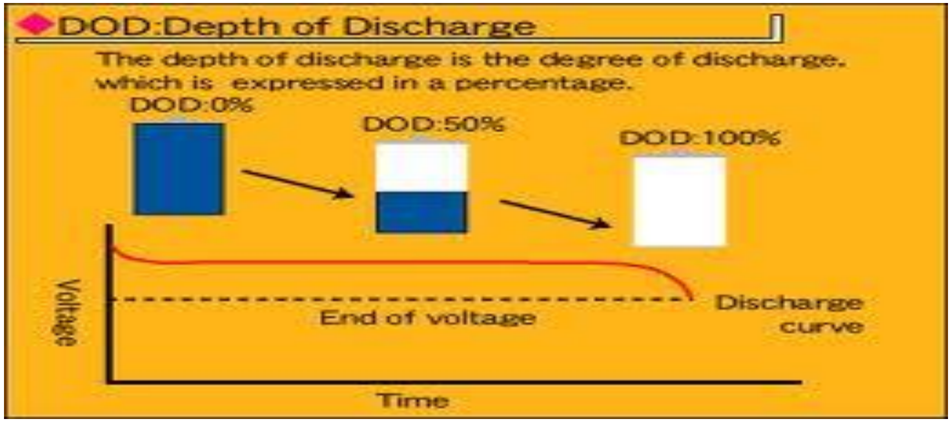


Satellite Orbits and Batteries

- The orbit of the satellite will have a great impact on the batteries which will need to be present on the satellite.
- LEO satellites take around 90 minutes to circle the earth. In this position, the satellite is eclipsed for 30 to 40 minutes per day so the batteries endure about 5,000 cycles per year.
- GEO satellites take 24 hours to rotate the earth; and, for eclipse seasons (two 45-day periods a year), they use batteries for 0 to 72 minutes per day. Batteries for such GEO satellites — used primarily for telecommunications, military, and meteorological systems — must last 15 to 18 years.



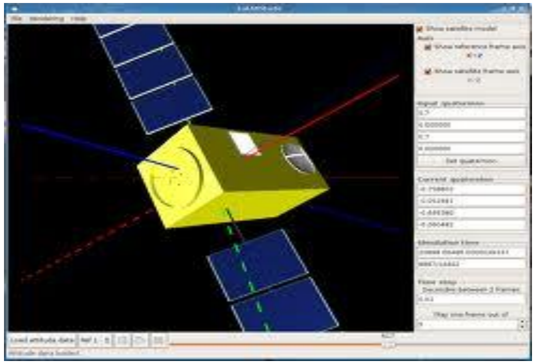
Importance of Depth of Discharge (DOD)



- Depth of discharge can determine the lifeterm of a battery in a satellite. 100% DOD means a complete discharge.
- In order to preserve battery function, lower depth of discharge is needed.
- 20% DOD is commonly used for space NiCd batteries to guarantee 5 years of life in LEO.
- Since GEO satellites will undergo less eclipses, higher DOD can be used.
- DOD also determines mass due to number of batteries required. If a satellite requires 2 kW of power, then battery mass will range from 50 kg to 100 kg at 100% DOD and from 250 kg to 500 kg at 20% DOD (because you need more batteries for the same function).

Solar Array Types

- Rotating Wings

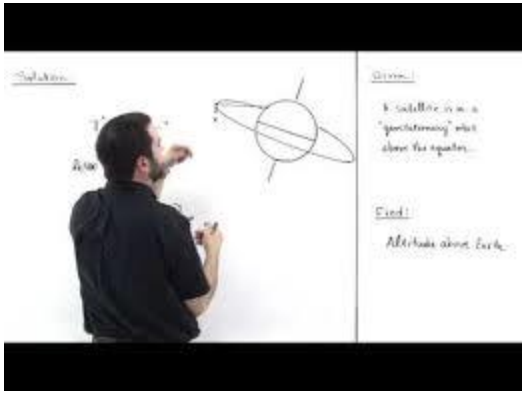


- Fixed Wing Design

- Body Mounted

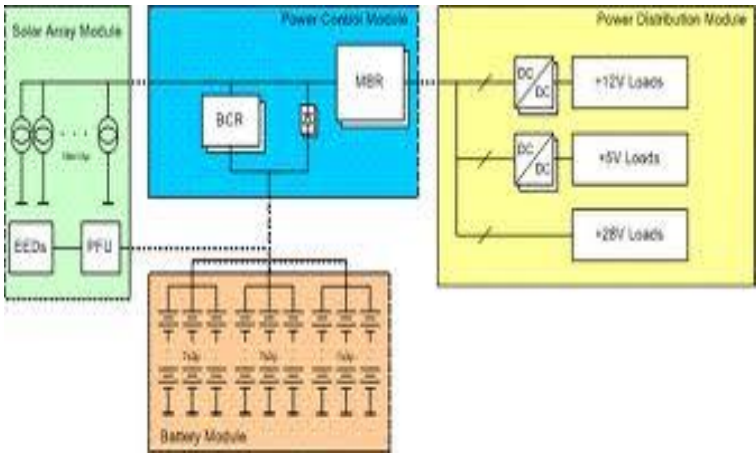
Solar Array Design

- The solar array mass must take into account the battery charging requirements along with load requirements.
- If the satellite requires 2kW to function and if the energy consumed by the batteries by the loads during the eclipse is 2kW-hr;then the array must be able to generate will be around 3 kW of power.
- Thus, the array mass in this example will be around 85 to 120 kg
- Current rigid panel solar arrays on US satellites have specific powers in the range of 15W/kg to 30 W/kg.
- Array's exposure to temperature must also be taken into account.



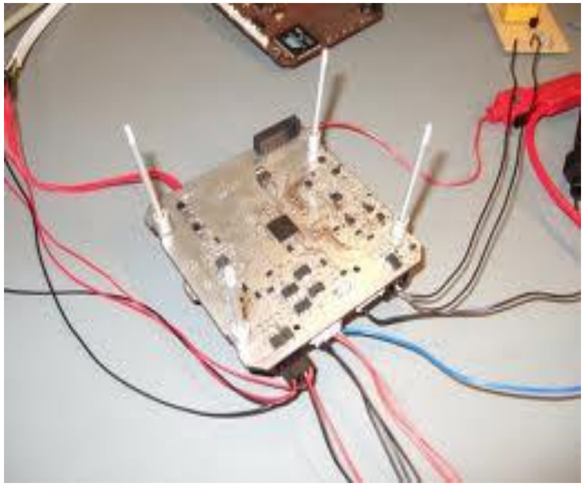
Solar Array Regulator

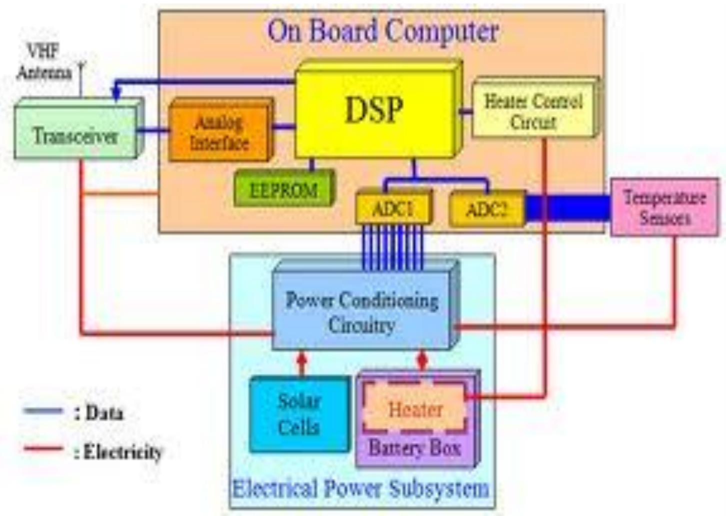
- There will be variance of loads during the satellite's operation and at times the power produced by the solar array may be more then it is needed.
- In this case, solar array regulator is used as it takes the excess power not required by the spacecraft loads and dissipates it externally as heat. In some cases, some parts of the solar array may be switched on and off in order to achieve the same objective.



PMAD

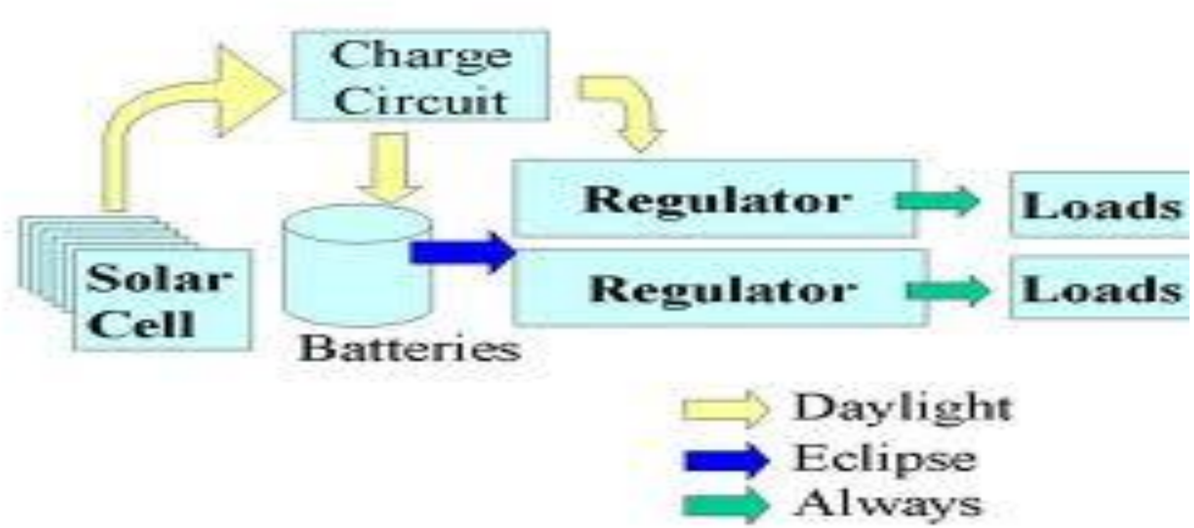
- Power Management and Distribution subsytem (PMAD) is an integral part of power system design for Earth orbiting satellites.
- Electronic loads within the satellite need different voltages to operate and and special power demands need to be met for variety of components during the mission. Early satellites used 28 V DC.
- PMAD will handle all of this such as controlling and monitoring batteries, monitoring degradation of solar arrays, and switching of the load distribution system.



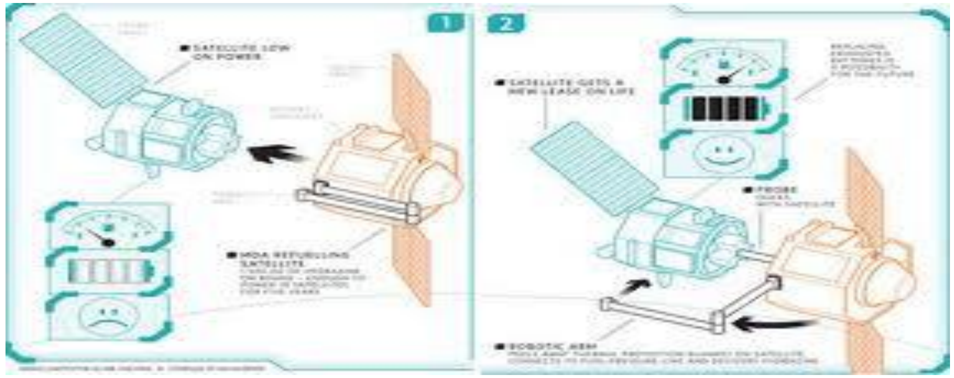


Importance of Electrical Control Subsystem

- If solar arrays are in specific configuration,they will provide specified amount of power.
- However, each instrument on the spacecraft can have varying loads of power. For example, payload may be switched on and off at times and reaction wheels as well as communication systems may need to be work at times.
- Battery charging and discharging will also need to be regulated, so that the batteries will match the lifetime of the satellite



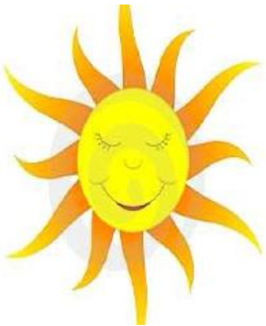
How to Design the Perfect Power System for Earth Satellites?



- Calculation of the exact orbit of the satellite
- The prior determination of the orientation of the satellite
- The requirements of the purpose of the satellite (communications, weather, GPS etc)
- Any extra payloads present on the satellite
- Calculation of the Required Solar Panel Array
- Calculation of the Requirements for Batteries
- Designing of the Overall System for Supplying Power to each Component

Power Subsystem Design Calculations

- It will be essential to calculate baseline power requirements for the satellite by -- taking mission and payload inputs,

  - the method of stabilization (as it effects the solar array),

  - the type of solar cells used,

  - the rigidity or the flexibility of the solar array

  - the orbit in order to determine eclipse times, battery mass and battery requirements.

  - Probable losses in the system

Power Subsystem Design Calculations

$$SolarPanelArea(m^2) = \frac{(BOLSolarPanelPower)x(AreaScaleFactor)}{(SolarcellWatt / sqmeter)}$$

$$SolarPanelMass(kg) = \frac{(BOLSolarPanelPower)x(MassScaleFactor)}{(SolarcellKg / sqmeter)}$$

$$Num.ofBatteries = \frac{TotalWHStored}{(busvoltage)x(AH / Batt)}$$

$$BatteryMass(kg) = (Busvoltage)x(AH / Batt)x(Num.ofBatts)x(Batt.MasstoPowerDensity)$$

Power Subsystem Design Calculations Tables to be Used

Stabilization Method	Area/Mass Scaling Factor
3 axis	1
Spin/Dual Spin	3.141593
Gravity Gradient	4

Rigid Array Solar Cell Design Characteristics

Name	Power(watts/m^2)	Mass(watts/kg)
SSF Silicon	153	28
Thin Si(APSA)	153	30
GaAs/GE	218	39
Cleft GaAs	223	45

Flexible Array Solar Cell Design Characteristics

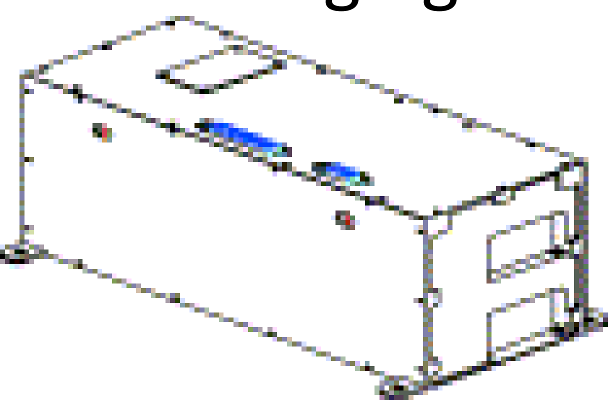
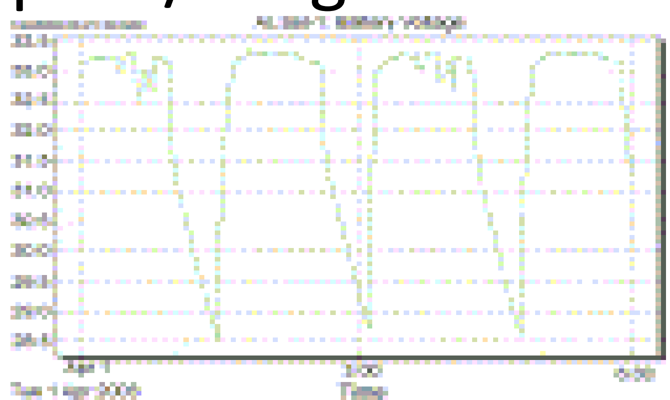
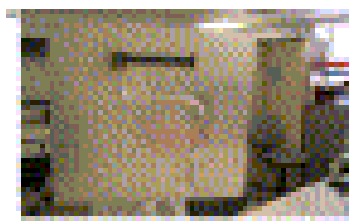
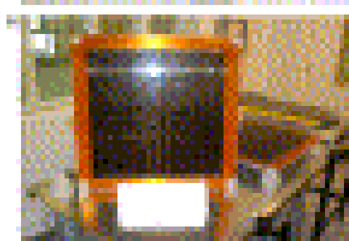
Name	Power(watts/m^2)	Mass(watts/kg)
SSF Silicon	153	84
Thin Si	153	115
GaAs/GE	218	110
Cleft GaAs	223	163

Spacecraft Battery Characteristics

Battery Type	Specific Energy Density	Allowable DOD %
NiCd	0.04 (kg/Whrs)	22
NiH_2	0.025(kg/Whrs)	60

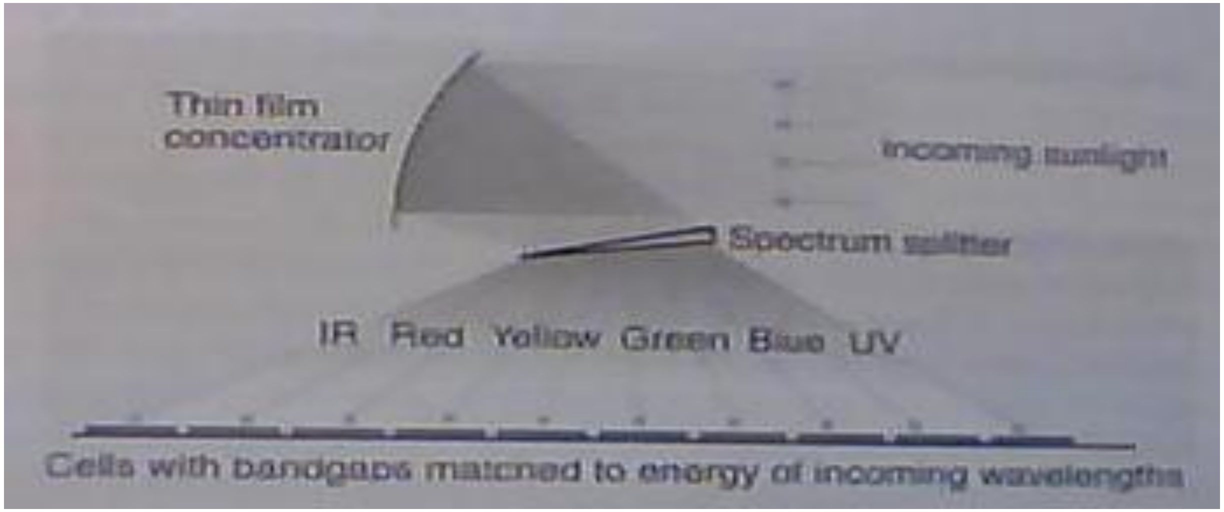
Power System Design Differences on Small Satellites

- Depending upon the size of the satellite, the power system design can change considerably. The reason for this stems from the fact that there are different power requirements and payload requirements
- Small satellites can have a range of power requirements from as little as a watt or two, to a few kilo watts. In fact, small LEO nanosatellites and microsatellites power system design will be more challenging due to space/weight constraints.

Future of Power Systems for Satellites

- Since solar power (photovoltaics) is the primary source of energy for satellites, it is essential to increase the efficenciency for longer lifeterm and for more efficient operation.
- One suggested technique by Dr. Neville Marzwell of NASA is to split the incoming solar spectrum into a continuum rainbow and impress it on a number of seperate cells, where each of them is tailored to match the incoming narrow range of wavelengths impressed upon it.
- As mentioned, the usage of Lithium Ion batteries are also helpful.



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Thank You

For further information, please contact:

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Every step to something new and unexplored is achieved by a narrow margin with a high price to pay... We have such a short period in our life for creating something

Sergei Pavlovich Korolev

First man to put a satellite in space