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Advances in Spacecraft Technology

by Robert A. Nelson

Several technical advances over the past decade have resulted in dramatically enhanced spacecraft for the twenty-first century. As a result, power has increased to around 15 kW, the beginning of life mass is in excess of 3000 kg, and payloads have become more complex. These developments have been made possible by improvements in electric power subsystems, propulsion, antennas, on-board processing, and launch vehicles.

Electric power is provided by the solar array during daylight and by batteries during eclipse. The standard solar cell used since the inception of the satellite age has been the silicon cell. This cell has an efficiency of about 15 percent. However, the newest generation satellites use a cell made from gallium arsenide. The efficiency of this cell is 18 percent, but with a dual junction configuration, the efficiency can be increased to 25 percent. Still higher efficiencies are foreseen with triple junction cells. In addition, many spacecraft use concentrators on the solar wings to intensify the incident sunlight. The same power must be provided by the battery during an eclipse. Today, the nickel-hydrogen cell is the chemistry of choice, with a specific energy of 30 W h/kg. However, the lithium ion cell, having an energy density of 110 W h/kg, offers the promise of reducing the battery mass to approximately one-fourth of what is now required for a given power. At this time, the cycle life limits its use for space applications.

There have been several breakthroughs in propulsion. One has been the arcjet technology used in the Lockheed Martin A2100 and Intelsat 8 spacecraft. The specific impulse is 500 seconds, compared to 300 seconds from an integrated propulsion bipropellant system or 220 seconds for the simple catalytic hydrazine thrusters used in the past. However, the most dramatic improvement is in the field of electric ion propulsion. The thrusters have a specific impulse of between 2000 and 4000 seconds and expel ions of xenon. They have a thrust on the order of micronewtons and are operated for periods of about an hour. The xenon ion propulsion system (XIPS) on the HS-702 satellite consumes some 4.5 kW of power from the 15 kW solar array, but requires only 5 kg of xenon per year, and permits a reduction of propellant mass by up to 90 percent for a 12 to 15 year mission life compared to chemical propulsion.

A significant advance in the design of antennas has been the ability to make shaped reflectors. A shaped reflector is a lightweight structure that resembles an oversized “potato chip.” It uses a single feed instead of multiple beams to provide the specified earth coverage. Thus the mass of the antenna subsystem is reduced and the power loss due to the beam forming network is eliminated. This development has been made possible by the fabrication of epoxy graphite materials with extremely low coefficients of thermal expansion that minimize shape distortion and by the creation of sophisticated computer software programs that can analyze the required antenna shape. Another technical advance has been the ability to produce large unfurlable antennas to produce small spot beams, such as those used by the Lockheed Martin Aces satellite for mobile telephony in the Pacific Rim.

As satellites have become larger, they have also become smarter. With on-board computers, the satellites have a large degree of autonomy. Thus instead of stationkeeping and attitude control maneuvers being performed manually, modern spacecraft are capable of maintaining their orbital position and orientation with a minimum amount of intervention from the ground.

It would not be possible to build such large satellites without the ability to put them in space. The Ariane V has a geostationary transfer orbit capability of 5900 kg and is expected to eventually reach 11 000 kg. The Atlas IIIB can put a 4500 kg payload into GTO, while a Zenit Sea Launch rocket has a payload capability of 5000 kg.

In the engineering design of communications satellites, there has been a classic tradeoff between bandwidth and power. In the past, bandwidth was available but the limitations of satellites and launch vehicles constrained the available power. Now the equation has been reversed. There is a tremendous demand for bandwidth, but power is no longer a major problem. As a result, the advances we shall see over the next decade will be in the exploitation of new frequency regimes, such as Ka-band (20 to 30 GHz), Q-band (30 to 40 GHz), and V-band (40 to 50 GHz). The effects of rain at these frequencies will be a challenging obstacle, however. In addition, we can expect to see advances in more spectrum efficient methods of modulation. In the past QPSK has been the industry standard, but other forms of modulation such as 8-PSK and 16-QAM will begin to be used more often. Although these methods require more power, they reduce the bandwidth by factors of 2/3 and 1/2 , respectively, compared to QPSK, thereby requiring less spectrum or permitting higher data rates