DAT330 – Principles of Digital Audio
Cogswell Polytechnical College
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Week 13 – Class Notes

Digital Radio and Television Broadcasting

Satellite Communication

Satellite communications operate at microwave frequencies; specifically they occupy the super-high-frequency (SHF) band extending from 3 - 30 GHz. There are two Fixed Satellite Services (FSS) bands for domestic use: the C-band (3.4 - 7.075 GHz) and the Ku-band (10.7 – 18.1 GHz). In either case, several higher-frequency subbands are used for uplink signals and several lower-frequency subbands used for downlink signals. Because many geostationary satellites share the same spectral space, ground stations must rely on physical satellite spacing and antenna directionality to differentiate between satellites.

Most C-band transponders (automatic device that receives, amplifies, and retransmits a signal on a different frequency) use a 36 MHz bandwidth placed on 40 MHz centers, although some cases 72 MHz transponders are used. Ku-band transponder bandwidths are either 36 or 72 MHz wide.

The C-band offers superior propagation characteristics, but Ku-band can offset this with greater transponder antenna gain. Terrestrial microwave interference is possible because of the shared spectral space, however by using lower transmitting power and larger antenna diameter, C-band devices can alleviate this problem.

Ku-band wavelengths, because of their shorter length, are easily absorbed by moisture and thus the signal can be degraded by rain, snow, or fog. However, Ku-band is not shared with terrestrial applications and does not suffer from microwave interference, thus higher power and smaller antennas can be used in broadcast applications. In some cases, a combination of bands is used.

A satellite's transponders receive the ground station's uplink signal and retransmit it back to earth where a downlink receives the signal. A communications satellite might have 48 or more transponders each capable or receiving multiple (8-12) data channels from an uplink, or transmitting those channels to a receiving downlink.

Satellite systems promise phone pricing that is competitive with terrestrial cellular services, and also offer data transfer, facsimile, paging, voice mail, messaging, and geopositioning.

Digital Transmission

Both analog and digital transmissions are used in audio and video satellite communication. Television signals are often transmitted with analog FM because it is immune to AM noise, supports multiplexing, and provides good carrier-to-noise (C/N) ratio. However, satellites also are widely used for digital data transmission of video and audio data. U.S. Radio networks use satellite digital distribution of programming.

Digital audio is provided with voice grade, 7.5 kHz, 15 kHz audio, or other data formats. The 7.5 kHz format is sampled at 16 kHz, and the 15 kHz format is sampled at 32 kHz; both use 15-bit quantization followed by μ-law companding to yield 11-bits plus a parity bit. Multiple channels are multiplexed into a T-1 stream and sent to the uplink station. By compading the individual audio channels in a multiplexed stream, it is possible to reduce the bit rate necessary for satellite distribution.

Radio signals are broadcast as either analog or digital baseband signals that modulate a high-frequency carrier signal to convey information. For example, an AM radio station might broadcast a 980 kHz carrier frequency, which is amplitude modulated by baseband audio information. The receiver is tuned to the carrier frequency and demodulates it to the output of the original baseband signal; IF (intermediate frequency) modulation techniques are used. Digital transmissions use a digital baseband signal, PCM or data reduction format. The digital data modulates a carrier signal (high frequency sinusoid) by digitally manipulating a property of the carrier; the modulated carrier signal is then transmitted. In addition, prior to modulation, multiple baseband signals can be multiplexed to forma digital composite baseband signal.

In any digital audio broadcasting system, it is important to distinguish between the source coder and the channel coder. The source coder performs data reduction coding so the wideband signal can be efficiently carried over reduced spectral space. The channel coder prepares the rate-reduced signal for modulation onto radio frequency (RF) carriers, the actual broadcasting medium; needed for robust and efficient transmission. Channel coding must consider the reduction of multipath interference that causes flat or frequency-selective interference (fade) in the received signal. Channel coders can use frequency diversity in which the source coder data is encoded on several carrier frequencies spread across a spectral band; a fade will not affect all of the received carriers. The use of adaptive equalization may also alleviate multipath interference and adjust the receiver sensitivity across the channel spectrum to minimize interference. Multipath can change over time, especially for mobile receivers, so time diversity transmits redundant data over a time interval to help ensure proper reception; a cancellation at one point might not exist at a later time, so that the receiver can choose the stronger received signal. Finally, space diversity allows for multiple antennas to be used and the receiver selects the strongest signal available.

Direct Broadcast Satellites

Direct Broadcast Satellite is a point-to-multipoint system in which individual households equipped with a small parabolic antenna and tuner receive broadcasts directly from a geostationary satellite. The satellite receives digital audio and video transmissions from ground stations and relays them directly to individuals.

The receiving system consists of an offset parabolic antenna that collects the microwave signals sent by the satellite, and a converter mounted at the antenna's focal point that converts the microwave signals to a lower frequency signal. Because of the high sensitivity of these devices and the relatively high satellite transmitting power, the parabolic antenna can be relatively small (0.5 m). The dishes are mounted outside the home and have a southern facing alignment that is finely tuned according to a signal strength diagnostics display. Indoors, a phase-locked loop tuner demodulates the signal from the converter into video and audio signals suitable for home television or stereo. Larger antennas can be used in areas that are not centrally located. DBS systems transmit in the Ku-band region.

The DirecTV system is an example of DBS system providing digital audio and video programming to consumers.

ISO/MPEG-2 coding is used to reduce the channel's nominal bit rate from 270 Mbps to 3.75-7.5 Mbps. The signal chain also includes Reed-Solomon and convolutional error coding, and quadrature phase-shift keying modulation.

Digital Audio Radio

Digital Audio Radio (DAR) or digital audio broadcasting (DAB) technologies transmit audio signals digitally, instead of using analog modulation methods such as AM or FM broadcasting. DAR is designed to replace analog broadcasting, providing a robust signal that is less susceptible to multipath interference and has a fidelity comparable to that of CD. In addition, DAR systems support the transmission of auxiliary data (text, graphics, or still video images).

Two principal DAR technologies have been developed: Eureka 147 DAB and in-band on-channel (IBOC) broadcasting known as HD radio.

Transmission Methods

DAR can be broadcasted in a number of different ways. It can be transmitted from transmission towers, much like analog broadcasting, but it is more power efficient (requiring far less power than analog broadcasting). Terrestrial transmission provide local programming by independent stations. Terrestrial DAR systems can be quickly implemented and at a low cost.

Satellite DAR broadcasting systems uplink programs to satellites and downlink them directly to the consumers equipped with digital radio. The resulting broadcasting network has a far reaching area and is ideal for long-distance motorists. Satellite systems can also effectively extend the range of terrestrial stations. Some proposed satellite radio transmission systems would have multiple spot beams, each aimed at a major metropolitan area, as well as a national beam; in this way, both regional and national programming could be accommodated. Receivers would use low-gain, nondirectional antennas. Satellite system implementation requires a significant capital investment.

Digital audio programs can also be broadcast over home cable systems. DAR programming originating from a satellite can be delivered to local cable providers. Time-division multiplexing is used to efficiently combine many digital audio channels into one wideband signals. At the cable head-end, the channels are demultiplexed, encrypted, and remodulated for distribution to cable subscribers over an unused television channel. The channel is decoded, de-crypted, and converted back to analog form for playback.

Spectral Space

DAR broadcasting systems have to consider the problem of locating the DAR band (~100 MHz wide) in the electromagnetic spectrum. Spectral space is a limited resource that has been substantially allocated. Any band from 100-1700 MHz could be used for terrestrial DAR, but the spectrum is already crowded with applications. Lower bands are preferable because RF attenuation increases with frequency, but are difficult to obtain. The S-band (2310-2360 MHz) is not suitable for terrestrial DAR because of it is prone to interference, however it is suitable for satellite delivery. Portions of the VHF and UHF bands have been allocated to DTV applications.

While a worldwide allocation scheme would assist manufacturers and lower cost, it is difficult to obtain a worldwide consensus. The World Administrative Radio Conference (WARC) allocated the L-band for digital audio broadcasting via satellite, but it deferred selection for a regional solution. Similarly, the International Radio Consultative Committee (CCIR) proposed a worldwide 60 MHz band at 1500 MHz for both terrestrial and satellite DAR; however, terrestrial broadcasting at this frequency is prone to absorption and obstruction.

The Federal Communications Commission (FCC) allocated the S-band spectrum to establish satellite-delivered digital audio broadcasting services.

Ideally DAR, would permit compatibility between terrestrial and satellite channels. However, there is not a mutually ideal band space, and allocation will require compromises.

New DAR systems could cohabit spectral space with existing applications. Shared-spectrum techniques could be used to locate the digital signal in the FM and AM bands. But regardless of any future DAR implementation, FM and AM broadcasts ultimately determine how the spectral space is redistributed.

Data Reduction

Digital audio signals in linear PCM format are not ideal for practical transmission because of the excessive bandwidth requirements. A stereo DAB signal might occupy 2 MHz of bandwidth, while an analog FM broadcast requires 200 kHz. Thus, data reduction methods have to be applied to DAR.

There are numerous perceptual coding methods suitable for broadcasting. For example, the ISO/MPEG algorithms, Dolby AC-3 systems can effectively reduce the bit rate of an audio signal transmission. In addition, an audio signal passing through a broadcasting chain may undergo multiple data reduction encoding/decoding stages; unfortunately, this also increases distortion and artifacts.

Technical Considerations

The performance of a DAB systems can be evaluated by its delivered sound quality, coverage range for reliable perception, interference between analog and digital signals at the same or adjacent frequencies, signal loss in mountains or tunnels, deep fades, signal “flutter” caused by passing aircraft, data errors in the presence of manmade and atmospheric noise, multipath distortion, receiver complexity, and capacity for auxiliary data services. Ideally, a receiver can be used for both terrestrial and satellite reception.

DAR designs must have low-error rates, moderate transmission power levels, and sufficient data rates, all with the smallest possible bandwidth. Error correction data accompanying the audio data must be used for error minimization, and for monitoring the given carrier-to-noise ration (C/N) of the received signal. Transmitted digital signals have relatively low C/N rations, whereas analog signals do not.

Pulse-shaping techniques applied prior to modulation helps limit the bandwidth requirements of a signal. This technique performs a lowpass filtering to reduce the high-frequency content of the data signal.

Multipath interference occurs when a direct signal and one or more strongly reflected and delayed signals destructively combine at the receiver. The delay might be on the order of 5 μs. In addition, other weak reflected signals might persist for up to 20 μs. The result at the receiver is a comb filter with 10-50 dB dips in signal strength.

This type of RF multipath is a frequency-selective problem, and short wavelengths are more vulnerable. Multiplath interference for moving receivers results in the amplitude modulation “picket fence” effect. In a stoplight fade, when the receiver is stopped in a signal null (a reflected signal completely cancels the transmitted signal's bandwidth), the signal is continuously degraded. In this case, FM signals can become noisy, but digital signals are completely lost.

Increasing the power is not an ideal solution since both the direct and reflected signals increase proportionally, preserving the interference nulls.

Multipath interference caused by short delays, can also affect the demoludated downstream. The delay spread by multiple reflections arriving at the receiver over a time interval of some 15 μs result in intersymbol interference in the received data (bits arrive at multiple times). This can be overcome with bit periods longer than the spread time or with frequency diversity techniques that place the data signal on multiple carriers.

Two types of multiplexing are used. The most common being time-division multiplexing (TDM), in which multiple channels share a single carrier by time interleaving their data streams on a bit or word basis. Different bit rates can be time multiplexed.

Frequency-division multiplexing (FDM) divides a band into subbands, and individual channels modulate individual carriers within the available bandwidth. A single channel can be frequency multiplexed, thus lowering the bit rate on each carrier, as well as lowering the bit error. Multipath interference is reduced, however, more spectral space is needed.

Phase-shift keying (PSK) modulation methods are commonly used because they yield the lowest BER for a given signal strength. In binary phase-shift keying (BPSK), two phase shifts represent two binary states. For example, a binary 0 places the carrier in phase, and a binary 1 places it 180º out of phase. This phase change codes the signal. The symbol rate equals the data rate.

In quadrature phase-shift keying (QPSK), four phase shifts are used. Thus, two bits per symbol are represented. For example, 11 places the carrier at 0º, 10 at 90º, 00 at 180º, and 01 at 270º. The symbol rate is twice the transmission rate. This method is the most widely used modulation for data rates above 100 Mbps.

Other modulation methods include amplitude shift-keying (ASK) in which different carrier powers represent binary values, frequency shift-keying (FSK) in which the carrier frequency is varied (used in modems), and quadrature amplitude modulation (QAM) in which both amplitude and phase are varied.