# Lecture 14

## PRINCIPLES OF SATELLITE COMMUNICATION

# L-Band

- While there is effectively no rain attenuation at L-band, the ionosphere does introduce a source of significant link degradation.
- This is in the form of rapid fading called ionospheric scintillation, which is the result of the RF signal being split into two parts:
  - The direct path and
  - a refracted (or bent) path.
- At the receiving station, the two signals combine with random phase sometime resulting in the cancellation of signals, producing a deep fade.
- Ionospheric scintillation is most pronounced in equatorial regions and around the equinoxes (March and September).
- Both ionospheric scintillation and Faraday rotation decrease as frequency increases and are nearly negligible at Ku-band and higher.
- Transmissions at UHF are potentially more seriously impaired and for that reason, and additional fade margin over and above that at L-band may be required.

# Polarization

- Polarization is the property of electromagnetic waves that describes the direction of the transverse electric field.
- Since electromagnetic waves consist of an electric and a magnetic field vibrating at right angles to each other.
- it is necessary to adopt a convention to determine the polarization of the signal.
- Conventionally, the magnetic field is ignored and the plane of the electric field is used.

# L-Band

- From an overall standpoint, L-band represents a regulatory challenge but not a technical one.
- There are more users and uses for this spectrum than there is spectrum to use.
- Over time, technology will improve spectrum efficiency.
- Techniques like digital speech compression and bandwidth efficient modulation may improve the utilization of this very attractive piece of spectrum.
- The business failure of LEO systems like Iridium and Globalstar had raised some doubts that L-band spectrum could be increased.
- One could argue that more profitable land-based mobile radio services (e.g., cellular and wireless data services) could end up winning over some of the L-band.
- This will require never-ending vigilance from the satellite community.

# S-Band

- S-band was adopted early for space communications by NASA and other governmental space research activities around the world.
- It has an inherently low background noise level and suffers less from ionospheric effects than L-band.
- DTH systems at S-band were operated in past years for experiments by NASA and as operational services by the Indian Space Research Organization and in Indonesia.
- More recently, the ITU allocated a segment of S-band for MSS and Digital Audio Radio (DAR) broadcasting.
- These applications hold the greatest prospect for expanded commercial use on a global basis.

# S-Band

- As a result of a spectrum auction, two companies were granted licenses by the FCC and subsequently went into service in 2001–2002.
- S-band spectrum in the range of 2,320 to 2,345 MHz is shared equally between the current operators, XM Radio and Sirius Satellite Radio.
- A matching uplink to the operating satellites was assigned in the 7,025- to 7,075-MHz bands.
- Both operators installed terrestrial repeaters that fill dead spots within urban areas.
- With an EIRP of nominally 68 dBW, these broadcast satellites can deliver compressed digital audio to vehicular terminals with low gain antennas.

# S-Band

- As a higher frequency band than L-band, it will suffer from somewhat greater (although still low) atmospheric loss and less ability to adapt to local terrain.
- LEO and MEO satellites are probably a good match to S-band since the path loss is inherently less than for GEO satellites.
- One can always compensate with greater power on the satellite, a technique used very effectively at Ku-band.

# C-Band

- Once viewed as obsolete, C-band remains the most heavily developed and used piece of the satellite spectrum.
- During recent World Radio-communication Conferences, the ITU increased the available uplink and downlink bandwidth from the original allocation of 500 to 800 MHz.
- This spectrum is effectively multiplied by a factor of two with dual polarization.
- Further reuse by a factor of between two and five takes advantage of the geographic separation of land coverage areas.
- The total usable C-band spectrum bandwidth is therefore in the range of 568 GHz to 1.44 THz, which compares well with land-based fiber optic systems.
- The added benefit of this bandwidth is that it can be delivered across an entire country or ocean region.

# C-Band

- Even though this represents a lot of capacity, there are situations in certain regions where additional satellites are not easily accommodated.
- In North America, there are more than 35 C-band satellites in operation across a 70° orbital arc.
- This is the environment that led the FCC in 1985 to adopt the radical (but necessary) policy of 2° spacing.
- The GEO orbit segments in Western Europe and east Asia are becoming just as crowded as more countries launch satellites.
- European governments mandated the use of Ku-band for domestic satellite communications, delaying somewhat the day of reckoning.
- Asian and African countries favor C-band because of reduced rain attenuation as compared to Ku- and Ka-bands, making C-band slots a vital issue in that region.

# C-Band

- C-band is a good compromise between radio propagation characteristics and available bandwidth.
- Service characteristics are excellent because of the modest amount of fading from rain and ionospheric scintillation.
- The one drawback is the somewhat large size of Earth station antenna that must be employed.
- The 2° spacing environment demands antenna diameters greater than 1m, and in fact 2.4m is more the norm.
- This size is also driven by the relatively low power of the satellite, itself the result of sharing with terrestrial microwave.
- High-power video carriers must generally be uplinked through antennas of between 7m and 13m; this assures an adequate signal and reduces the radiation into adjacent satellites and terrestrial receivers.

# C-Band

- The prospects for C-band are good because of the rapid introduction of digital compression for video transmission.
- New C-band satellites with higher EIRP, more transponders, and better coverage are giving C-band new life in the wide expanse of developing regions such as Africa, Asia, and the Pacific.

# X-Band

- Government and military users of satellite communication established their fixed applications at X-band.
- This is more by practice than international rule, as the ITU frequency allocations only indicate that the 8-GHz portion of the spectrum is designated for the FSS regardless of who operates the satellite.
- From a practical standpoint, X-band can provide service quality at par with C-band; however, commercial users will find equipment costs to be substantially higher due to the thinner market.
- Also, military-type Earth stations are inherently expensive due to the need for rugged design and secure operation.
- Some countries have filed for X-band as an expansion band, hoping to exploit it for commercial applications like VSAT networks and DTH services. As discussed previously, S-DARS in the United States employs X-band feeder uplinks.
- On the other hand, military usage still dominates for many fixed and mobile applications.

# Ku-Band

- Ku-band spectrum allocations are somewhat more plentiful than C-band, comprising 750 MHz for FSS and another 800 MHz for the BSS. Again, we can use dual polarization and satellites positions 2° apart.
- Closer spacings are not feasible because users prefer to install yet smaller antennas, which have the same or wider beam-width than the correspondingly larger antennas for C-band service.
- Typically implemented by different satellites covering different regions, Ku regional shaped spot beams with geographic separation allow up to approximately 10X frequency reuse.
- This has the added benefit of elevating EIRP using modest transmit power;
- G/T likewise increases due to the use of spot beams.
- The maximum available Ku-band spectrum could therefore amount to more than 4 THz.

# Ku-Band

- Exploiting the lack of frequency sharing and the application of higher power in space, digital DTH services from DIRECTV and EchoStar in North America ushered in the age of low-cost and user-friendly home satellite TV.
- The United Kingdom, continental Western Europe, Japan, and a variety of other Asian countries likewise enjoy the benefits of satellite DTH.
- As a result of these developments, Ku-band has become a household fixture (if not a household word).

# Ku-Band

- The more progressive regulations at Ku-band also favor its use for two-way interactive services like voice and data communication.
- Low-cost VSAT networks typify this exploitation of the band and the regulations. Being above C-band, the Ku-band VSATs and DTH receivers must anticipate more rain attenuation.
- A decrease in capacity can be countered by increasing satellite EIRP.
- Also, improvements on modulation and forward error correction are making terminals smaller and more affordable for a wider range of uses.
- Thin route applications for telephony and data, benefit from the lack of terrestrial microwave radios, allowing VSATs to be placed in urban and suburban sites.

# Ka-Band

- Ka-band spectrum is relatively abundant and therefore attractive for services that cannot find room at the lower frequencies.
- There is 2 GHz of uplink and downlink spectrum available on a worldwide basis.
- Conversely, with enough downlink EIRP, smaller antennas will still be compatible with 2° spacing.
- Another facet of Ka-band is that small spot beams can be generated onboard the satellite with achievable antenna apertures.
- The design of the satellite repeater is somewhat more complex in this band because of the need for cross connection and routing of information between beams.
- Consequently, there is considerable interest in the use of onboard processing to provide a degree of flexibility in matching satellite resources to network demands.

# Ka-Band

- The Ka-band region of the spectrum is perhaps the last to be exploited for commercial satellite communications.
- Research organizations in the United States, Western Europe, and Japan have spent significant sums of money on experimental satellites and network application tests.

# Ka-Band

- From a technical standpoint, Ka-band has many challenges, the biggest being the much greater attenuation for a given amount of rainfall (nominally by a factor of three to four, in decibel terms, for the same availability).
- This can, of course, be overcome by increasing the transmitted power or receiver sensitivity (e.g., antenna diameter) to gain link margin.
- Some other techniques that could be applied in addition to or in place of these include:
  - (1) dynamic power control on the uplink and downlink,
  - (2) reducing the data rate during rainfall,
  - (3) transferring the transmission to a lower frequency such as Ku- or C-bands, and
  - (4) using multiple-site diversity to sidestep heavy rain-cells.
- Consideration of Ka-band for an application will involve finding the most optimum combination of these techniques.

# Ka-Band

- The popularity of broadband access to the Internet through DSL and cable modems has encouraged several organizations to consider Ka-band as an effective means to reach the individual subscriber.
- Ultra-small aperture terminals (USATs) capable of providing two-way high-speed data, in the range of 384 Kbps to 20 Mbps, are entirely feasible at Ka-band.
- Hughes Electronics filed with the FCC in 1993 for a two-satellite system called Spaceway that would support such low-cost terminals.
- In 1994, they extended this application to include up to an additional 15 satellites to extend the service worldwide.
- The timetable for Spaceway has been delayed several times since its intended introduction in 1999.
- While this sounds amazing, strong support from Craig McCaw, founder of McCaw Cellular (now part of AT&T Wireless), and Bill Gates (cofounder of Microsoft) lent apparent credibility to Teledesic.
- In 2001, Teledesic delayed introduction of the Ka-band LEO system. A further development occurred in 2003 when Craig McCaw bought a controlling interest in L/S-band non-GEO Globalstar system.

# Ka-Band

- While the commercial segment has taken a breather on Ka-band, the same cannot be said of military users.
- The U.S. Navy installed a Ka-band repeater on some of their UHF Follow-On Satellites to provide a digital broadcast akin to the commercial DTH services at Ku-band.
- It is known as the Global Broadcast Service (GBS) and provides a broadband delivery system for video and other content to ships and land-based terminals.
- In 2001, the U.S. Air Force purchased three X- and Ka-band satellites from Boeing Satellite Systems.
- These will expand the Ka-band capacity by about three on a global basis, in time to support a growth in the quantity and quality of Ka-band military terminals.
- The armed services, therefore, are providing the proving grounds for extensive use of this piece of the satellite spectrum.

# Q and V-Bands

- Frequencies above 30 GHz are still considered to be experimental in nature, and as yet no organization has seen fit to exploit this region.
- This is because of the yet more intense rain attenuation and even atmospheric absorption that can be experienced on space-ground paths.
- Q- and V-bands are also a challenge in terms of the active and passive electronics onboard the satellite and within Earth stations.
- Dimensions are extremely small, amplifier efficiencies are low, and everything is more expensive to build and test.
- For these reasons, few have ventured into the regime, which is likely to be the story for some time.
- Perhaps one promising application is for ISLs, also called cross links, to connect GEO and possibly non-GEO satellites to each other.
- To date, the only commercial application of ISLs is for the Iridium system, and these employ Ka-band.

# Laser Communications

- Optical wavelengths are useful on the ground for fiber optic systems and for limited use in line-of-sight transmission.
- Satellite developers have considered and experimented with lasers for ISL applications, since the size of aperture is considerably smaller than what would be required at microwave.
- On the other hand, laser links are more complex to use because of the small beam-widths involved.
- Control of pointing is extremely critical and the laser often must be mounted on its own control platform.
- In 2002, the European Space Agency demonstrated a laser ISL called SILEX, which was carried by the Artemis spacecraft.
- The developers of this equipment achieved everything that they intended in this government-funded program.

# Summary of Spectrum Options

- The frequency bands just reviewed have been treated differently in terms of their developmental timelines (C-band first, Ka-band last) and applications (L-band for MSS and Ku band for BSS and DTH).
- However, the properties of the microwave link that relate to the link budget are the same.
- Of course, properties of different types of atmospheric losses and other impairments may vary to a significant degree.
- This requires a careful review of each of the  terms in the link budget prior to making any selection or attempting to implement particular applications.