Satellites and Computer Communication in the Classroom

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Abstract

Dozens of amateur radio satellites are now available to use in the classroom. These are satellites made by Amateur Radio Organizations and Universities. They are launched as part of other satellite launches. Most of them are very small (10 cm x 10 cm x 10 cm) but they carry amateur radio receivers and transmitters. These satellites can be monitored with simple ground stations and with the proper license, communication can be carried out with stations thousands of miles away. An explosion of "cube sats" over the past year allows us to demonstrate many of the features of data communication:

Bandwidth
Data Rate
Data Latency
Data Packets
Transport Protocols
Data Modulation
Data Noise and Channel Capacity
Time and Frequency Multiplexing

This paper will discuss use of satellites to demonstrate the above characteristics of many communication systems. In addition, satellites give us the ability to show Doppler shift and satellite tracking used for communication systems such as GPS and Iridium Satellite phones.

Satellite Basics

Satellites orbit the earth above about 300 miles. The satellites used by Amateur Radio are typically launched with larger satellites as hangers on. Low orbit satellites (LEO's) usually circle the earth every 100 minutes and are overhead any one location about 13 minutes, During that 13 minute span a simple ground station can hear radio transmissions from the satellite on frequencies allocated internationally to Amateur Radio. Most of these satellites communicate in the VHF (30 – 300 Mhz) or UHF (300 – 3000 Mhz) band. The satellites range from a few inches in size to a meter or so.

Figure 1 -- The next AMSAT Phase 3 satellite
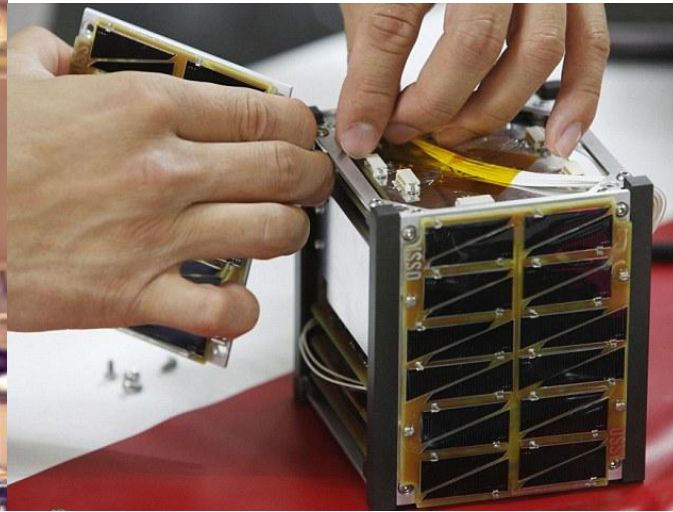
Figure 2 -- Early Amateur
Satellite

Figure 3 – Korean Microsat by Song Hojun

Each satellite includes solar cells and a batteries for power, radio receivers and transmitters, antennas, some environmental sensors (magnetic field, temperature, particle impact, etc.) and a control system. Selected Amateur Radio operators have the code for controlling the satellite and often the satellite includes some automatic sequencing system to connect sensors, receivers and transmitters.

A worldwide consortium of schools now designs and builds microsats like those in Figure 3 above. That satellite was built for under $500 by a Korean engineering student. Most of the recent microsatellites are 10 cm x 10 cm x 10 cm and launched from a rectangular tube mounted in the ring between the rocket and a large satellite. As of March 10, 2014 there are 61 active Amateur satellites. Twenty-four of these allow for two-way radio communication and the rest just transmit their status on an amateur frequency. A new launch is planned for March 16, 2014 which will place approximately 100 femtosatellites each measuring 3.5 cm x 3.5 cm and each transmitting its status on 437.240 Mhz. Details are on line.

The next challenge is to track the satellites in the sky. On line, heavens-above.com tracks all of the amateur satellites. A number of PC and OS X programs also track satellites. The Air Force provides orbital parameters for each of these satellites. I recommend a program called WxTrack from David Taylor in Figure 4. This is a real time mapping program that indicates the position of satellites and the time until their acquisition. Additional satellite tracking web sites are listed in the Appendix.
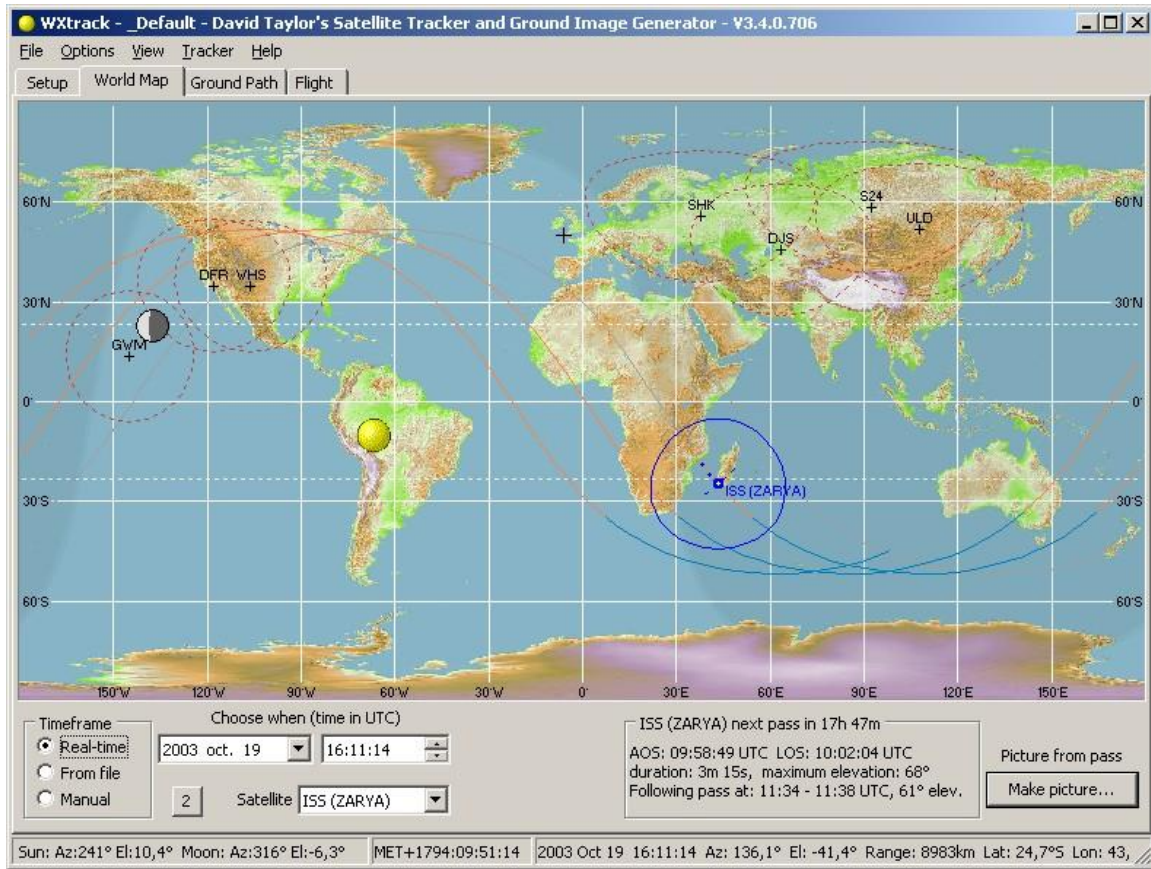
Figure 4 – WxTrack following the International Space Station (blue circle)

Receiving Satellite Signals

Most of the satellite transmissions occur at 145 Mhz or 440 Mhz in the Amateur Radio Band. In the U. S. one can receive these signals without a license but to transmit to the satellites you (or someone in your class) must have a Technician Amateur Radio License. Volunteer examiners administer these tests in your region; the only test is a multiple choice test of published questions. See the Amateur Radio Relay League or other organizations in the appendix for information on classes and tests in your area. Receivers for these signals must be sensitive and selective – which gives us an opportunity to discuss the limitations on radio communications. Normal scanners are not sensitive enough to receive satellite signals but will pick up local communication in both the VHF and UHF bands. Listening to a scanner, one can hear local police, weather radio, amateur radio and other services. Because these signals are not reflected by the ionosphere, only local (within 20-30 miles) signals can be heard. This is similar to the local range of typical wireless systems and allows us to reuse frequencies for wifi across the globe.

It is necessary to use directional antennae for satellite reception to hear the satellite from horizon to horizon. Directional antennae can be built from PVC and aluminum

rods from plans in the ARRL Antenna Book [1] or numerous web sites . Typical Yagi antennae must have about 6 to 10 db of gain in the preferred direction. This gives you an opportunity to discuss directional antennae and the size of antennae for various frequencies. I discuss the relationship between wavelength and antenna size and have students determine wavelengths for 2.4 and 5 Ghz wifi systems.

There are handheld and rotatable Yagi antennae that will give very good coverage from horizon to horizon; see Figure 5. In addition, there are turnstile and quadrafilar antennae that are omnidirectional. These omnidirectional antennae will not be as sensitive near the horizon, but do not require tracking; see figure 6.

Figure 5 – Handheld Yagi   Figure 6 – Turnstile Antenna

Receivers must be sensitive to receive the signals from satellites. In addition, many of the satellite transmitters use Single Side Band and Phase Shift Keying modulation. Many amateur radio receiving systems will have VHF and UHF receivers and I recommend a radio like the Yaesu FT-817 in Figure 7. This radio will cost $600 and

may be out of reach for your budget but there now are PC based software defined radios that cost $60 which will also do the job [2]. Software Defined Radios (SDR's) are direct conversion VHF/UHF receivers that connect to your PC via the USB port. The radio converts frequencies down to 0 to 3 Mhz and directly convert the signal via a fast (2.5 Megasamples/second) A/D converter. In the PC the signal is converted by software to an audio signal See Figure 8. The system in Figure 8 has a small antenna connection on the left and plugs into the USB port on the right. You can see it is very small. These SDR's are new and the technology is evolving rapidly.

Figure 7 – All Mode Transceiver   Figure 8 – USB powered SDR

What we learn by tracking a satellite?

Satellite Orbits

Ephemeris data from each satellite describes the orbit and is the basis for tracking programs. First we can learn about satellite orbits and the differences among Low Earth Orbit (LEO), Medium Earth Orbit (MEO) and Stationary Earth Orbit (SEO) satellites. We discuss the use of each type of satellite and especially note the problems with stationary satellites. A satellite in such an orbit is at an altitude of approximately 35,786 km (22,236 mi) above mean sea level. This means that the radio signal must traverse approximately 70,000 km from the earth to satellite to earth if used for network communication. This causes a nearly .25 second delay in the transmission just due to the long distance and for most communication this is a very long delay.

Why not use satellites for Internet communication?

If you use any of the ping or traceroute programs to overseas internet sites, you will discover that most round trip delays are less that .2 seconds. Since any round trip ping must traverse the distance from earth to the satellite four times, any communication via stationary satellites would have ping times in excess of .5

seconds. This will be a chance to discuss how transit times affect packet communication and why we cannot use stationary satellites for Internet connections if terrestrial cables are available.

In locations without terrestrial Internet connections, satellites must be used. Some examples of these are remote sensing of river gauges, weather stations, and other instruments. Using LEO and MEO satellites reduces the time delay to the satellite but also means that satellites are only overhead for 10 to 15 minutes for LEO's and somewhat longer for MEO's. What new technical problems does this present. Now we must coordinate satellite use among rising and setting satellites and also must account for vast signal strength changes as the satellite goes from the horizon to overhead. This is an opportunity to use link calculations to estimate the signal strength of radio signals. This introduces transmitter power, antenna gain, signal path loss and modulation sensitivity to students. Link calculations will tell us when the satellite signals are strong enough to detect and when we will lose signal. [3]

What about GPS systems?

GPS satellites are MEO's and orbit 20,000 to 26,000 km above sea level . At that altitude, ,the satellite is visible over a large portion of the globe and can be heard for approximately 5 hours. The GPS system transmits to earth at 1227 and 1575 Mhz. These signals can be received with some new SDR's but a hand held GPS is just as useful. Since all of the satellite transmit at the same frequency we must demonstrate the use of Code Division Multplexing to differentiate signals from as many as 12 satellites overhead at any time. The GPS receiver decodes the UHF signal and applies a pseudo random code PRN to the incoming signal. This is an opportunity to discuss frequency, time and code multiplexing when limited radio resources are available. See figure 9.
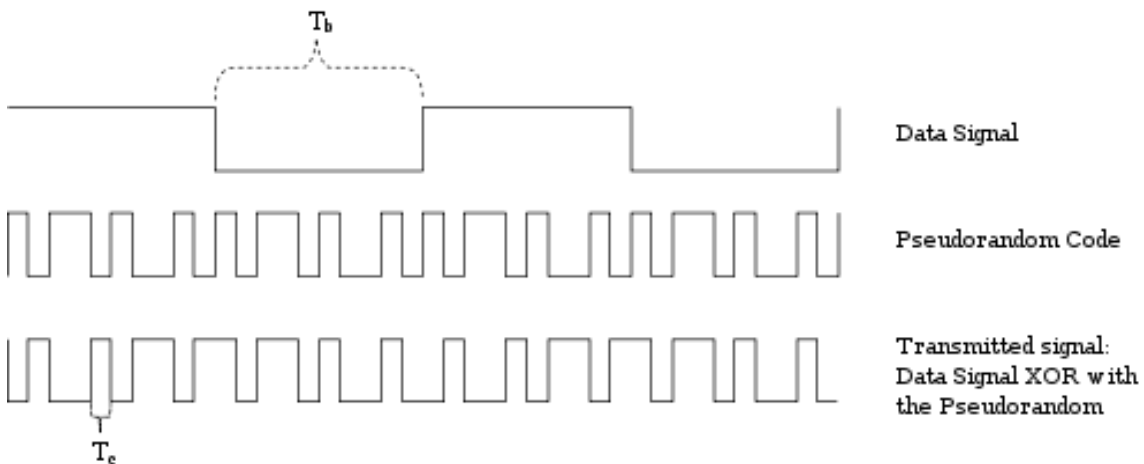

Figure 9 – A single code channel for CDMA systems

The PRN will be different for each satellite and the receiver must apply all of the PRN codes it knows to the incoming signal. Only when the receiver's PRN matches the satellite's PRN will a successful Data Signal appear in the receiver. All other PRNs will yield gibberish.

To demonstrate this with existing Amateur Radio Satellites is challenging. However, there are a group of satellites to be launched in late March 2014 called KickSats that will broadcast with Code Modulated signals that might be useful (4).

Modulation

Amateur Satellites receive and transmit signals in a number of standard modulation schemes:

Single Side Band – SSB – for voice
Phase and Frequency Shift Keying – for digital and voice systems
Frequency Modulation – for voice
Continuous Wave Modulation – CW for Morse Code systems

Each has its advantages and disadvantages. Most of these are limited in bandwidth to 3 Khz and data rates from 1200 bits/second to 9600 bits/second. To demonstrate bandwidth, use one of the programs that takes signals into you computer's soundcard and produces a waterfall display of the signal as seen in Figure 10.
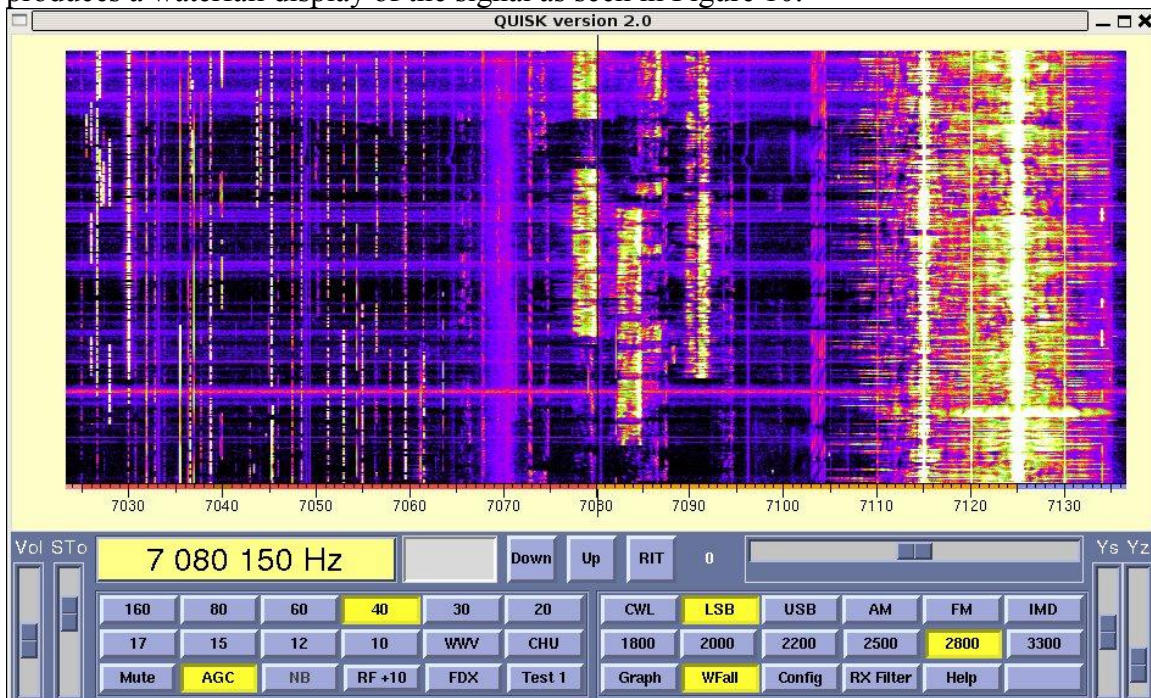

Figure 10 – Broadband Waterfall Display – 100 Khz wide at 7100 Khz

In Figure 10, time is on the vertical display and frequency on the horizontal. For this display the narrow signals on the left side of the display. These are Morse Code (CW) stations and other narrow band modulations. These modulations typically are limited to 300 bits/second or less due to their narrow bandwidth. From the middle of the display to the right are all voice signals with bandwidths of 3 Khz or so. These are all Lower Side Band signals and appear with most of their energy near the left side of the display (low audio frequencies). The bright signal at 7250 Khz on the right is a shortwave AM station. Its carrier appears as the bright line in the center with mirrored sidebands on either side of 7250 Khz. Broadcast FM stations also appear with bright center carriers and 150 Khz wide sidebands. This is an excellent demonstration of frequency domain modulation as well as how bandwidth can affect the data rate of a transmitted signal.

Doppler Shift

Because earth satellites typically travel about 18,000 mph (8000 meters/second) the radio signal exhibits significant Doppler shift as the satellite passed overhead. For the 440 Mhz radio downlink the amount of frequency shift is the ratio of the satellite speed to the speed of light:

At 440 Mhz

Doppler = 4.4×10^8 hz * 8.0×10^3 m/sec / 3.0×10^8 m/sec = 12,000 hz

At 145 Mhz

Doppler = 1.4×10^8 hz * 8.0×10^3 m/sec / 3.0×10^8 m/sec = 4,000 hz

This Doppler shift is far wider than the signal width of typical voice (3 khz) or CW (100 hz) signals and the receiver must track the changing frequency as the satellite passes over. Figure 11 shows the waterfall display of an amateur satellite as a slanted line across the spectrum. This is from the VO-52 Satellite transmitting at 145.90 Mhz. Over 1.5 minutes the satellite signal shifts 1.5 khz due to Doppler.
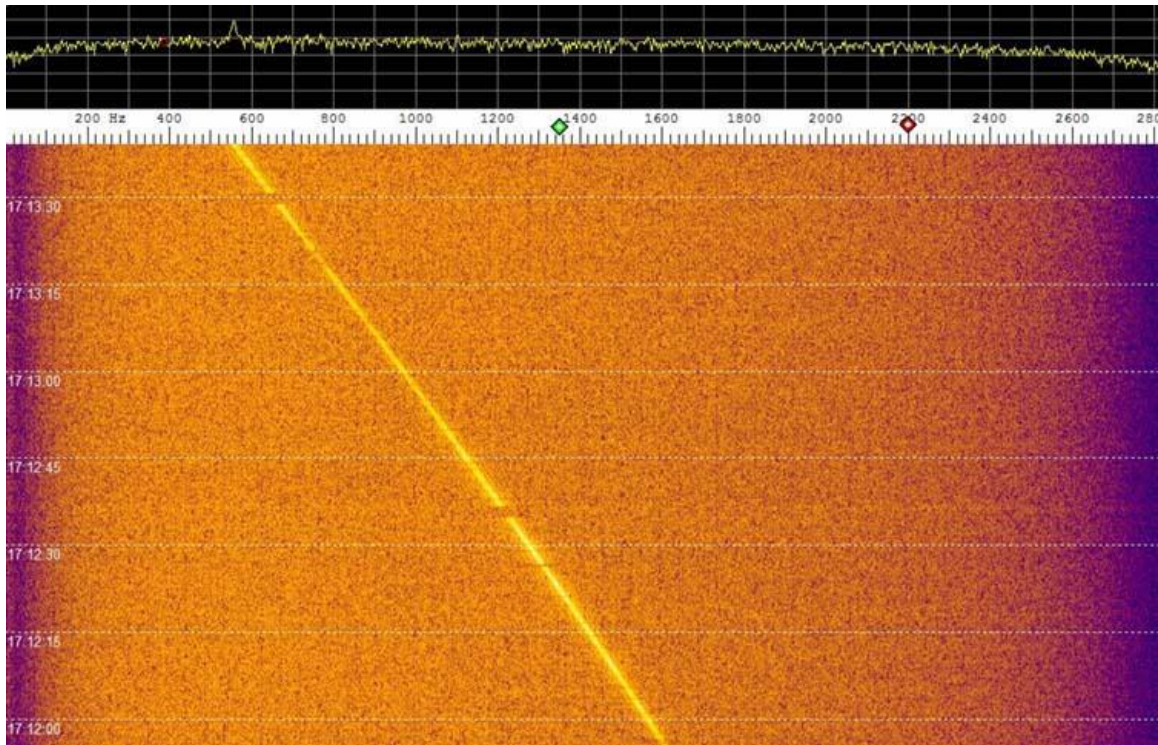
Figure 11 – Doppler Shift of VO-52 (145 Mhz) transmitter seen from earth.

Other Resources

There are also many resources available for instructors who want to use satellites in the classroom(5).

ARRL Radio Waves
AMSAT Education and Outreach
KA7FVV
N2YO tracking
AMSAT Youtube Channel

Satellite Tracking
       Heavens-Above.com
       N2YO
       AMSAT – list of other tracking programs

Amateur Radio Licensing
       ARRL
       Gordon West Publishing
       HamTestOnLine

Dave Casler
EHam.net
FCC Satellite Learning Center

These resources provide up-to-date information on the status and location of satellites. There are enough satellites in orbit now so that one is overhead nearly all day long. This is a chance for students to hear actual two-way communication and understand many of the limitations of radio communication.

References:

1. ARRL Antenna Handbook ,, Publisher: The American Radio Relay League, Inc.; Twenty-Second Edition/First Printing (October 2011)
Language: English
ISBN: 978-0-87259-694-8

2. RANverter Software Defined Radio. Hayseed Hamfest.
http://hayseedhamfest.com/sdr.html

3. Link Budget – Wikipedia http://en.wikipedia.org/wiki/Link_budget

4. Kicksat System - http://en.wikipedia.org/wiki/KickSat

5. E. Mike McCardel Symposium Presentation