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Instructor

Dr. Robert A. Nelson is president of Satellite Engineering Research Corporation, a consulting firm in

Bethesda, Maryland, with clients in both commercial industry and government. Dr. Nelson holds the degree of Ph.D. in physics from the University of Maryland and is a licensed Professional Engineer. He is coauthor of the textbook *Satellite Communication Systems Engineering, 2nd ed.* (Prentice Hall, 1993) and is Technical Editor of *Via Satellite magazine.* He is a member of IEEE, AIAA, APS, AAPT, AAS, IAU, and ION.

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Course Outline

1. Mission Analysis. Kepler's laws. Circular and elliptical satellite orbits. Altitude regimes. Period of revolution. Geostationary Orbit. Orbital elements. Ground trace.

2. Earth-Satellite Geometry. Azimuth and elevation. Slant range. Coverage area.

3. Signals and Spectra. Properties of a sinusoidal wave. Synthesis and analysis of an arbitrary waveform. Fourier Principle. Harmonics. Fourier series and Fourier transform. Frequency spectrum.

4. Methods of Modulation. Overview of modulation. Carrier. Sidebands. Analog and digital modulation. Need for RF frequencies.

5. Analog Modulation. Amplitude Modulation (AM). Frequency Modulation (FM).

6. Digital Modulation. Analog to digital conversion. BPSK, QPSK, 8PSK FSK, QAM. Coherent detection and carrier recovery. NRZ and RZ pulse shapes. Power spectral density. ISI. Nyquist pulse shaping. Raised cosine filtering.

7. Bit Error Rate. Performance objectives. Eb/No. Relationship between BER and Eb/No. Constellation diagrams. Why do BPSK and QPSK require the same power?

8. Coding. Shannon's theorem. Code rate. Coding gain. Methods of FEC coding. Hamming, BCH, and Reed-Solomon block codes. Convolutional codes. Viterbi and sequential decoding. Hard and soft decisions. Concatenated coding. Turbo coding. Trellis coding.

9. Bandwidth. Equivalent (noise) bandwidth. Occupied bandwidth. Allocated bandwidth. Relationship between bandwidth and data rate. Dependence of bandwidth on methods of modulation and coding. Tradeoff between bandwidth and power. Emerging trends for bandwidth efficient modulation.

10. The Electromagnetic Spectrum. Frequency bands used for satellite communication. ITU regulations. Fixed Satellite Service. Direct Broadcast Service. Digital Audio Radio Service. Mobile Satellite Service.

11. Earth Stations. Facility layout. RF components. Network Operations Center. Data displays.

12. Antennas. Antenna patterns. Gain. Half power beamwidth. Efficiency. Sidelobes.

13. System Temperature. Antenna temperature. LNA. Noise figure. Total system noise temperature.

14. Satellite Transponders. Satellite communications payload architecture. Frequency plan. Transponder gain. TWTA and SSPA. Amplifier characteristics. Nonlinearity. Intermodulation products. SFD. Backoff.

15. The RF Link. Decibel (dB) notation. Equivalent isotropic radiated power (EIRP). Figure of Merit (G/T). Free space loss. WhyPower flux density. Carrier to noise ratio. The RF link equation.

16. Link Budgets. Communications link calculations. Uplink, downlink, and composite performance. Link budgets for single carrier and multiple carrier operation. Detailed worked examples.

17. Performance Measurements. Satellite modem. Use of a spectrum analyzer to measure bandwidth, C/N, and Eb/No. Comparison of actual measurements with theory using a mobile antenna and a geostationary satellite.

18. Multiple Access Techniques. Frequency division multiple access (FDMA). Time division multiple access (TDMA). Code division multiple access (CDMA) or spread spectrum. Capacity estimates.

19. Polarization. Linear and circular polarization. Misalignment angle.

20. Rain Loss. Rain attenuation. Crane rain model. Effect on G/T.

Via Satellite February, 1998

V-Band

Expansion of the Spectrum Frontier

by Robert A. Nelson

The settlement of the American west during the nineteenth century was bounded by a natural frontier: the Pacific Ocean. For pioneers in the satellite industry, there appears to be no analogous frontier in the electromagnetic frequencies used for satellite communications as the upper bound of frequencies is being pushed ever higher.

On September 26, 1997, a dozen companies submitted proposals to the U.S. Federal Communications Commission (FCC) for authorization to build satellite systems that will exploit the frequency bands from 36 GHz to 51.4 GHz, which includes Q-band and V-band. These new systems will supplement the many Ka-band broadband systems now in various stages of development. The proposed constellations span the full range of altitude regimes, including Low Earth Orbit (LEO), Medium Earth Orbit (MEO), and geostationary orbit (GEO).

As historians have noted, the expansion of the American west was made possible through the sudden advance of technology – the steamboat, the telegraph, and the railroad. Similarly, the focus on broadband applications at higher frequencies has been made possible through technological change, including processing satellites, sophisticated switching networks, low-noise amplifiers, modems, codecs, tracking antennas, and intelligent receivers.

High frequencies, together with wide bandwidths, permit the use of small Earth terminals and high data rates and thus make satellite communication available to the home, business, and mobile terminal for diverse applications such as internet access, data retrieval, teleconferencing, and electronic library research.

Bary Bertiger, Corporate Vice President and General Manager of the Motorola Satellite Communication Group, described this capability as “global, instantaneous infrastructure that will be equally available at low cost to consumers in developing countries and industrialized nations. Virtually any intellectual property, such as documents and computer software, can be digitized and delivered via satellite instead of being physically transported by hand or transmitted over wires.”

The development of these broadband satellite systems over the next few years will represent a communication revolution, notable both as a new stage of development and as a lens to alter our view of the world. Their existence will affect our very perception of how we communicate and the information resources that we can access, just as the invention of mechanical clocks in the middle ages altered the public perception of time, the growth of high speed travel during the twentieth century altered the perception of geographical distance, and the exploration of space has altered the perception of our place in the universe.

FREQUENCY BANDS

The first band used for commercial satellite communication in the Fixed Satellite Service (FSS) was C-band (6/4 GHz, where the uplink frequency is given first). During the mid-1980s, Ku-band (14/12 GHz) came into use. Due to its higher frequency, this band is sensitive to rain fade but with higher power satellites it has become popular because it permits smaller Earth station antennas.

Mobile telephony systems such as Motorola's IRIDIUM and Loral/Qualcomm's GLOBALSTAR, both in the process of deployment, will use lower frequencies, which are desirable because they maximize the received carrier power for fixed satellite and handset antenna gains. For example, IRIDIUM will use L-band (1.6 GHz) for both uplink and downlink, while GLOBALSTAR will use L-band (1.6 MHz) for the uplink and S-band (2.5 GHz) for the downlink. Satellite systems in the emerging Digital Audio Radio Service (DARS), such as CD Radio and AMRC, will use S-band in the vicinity of 2.3 GHz.

In the early 1990s, a variety of systems were designed for Ka-band (30/20 GHz) for broadband applications, such as Motorola's Millennium, Hughes' Spaceway, SS/Loral's Cyberstar, Lockheed Martin's Astrolink, Echostar, GE*Star, KaStar, Morning Star, Net Sat 28, Orion, and PanAmSat, which are all geostationary constellations, as well as the Teledesic LEO system. The practical use of such high frequencies for communication was first demonstrated by the NASA ACTS program. (The term K-band was originally given to the range 18 – 27 GHz, but after a molecular water vapor absorption resonance was discovered at the center of the band at 22.3 GHz, the terms Ku band (12 – 18 GHz) and Ka band (27 – 40 GHz) were introduced to denote “under” and “above” K-band; however, the regime 20 – 30 GHz for Ka-band is now common usage.)

The new systems will be at even higher frequencies in the so-called Q-band (33 – 50 GHz) and V-band (50 – 75 GHz) as defined by the FCC in its *Bulletin No. 70*, July, 1997. The FCC also defines U-band as 40 – 60 GHz, thus overlapping Q- and V-bands, and W-band as 75 – 110 GHz with additional letter designations all the way up to 220 GHz. However, conventional usage seems to be converging on the definition 40 – 50 GHz for V-band, which has also been called EHF; this trend would suggest designating 30 – 40 GHz as Q-band, 50 – 60 GHz as U-band, and 60 – 70 GHz as W-band if 10 – 20 GHz represents Ku-band, including both the FSS and BSS bands, and 20 – 30 GHz represents Ka-band.

ANTENNAS

Since the product of wavelength and frequency is equal to the speed of light (3×10^8 m/s), the wavelength decreases as the frequency increases. It is significant to note that at V-band (50 GHz), the signal wavelength is only 6 millimeters. By comparison, at C-band (6 GHz) the wavelength is 50 millimeters (5 cm) and at L-band (1.6 GHz) the wavelength is about 200 millimeters (20 cm). It is the very small wavelength that permits the fabrication of a high gain antenna with a small physical aperture.

Earth terminals that communicate with nongeostationary satellites will be required to have tracking and handover capability. A satellite in Medium Earth Orbit at an altitude of 10,000 km is visible for about 2 hours. In Low Earth Orbit at an altitude of 1000 km the maximum time in view is only 15 minutes.

The antennas, with gains on the order of 50 dB, will be either mechanically-steered reflectors or electronically steered phased arrays. The reflector antennas will be typical for business installations, while the phased arrays will find application in lower capacity systems at residential sites or mobile terminals.

The phased array antennas under development will represent a major achievement in technology. The tracking requirement will depend on advances in microcircuit state of the art more than antenna design and it will be a challenge for the industry to offer them at attractive prices.

RAIN

At high frequencies, rain attenuation is a serious problem. Physically, rain attenuation is due to scattering and absorption of the microwave energy by the rain. As the wavelength decreases and approaches the size of a typical rain drop (approximately 1.5 mm), more scattering and absorption occurs and the attenuation increases. Also, as the rain rate increases during a heavy downpour, the size of the rain drops, and hence the attenuation, increases.

It is the rain rate, and not the annual rainfall, that determines availability. Thus San Francisco and Seattle are in the same rain climate region because the probability of a given rain rate being exceeded is about the same, despite the disparity in the total annual rainfall.

By way of example, for an availability of 99.95 percent or a total outage of 43.8 hours per year in Washington, DC, the maximum rain rate is 22 mm/h. The corresponding specific rain attenuation is approximately 0.05 dB/km at C-band, 1 dB/km at Ku-band, 3 dB/km at Ka-band, and 9 dB/km at V-band. For a given rain attenuation allowance, the availability at V-band is simply not as high as at Ku-band or even Ka-band.

The problem may be mitigated by switching to lower frequencies during periods of heavy rain. Thus dual payload satellites with both Ka-band and V-band steerable beams may be desirable from the point of view of engineering design. Nevertheless, customer awareness of the rain fade issue will be necessary.

For large, high capacity Earth stations, site diversity is used to overcome rain. Earth stations about 10 km apart and connected by terrestrial microwave circuits will see different rain cells, so that at least one Earth station will maintain the satellite link. For example, IRIDIUM uses this technique for its Ka-band mobile telephony gateways. Terrestrial systems can also be used for backup.

PROPOSED V-BAND SYSTEMS

Motorola was the first to explore the use of nongeostationary satellites in the new frequency regime. In September, 1996 the company submitted an application to the FCC for a Low Earth Orbit satellite constellation called M-Star to provide broadband services to businesses in the 40 GHz band. The proposed constellation consists of 72 satellites in circular orbits at an altitude of 1350 km and distributed in 12 planes inclined at 47°. The M-Star system is designed to offer two types of service: voice and data transport to service providers and business customers at 2.048 Mbps and interconnection and backhaul services at up to 51.84 Mbps.

Last June, Motorola submitted an application for a Ka-band LEO system called Celestri. The Celestri LEO system will comprise 63 satellites at an altitude of 1400 km distributed into 7 orbital planes inclined at 48°. Services to be offered include point-to-point symmetric transfer at 64 kbps to 155 Mbps; point-to-point asymmetric transfer with "bandwidth on demand" up to 16 Mbps; broadcast services; and interactive real-time response services.

The market comprises residential consumers seeking work-at-home, entertainment, education, and security capabilities; small businesses purchasing from multimedia outlets; and large multinational corporations seeking improved customer awareness. The Celestri system would augment the recently licensed Millennium Ka-band system of four geostationary satellites and the proposed M-Star system to form a three-tier LEO/GEO FDMA/TDMA communication architecture.

Celestri is presently regarded as an umbrella designation for all three systems. The available data rates for the LEO component is 2 Mbps on the uplink and 16 Mbps on the downlink; the GEO component provides a downlink data rate of 20 Mbps. Motorola has amended its application to request authorization for both V-band and Ka-band payloads on the Celestri satellites, and is considering the incorporation of the M-Star payload on the Celestri bus. Celestri is entirely different from IRIDIUM. Celestri will offer broadband services for high speed data transfer to fixed terminals, while IRIDIUM will provide narrowband services for voice communication and messaging to mobile terminals.

In order to connect the satellite system to end-users, Motorola has developed a range of terminal sizes, which collectively are described by the broad term "Customer Premises Equipment (CPE)". This equipment can be as large as a gateway station for telecommunications carriers and as small as a home unit that can be mounted on a roof. The home unit antenna is a high gain phased array capable of tracking the LEO satellite and providing seamless handover from leading to following satellites. According to Motorola spokesperson Robert Edwards, the projected cost of this unit is about $700, a surprisingly low estimate given the advanced technology it represents.

Three new V-band systems have been proposed by Hughes. "The V-band filings pioneer new spectrum to keep the satellite market strong by advancing technology into the realm of new market demands for mobile connectivity and increased bandwidth," said Wendy Greene, spokesperson for Hughes.

The first is Expressway, a constellation of 14 geostationary satellites at 10 orbital locations to provide global high-capacity, wideband satellite communications. Expressway will use 3 GHz of uplink and downlink bandwidth in V-band and 500 MHz of uplink and downlink bandwidth in Ku-band. The V-band capacity will be used to serve high data rate users, such as multinational companies, with spot beams that can be activated in response to demand. The Ku-band capacity will be distributed through a series of larger beams. A typical user terminal has a 2.5 meter antenna and a 30 watt HPA.

The satellite architecture uses a piece of proven ACTS technology. On-board TDMA, IF-switched processing facilitates the allocation of "bandwidth on demand" and the satellites are interconnected by optical (laser) links. The data rates vary from T1 (1.544 Mbps) to OC-3 (155 Mbps), a 100:1 ratio on an individual carrier basis. The total capacity is 588,000 equivalent T1 circuits.

Expressway uses a "systems" approach to availability, seamlessly migrating traffic between its V-band and Ku-band capacity on an individual user basis. With a typical allocation for rain fade of about 3 dB, the V-band availability will be around 98 percent; higher availabilities are provided with the satellite's Ku-band capability.

Expressway has been engineered to optimize capacity. This system is intended for a "leased line" dedicated user. The Ku-band capacity will be used sparingly to enhance availability where needed during periods of rain, and will be allocated depending on user level of service and pricing schedule.

By comparison, the Hughes Ka-band Spaceway system of eight geostationary satellites is optimized to user terminal and availability requirements. It is intended for occasional access, such as to small business and residential consumers, and will be priced by the bit. Spaceway involves substantial processing on the satellite.

The second component of the Hughes system is Spacecast, which will consist of six geostationary satellites. Spacecast will offer video and multimedia services at V-band and Ku-band. Using spot beams, the system will have multitasking capabilities for one-way transmission to small terminals for applications such as corporate training and distance learning. The data rate to a 45 cm terminal would be 26 Mbps and the data rate to a 1 meter terminal would be 155 Mbps.

The third component of the Hughes system is Starlynx. This is a hybrid V-band constellation with four geostationary satellites (two satellites in each of two orbital slots) and 20 Medium Earth Orbit satellites at an altitude of 10,352 km. The MEO constellation consists of four planes inclined at 55° with five satellites per plane. Starlynx will provide two-way data connectivity to portable terminals, such as notebook and desktop computers, using small, flat antennas. The terminals can be either stationary or mobile. For stationary terminals, the antenna size will be about 30 cm $\times$ 30 cm and the data rates will be up to 2 Mbps, while for mobile terminals the antenna size will be about 60 cm $\times$ 60 cm and the data rates will be up to 8 Mbps.

PanAmSat, an independent company with majority ownership by Hughes, has asked the FCC for approval to launch a 12 satellite geostationary constellation to provide global digital services at V-band. The system, called V-Stream, is to be deployed in 11 orbital slots, from 99° W longitude for North America to 124.5° E longitude for the Pacific Rim. It will use 3 GHz of spectrum in the 50/40 GHz band and will include high powered spot beams with onboard processing and intersatellite links at 33/23 GHz and/or 60 GHz. (The 60 GHz frequency is particularly appropriate for intersatellite links because the atmosphere is opaque in this neighborhood due to resonance absorption by molecular oxygen.)

The V-Stream system will augment PanAmSat's existing network of 16 satellites providing C-band and Ku-band services; in addition, the company has received FCC authorization to operate Ka-band satellites in nine orbital slots.

TRW has requested FCC authorization to launch and operate a system called the TRW Global EHF Satellite Network (GESN). The GESN system space segment consists of a hybrid constellation of four geostationary satellites and 15 MEO satellites that will operate in 6 hour circular orbits at an altitude of 10,355 km. The satellites are distributed in three orbital planes inclined at 50° with five equally spaced satellites per plane to ensure high elevation angle links (greater than 30°).

The MEO component of the constellation has an obvious similarity with TRW's former 12 satellite ODYSSEY system for mobile telephony, which was abandoned in favor of a partnership with ICO, and suggests that TRW may be placing its commercial satellite development emphasis in a new direction.

According to TRW's Director of Telecommunications Policy Peter Hadinger, the requirements of a V-band system certainly complement the experience the company has gained in the satellite arena. "This is really playing to our forté, in terms of the millimeter wave frequency bands and the use of onboard signal processing," Hadinger says. He believes TRW's work on the Milstar project and other military payloads will give the company an advantage on technical development.

The services to be offered on a global basis will be two-way point-to-point wideband data connectivity, multimedia distribution services, and private network services. The GESN system application requests the use 3 GHz of bandwidth in each direction, specifically 47.2 to 50.2 GHz for the uplink and 37.5 to 40.5 GHz for the downlink.

The system will use optical intersatellite links. The uplink supports a standard service link (SSL) of 155.52 Mbps and a wideband service link (WSL) of 1.5552 Gbps The downlink supports a total channel rate, including data rate and overhead, of either 317 Mbps (SSL) or 3.17 Mbps (WSL). The modulation format is OQPSK. These signal structures are used for both the GEO and MEO satellites.

TRW is targeting large businesses and international carriers, not the residential consumer market. The user terminal antenna aperture is 1.5 to 2.2 meters and the RF power is 12 to 30 watts for the SSL, while the antenna aperture is 2.2 to 2.5 meters and the RF power is 100 W for the WSL. Terminals that operate through the MEO constellation will be required to mechanically track the satellites through a 120° arc and will also be required to have dual tracking capability to achieve transparent handovers between leading and following satellites. Recognizing that mechanically steered reflector antennas may be objectionable or impractical for some users, TRW has indicated that it will work with established manufacturers of commercial satellite terminals to develop small, attractively priced, electronically steered, flat phased array antennas using monolithic microwave integrated circuit (MMIC) devices.

Lockheed Martin's proposed Global Q/V-Band Satellite Communications System will consist of 9 geostationary satellites. It requests FCC authorization to provide broadband services requiring 3 GHz for the uplink in the range 47.2 – 50.2 GHz and 3 GHz for the downlink in the range 39.5 – 42.5 GHz.

This system will provide high data rate communication to provide infrastructure to areas not adequately served by terrestrial systems. Through the use of both small and large user terminals, it will provide instant connectivity for the exchange of data at rates up to OC-3 (155 Mbps). This capability will extend the services provided at Ka-band by Astrolink, which will be optimized to provide switched data services at data rates from 64 kbps to 2 Mbps. Astrolink is a Lockheed Martin strategic venture.

The coverage will be composed of 48 transmit and receive beams serving user terminals and 8 transmit and receive beams serving gateway Earth stations. Each beam has a nominal half power beamwidth of 0.3° and occupies 125 MHz of bandwidth.

The transmission scheme utilizes a unique TDM architecture in which redundant data bits are added to user channels experiencing significant rain fading. Each 125 MHz downlink channel contains a single 96.29 Mbps carrier. Ground terminals extract and buffer data addressed only to them. The bi-directional user terminals will have antenna diameters as small as 45 cm with a transmit gain of 44.8 dB. A terminal of this size will have a traveling wave tube amplifier (TWTA) with an output power of 4 watts and for a minimum elevation angle of 30° will support a maximum information uplink data rate of 384 kbps.

Larger antennas will be used for lower elevation angles and high rain rate regions. A 2.4 meter reflector with a transmit gain of 59.3 dB and an output power of 12 watts will support uplink data rates up to 9.216 Mbps. The target availability for the allocated rain margin is 98%. Interference to adjacent satellites is mitigated by interactive power control with the spacecraft.

The Loral Space and Communications system, called CyberPath, consists of 10 geostationary satellites. Loral seeks 1 GHz of spectrum for the uplink and 1 GHz of spectrum for the downlink. Data rates begin at 16 kbps. Higher data rates, such as 6 Mbps, are available on demand for video and data transmission. Trunking data rates up to 90 Mbps are also available. The CyberPath system capacity is 17.9 Gbps.

Each satellite uses on-board demodulation and decoding and ATM-like switching to achieve connectivity among the 100 V-band spot beams and the two inter-satellite links. Data are routed according to the packet header using a TDM/FDM/CDMA format.

The subscriber Earth station, ranging in size from 0.5 to 3.0 meters, is selected to achieve the desired availability in rain. It may be installed at the home, business, or government facility and are expected to initially cost $1500 installed. The Earth station is connected via the subscriber's computer to home or office equipment utilizing the multimedia services. The link is designed to have an availability of 99.5%, reflecting a larger rain allowance than most other systems.

GE American Communications seeks authorization for a constellation of 11 geostationary satellites in nine orbital locations. The global broadband system, called GE*StarPlus, would offer connectivity for data-based applications at rates up to 155 Mbps. The system would use 3 GHz for both uplink and downlink in the 50/40 GHz V-band and 500 MHz within Ku-band. The system will use optical intersatellite links.

Each satellite payload receives uplink signals, demodulates them, and routes them to 20 V-band and 8 Ku-band spot beams and one Ku-band hemispheric beam with dual circular polarizations.

The proposed GE*Starplus system would serve a diverse market for high-data rate communications that previously relied on less suitable telephone network lines, such as for the transport of medical images, desktop publishing, and academic information. Users will be able to change locations easily without requiring connection to wire-based data services. Each satellite will have an estimated capacity of 40,000 equivalent T1 circuits.

Spectrum Astro has designed a 25 satellite, 50/40 GHz V-band system called Aster that will consist of five clusters of collocated geostationary satellites. The cluster approach will enable the company to build up its system in conformance with market demand.

Each of the satellites produces 48 spot beams 0.5° in diameter, 8 elliptical 1° × 1.5° regional beams, and 2 steerable 0.8° beams. The spot beams and regional beams divide the required 2 GHz of bandwidth in each direction. Service is offered at data rates of 155 Mbps and higher through terminals in the range from 4 m to 7 m. Lower data rates from 2 Mbps to 51 Mbps are available through terminals in the 1.2 m to 5 m range. Spectrum Astro’s system will be available to homes, businesses, medical clinics, educational institutions, government agencies, and laboratories.

CAI Satellite Communications, Inc. intends to launch a single V-band geostationary satellite that has the ability to provide high quality two-way video, voice, and data services to business and residential customers in the contiguous United States (CONUS). The satellite would be collocated with a Ka-band satellite proposed by CAI's affiliate, CAI Data Systems, Inc., at 93°, 95°, or 102° W longitude.

The company seeks 1 GHz of spectrum from 49.2 to 50.2 GHz for Earth-to-space and 1 GHz of spectrum from 40.5 to 41.5 GHz for space-to-Earth. This system will complement CAI's existing terrestrial MMDS “wireless cable” system operating in the 2 GHz band to provide subscribers with a greater variety of video and interactive services.

Orbital Sciences is proposing a seven satellite broadband system from MEO called Orblink. The satellites will operate at an altitude of 9000 km in a single equatorial plane and will be equally spaced by 51.4°, forming a "wireless ring" around the Earth.

Two primary services will be offered: service to large gateways for digital trunks and “bandwidth on demand” for high-speed data users. Each satellite will be able to simultaneously accommodate 20 gateway users at 1.244 Gbps each and up to 4000 wideband users at 10 to 51 Mbps each. Orbcomm requests the bands 47.7 to 48.7 GHz for user to satellite, 37.5 to 38.5 GHz for satellite to user, and 65.0 to 71.0 GHz for intersatellite links, all using dual circular polarization.

Pentriad, a system developed by Denali Telecom, LLC, is proposed as an international system to provide broadband multicasting and Direct To Home (DTH) services in the northern hemisphere. The main capacity of the Pentriad satellite system would be utilized for broadband services to telecommunications carriers. It employs a unique constellation of nine operational satellites in highly elliptical orbits distributed into three orbital planes plus three in-orbit spares and one ground spare.

Pentriad proposes to use 2 GHz of V-band (near 50 GHz) for the uplink and 2 GHz of Q-band (near 40 GHz) and 200 MHz of Ku-band (near 12 MHz) for the downlink. The Pentriad satellites have “bent pipe” transponders that relay, but do not process, data from one ground location to another. The basic channel data rate is 155 Mbps, which can be subdivided to provide slower rates down to 10 Mbps or grouped together to provide higher rates up to 3.875 Gbps.

Teledesic is proposing a 72-satellite system called V-Band Supplement (VBS) to augment its already ambitious 288 satellite Ka-band system (down from the original 840 satellite constellation).

LEO One has asked for additional spectrum at 40 GHz for its 48 satellite “Little LEO” constellation for tracking and messaging.

Globalstar plans to launch an 80 satellite V-band constellation called GS-40 to expand its mobile telephony system. In addition, it plans to launch 64 Low Earth Orbit satellites and four geostationary satellites that will operate at 2 GHz.

ANOTHER GOLD RUSH

V-band spectrum was not the only territory on which companies rushed to stake claims. Additional new proposals at 2 GHz meeting the FCC September 26 deadline, contemporaneous with the V-band deadline, include a 16 satellite Medium Earth Orbit constellation proposed by Boeing for navigation services to airlines, a 96 satellite constellation called Macrocell to expand and complement the IRIDIUM 66 satellite constellation, and a 26 satellite constellation to expand the capacity of the 17 satellite Ellipso system.

In addition to the new filings, three letters of intent asking spectrum at 2 GHz were submitted by ICO Global Communications for its 10 satellite MEO mobile telephony system, TMI Communications for CanSat-M3 to supplement its operational MSat-1 satellite that provides two-way voice, tracking, and paging services, and INMARSAT for its 4 satellite Horizons system that will provide data, voice, and videoconferencing capabilities to portable computers.

CROWDED SKIES

The first geostationary satellite, SYNCOM III, was successfully launched in 1964. Since that time approximately 250 satellites have been launched into GEO, of which about 170 are operational. Roughly another 80 satellites are on order to increase or replace services at C-band and Ku-band. About 165 "Big LEO" satellites are planned for mobile telephony and another 200 "Little LEO" satellites are planned for messaging and data gathering. In Ka-band, about 70 geostationary satellites have been proposed in addition to the 288 satellite Teledesic LEO constellation. To these we now add another 250 satellites at S-band and nearly 300 more at Q- and V-bands. The total number of new satellites is staggering and is in excess of 1300 satellites. Not every proposed system will be approved, funded, built, and supported by the market. However, it is clear that there is an enormous growth ahead in satellite hardware and services. The true frontier is nowhere in sight.

Dr. Robert A. Nelson, P.E. is president of Satellite Engineering Research Corporation, a satellite engineering consulting firm in Bethesda, Maryland.