NEXT GENERATION C-BAND SATELLITE SYSTEMS FOR CABLE PROGRAM DISTRIBUTION

Bruce R. Elbert
Director
Galaxy Systems
Hughes Communications, Inc.

Abstract

C-band satellite transmission is the established standard for the delivery of cable TV programming to cable headends. The basic 24 transponder design is used by every cablenet satellite, greatly simplifying ground equipment design and minimizing investment cost. The current generation of cable satellites, including Galaxy I and III, Satcom 3R and 4, will exhaust its fuel supply during the 1992 to 1995 timeframe; therefore, a new generation of C-band satellites will be launched as replacements. The technology to be incorporated into the replacements will add capability but will not cause the existing C-band ground infrastructure of antennas and receivers to be obsolete. The features that we foresee for the replacements include higher power, longer life, improved reliability and interference protection.

Introduction

C-band satellite transmission is the established standard for the delivery of cable TV programming to cable headends. Receiving a wide array of video and audio programming is a ground infrastructure of C-band antennas and associated electronics worth in excess of $500 million. These facilities are standardized on the frequency plan of the current generation of C-band satellites. Antenna diameters in the range of 3 to 5 meters are also part and parcel of cable TV networks, which is consistent with the satellite power levels and benign propagation environment.

This solid foundation provides the motivation for satellite operators to solidify their plans for the next generation of C-band cable satellites. A representation of the geostationary arc serving the United States and the satellites therein is provided in Figure 1. The current generation of cable satellites, including Galaxy I and III, and Satcom 3R and 4, will reach end of life during the 1992 to 1995 timeframe. End-of-life is predictable since it is mainly based on the fuel supply to the on-board propulsion system, which is used to maintain orbit position.

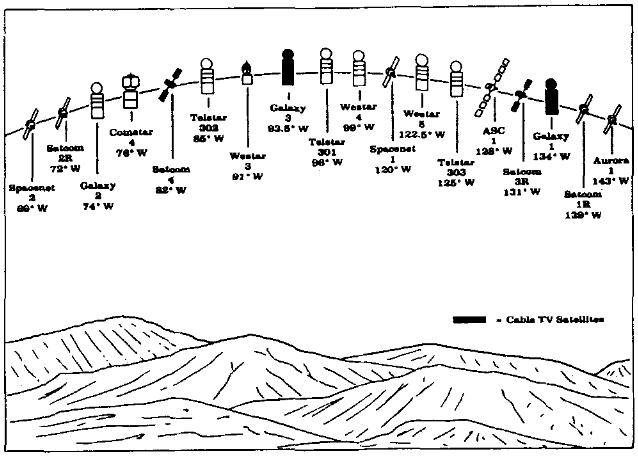

Figure 1. C-Band Satellites Serving the United States

A new generation of satellites will replace that now operating, employing significant technology improvements derived over the past five to ten years.

A key point throughout is that any new characteristic will add capability but will not cause the existing C-band ground infrastructure of antennas and receivers to become obsolete.

Communications Performance

The basic 24 transponder design is used on every cablenet satellite and this arrangement will be maintained in future satellites. In its Two-Degree Spacing Order, the FCC has stated its intention to standardize on this plan, which is illustrated in Figure 2. There are two orthogonal

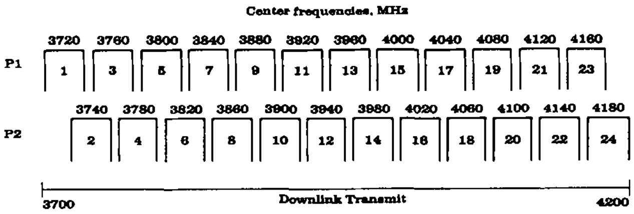

Figure 2. C-Band Frequency and Polarization Plan

linear polarizations, P1 and P2, each containing 500 MHz of spectrum divided into 12 transponders. The sense of P1 and P2 is reversed on adjacent satellites to improve isolation from interference. Consequently, particular orbital slots are designated for a particular sense, e.g., P1 is horizontal for Galaxy 1 at 134°W and it is vertical for Satcom 3R at 131°W. A generalized repeater block diagram of a C-band satellite is shown in Figure 3.

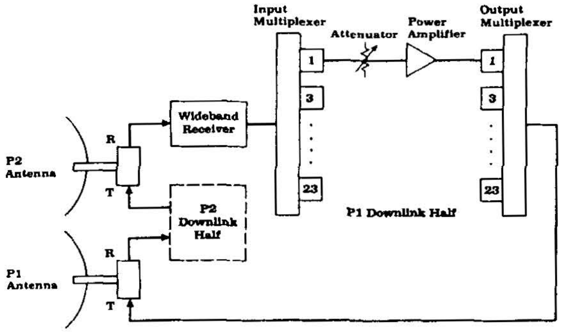

Figure 3. Satellite Repeater Block Diagram

We can expect that the footprint of the next generation C-band cable satellites will remain unchanged, as illustrated in Figure 4. From any of the established cable satellites, coverage of 50 states is possible, including portions of the Caribbean. The aspect that will be modified is the radiated power level of the transponders.

The current generation of Hughes and GE satellites employs power amplifiers with powers in the range of 5 to 10 watts. For a footprint like that in Figure 4, the effective isotropic radiated power (EIRP) over 80 to 90% of the land mass of the Continental United States (CONUS) is approximately 33 to 36 dBW. Experience has shown that at 36 dBW such as Galaxy I transmits commercial quality for cable programming is achieved with a receive antenna of 3.2 meters or greater diameter. This size is considerably smaller than the 5 meter antennas first employed in TVROs. The larger size was dictated by the 5 watt power levels of the first domestic satellites; in addition, early spacecraft antennas were less efficient than current technology and hence provided lower overall gain.

In the next generation of Galaxy satellites, overall EIRP within the footprint will be increased by approximately 3 dB to about 39 dBW (a factor of two in power) by a combination of factors. First, the power output of each amplifier will be increased to approximately 16 watts, representing a change of 2 to 2.5 dB. The types of amplifiers to be employed are the traveling wave tube amplifier (TWTA) and the solid state power amplifier (SSPA). TWTAs have been around since the first geosynchronous satellite was launched in 1963. Their performance and reliability are both well understood. A few of the current satellites employ SSPAs although TWTAs still dominate. A comparison of salient properties of the two amplifier types is presented in Table 1.

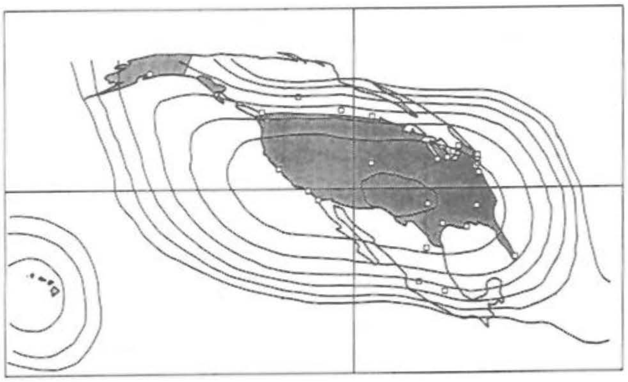

Figure 4. Downlink Footprint of Galaxy I

Table 1

A Comparison of TWTA and SSPA Properties at C-band

	TWTA	SSPA
Current power levels (watts)	8 to 16	6 to 9
Efficiency, RF out/DC in (%)	33 to 40	25 to 30
Weight (lbs)	2 to 3	3 to 4
Lifetime, minimum (years)	12	20

The power from space-proven TWTAs is already adequate to meet the needs of the next generation of Galaxy satellites. With regard to SSPAs, power must be increased by a factor of approximately two, primarily by paralleling two amplifier modules. This tends to increase weight while overall efficiency can be expected to decline slightly. In an overall sense, the performance of SSPAs for video transmission from space is less satisfactory than that of TWTAs. However, the TWT itself has a wearout mechanism not present in the SSPA. For lifetimes of 12 years or less, and provided that redundant amplifiers are on board, the TWTA will provide reliable service.

The rest of the increase in EIRP for Galaxy is provided through increased efficiency of the spacecraft antenna. Approximately 0.5 dB of gain enhancement over the footprint results from better antenna beam shaping with an advanced feed horn array. On top of this, a reduction in power loss through the output multiplexer and feed system will increase power delivered to the reflector by another 0.5 dB.

Impact of Higher EIRP

The 3 dB increase in EIRP can contribute measurably to the quality and utility of cable video transmissions. However, careful consideration must be given to the regulatory environment and the potential for interference with adjacent satellites. A primary test for C-band satellite radiation levels is the spectral power flux density which falls in a neighboring country. International and FCC regulations stipulate that the maximum flux density at the earth's surface shall not exceed

$-152\ \text{dBW/m}^2$ for $E \leq 5^\circ$

$-152 + 1/2\ (E - 5^\circ)\ \text{dBW/m}^2$ for $5^\circ < E \leq 25^\circ$

$-142\ \text{dBW/m}^2$ for $E > 25^\circ$

in any 4 kHz band, where E is the earth station elevation angle in degrees. Video transmissions must employ energy dispersal to spread the power of strong spectral components.

The worst case for a satellite with the type of footprint shown in Figure 4 and providing 38 dBW over CONUS is -154.2 dBW/m^2 at the northeast corner of Maine on the Canadian border. The regulatory limit at this point, where the elevation angle is 7.2°, is computed as follows

$$-152.0 + 1/2\ (7.2^\circ - 5^\circ) = -150.9\ \text{dBW/m}^2.$$

The difference between -154.2 and -150.9 represents a positive interference margin of 3.3 dB; therefore, the power flux density limit is met. All other points along the borders have greater margins.

In terms of adjacent satellite interference, Figure 5 summarizes an analysis of the carrier to interference ratio (C/I) as a function of orbital separation. Two cases are examined: one for a 5 meter receiving antenna and the other for the newer 3 meter antenna. The data demonstrates that adequate protection from interference is afforded, even for a receiving antenna of 3 m diameter.

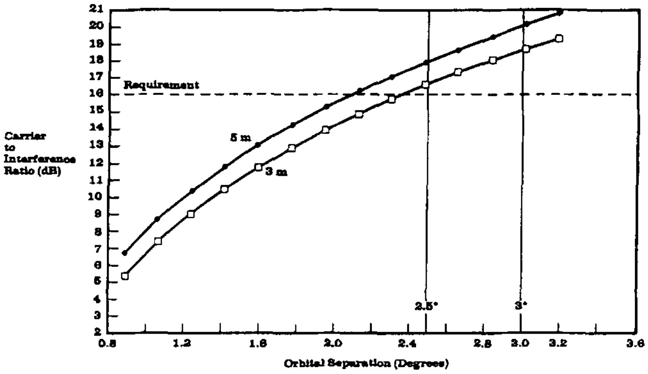

Figure 5. Adjacent Satellite Interference (C-Band)

The question naturally arises as to the purpose of raising the EIRP in the first place. Perhaps the most fundamental benefit is an increase in overall link margin, which is quantified in Figure 6. The 3 dB EIRP increase will raise overall link performance for the 3 meter antenna by approximately 2.5 dB. The popularity of the 3 meter class antenna for cable reception is enhanced by this added margin, since both reliability and noise suppression improve. Terrestrial interference in urban areas will be diminished in its effect by the added margin.

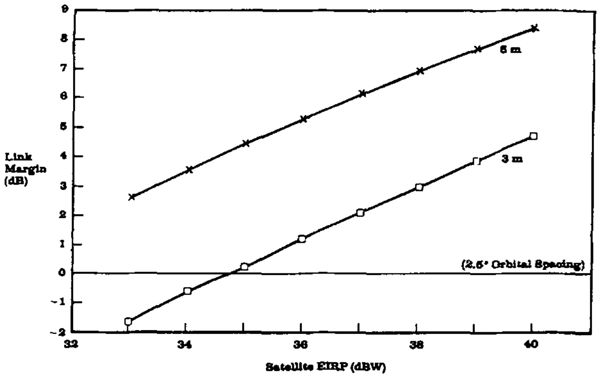

Figure 6. TV Link Margin vs Satellite EIRP

Antennas in the 4 to 5 meter range will produce somewhat higher quality video signals for standard NTSC transmissions. However, the real payoff in the future could be in High Definition Television (HDTV) which will require 3 to 6 dB more EIRP (depending on system finally adopted) than does NTSC. In many cable systems the 3 dB increase would support HDTV without increasing the size of the ground antennas. The standard transponder bandwidth of 36 MHz is adequate to support HDTV signals such as MUSE, the NHK HDTV system.

Spacecraft Characteristics

The communications requirements just described can be supported by spacecraft of comparable design to those now operating. Some upgrade in payload weight and power would be necessary to handle the 50% increase (2dB) in power requirements. The impact on a standard spacecraft "bus" design such as the Hughes HS-376 is quite minimal. The total "dry" weight (exclusive of fuel) increases from 1100 lbs to 1400 lbs, representing only a 25% change. Much larger spacecraft, with their attendant complexity and financial risk, are not required.

The lifetime of the next generation of satellites will increase from 10 to approximately 12 years even though dry weight will increase. This will be obtained through launch vehicle performance improvements and next generation propulsion systems. In Figure 7, the expected lifetime is presented for each of three available expandable launch vehicles: Ariane IV, Delta II and Long March 3. In the future, no space shuttle flights are anticipated for commercial purposes. The Titan rocket, while on the commercial market, is matched to much larger payloads and is not as appropriate for this class of satellite.

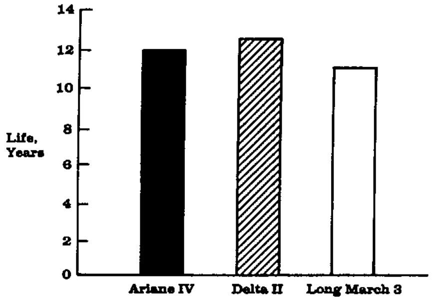

Figure 7. Expendable Launch Vehicle Performance

Other Considerations

Beyond the issues of EIRP and orbital lifetime, there are a few other enhancements that can be foreseen. The reliability of current domestic satellites has proven to be very high once final orbital station is reached. The end-to-end link availability at C-band is typically 99.9%, which is considerably better than can be obtained with terrestrial transmission systems. To obtain this level of availability at Ku band requires higher satellite EIRP and ground antennas of 3 to 5 meters.

The portion of the spacecraft most prone to outage is the same power amplifier used to generate EIRP. Occasional failures of TWTAs and SSPAs have been experienced, and the best remedy is to have spare amplifiers on board the satellite. With an appropriate switching scheme, a failed amplifier can be replaced with a spare in a matter of minutes. The obvious advantage of this approach is that a change of frequency is not required. Current cable satellites have either 1 spare for 4 operating amplifiers (called 5 for 4) or 1 spare for 6 operating amplifiers (7 for 6). There are limitations on how spares can be switched in. In the next generation, we recommend an increase in the number of spares, so that satellites have either a 5 for 4 or 6 for 4 scheme. Also, switching can be improved so a spare can replace any of a number of failed amplifiers and operating amplifiers can be interchanged.

A consideration which gained notoriety in the past few years is double illumination and intentional interference. Some of our worst fears seemed to be confirmed with Captain Midnight. Of course, one or two incidents like this is really minor in the grand scheme. Some control of the threat is possible by including a commandable variable attenuator, illustrated in Figure 3. A low powered intruder can be suppressed be activating the attenuator and increasing the uplink power of the authorized video uplink by the amount of attenuation. Other modes and uses are possible.

Conclusion

Providing these added capabilities of greater EIRP and longer life in the next generation can be done without added technical risk. Cable programmers and system operators can therefore expect continuity of service and even higher levels of quality and reliability. Finally, these benefits can be obtained at costs considerably below those of the class of Ku band satellites need to provide similar service.