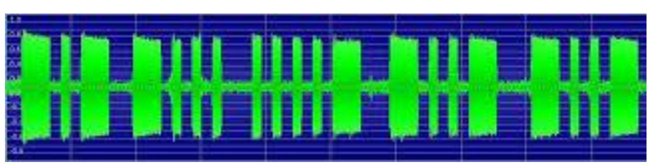
Radio Modulation Modes

1. **CW means Continuous Wave**. It is the simple transmission of a radio carrier with constant amplitude and frequency. **Intelligence is transmitted** by on and off switching of the carrier wave **using Morse code**. Since the Carrier Wave is transmitted and received at radio frequencies; in the process of reception, it must be converted to human hearing frequencies in the radio receiver. This is usually done by having another radio frequency (RF) oscillator known as a **Beat Frequency Oscillator or "BFO**" operating within 1000 Hz (1 kHz) of the carrier frequency within the workings of the receiver. This produces an audible "beat frequency" with the incoming signal that can be heard as an audio frequency (AF).

- **A CW signal takes up very little spectrum bandwidth**. We often set the bandwidth selectivity of a receiver to 500 Hz or less for reception of a CW signal.

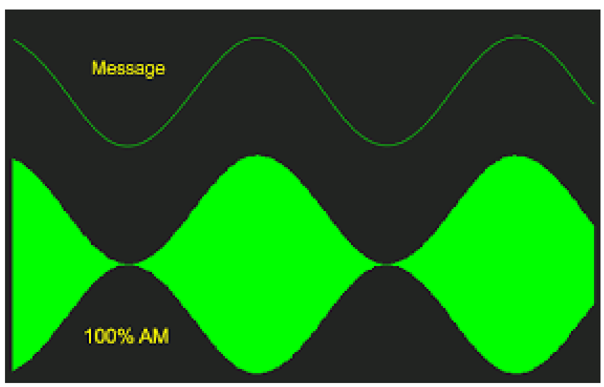
Oscilloscope image of Keyed Morse code CW signal



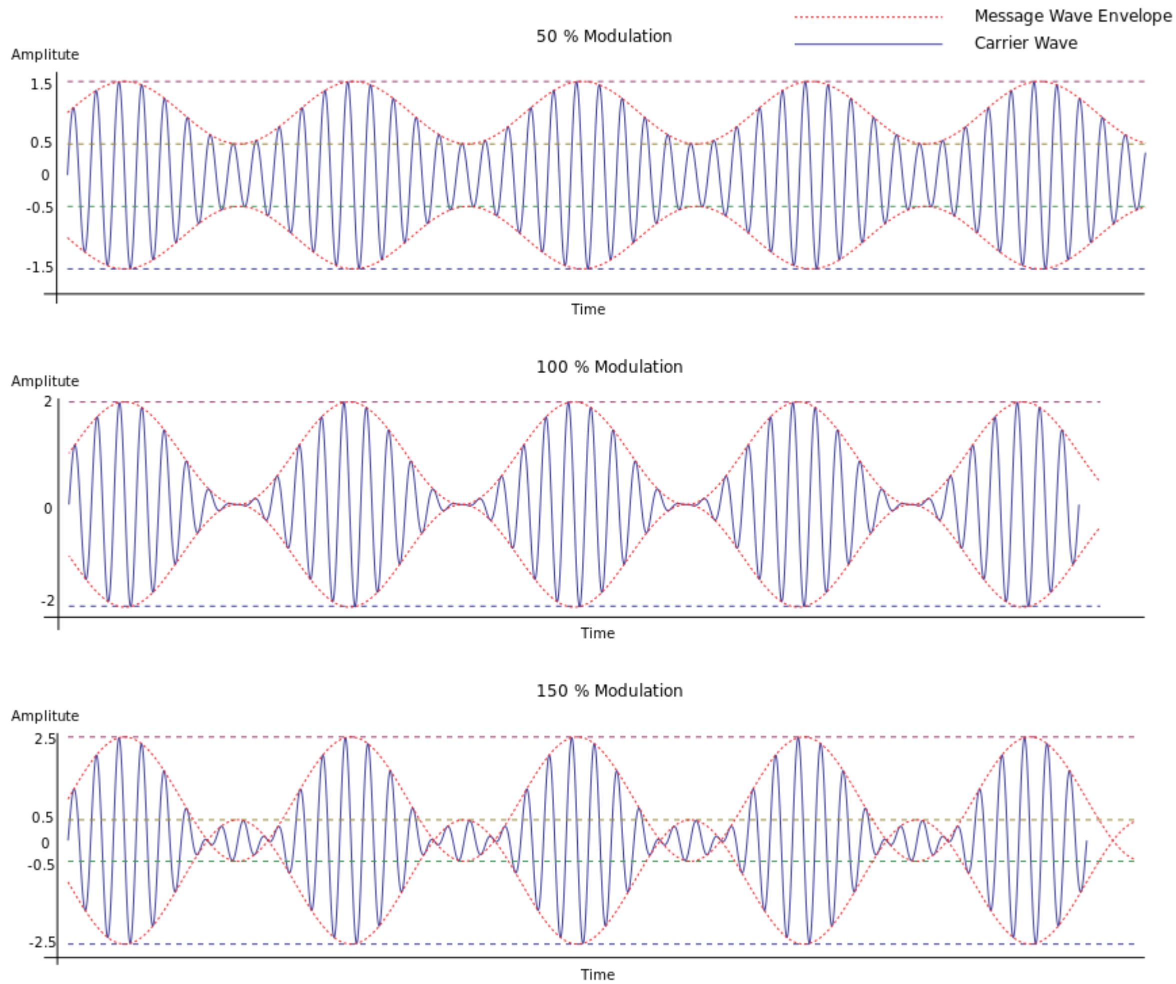
Call sign: K B 4 X X

- **CW (Morse code) remains very popular on the HF amateur bands** and is the mode of choice by those that become proficient with it. Some folks become so proficient they can send and receive at 30 words per minute or more where full syllables and words become recognized and comprehended. There are automated ways to do Morse code that include software that copies Morse and keyboard sending using a computer. *see: http://www.dxsoft.com/en/products/cwget/*

2. **AM means Amplitude Modulation**. This is the oldest form of voice modulation of a radio carrier wave. It is essentially the voice audio waveform superimposed onto a Radio Frequency carrier waveform as amplitude intensity changes.

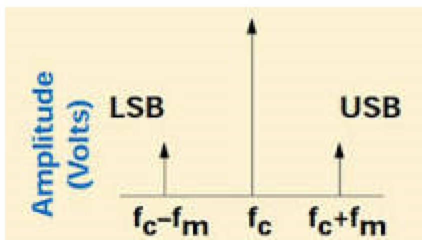


- The top portion of the image above shows the "modulating" signal which would normally be voice or music. In this case, it is represented by a steady modulating tone frequency, eg. 1000 Hz. The bottom trace is the resulting carrier waveform at 100 % modulation. Other than 100% AM modulation would look something like the following series of waveforms:



- As we indicated in the presentation notes on Rules and Regulations, it is necessary that an **amateur radio station using AM be able to determine by measuring equipment that the AM modulated signal is maintained under 100 % modulation.** Exceeding 100 % introduces distortion and creates interference beyond the bandwidth normally taken up by a properly adjusted AM transmitter.

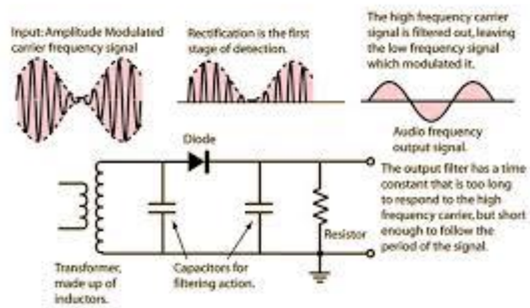
- Amplitude Modulation in the previous oscilloscope tracings have been viewed in the **"amplitude vs time" domain.** To fully appreciate AM (and other signals), we should view them also in the **"Frequency Domain".** An AM signal modulated with a steady 1000 Hz tone frequency will actually result in **3 discrete RF signals** being generated; these are the carrier frequency and the lower and upper sidebands. In this example, the lower sideband signal will be 1000 Hz below the carrier and the upper sideband will be 1000 Hz above the carrier if there is a steady 1000 Hz tone modulating the AM transmitter.



- Assuming the AM transmitter has **100 watts RF carrier output power with no modulation**, then with 100 % modulation applied, the carrier wave signal will be reduced to 50 watts and **each of the 2 sidebands** (upper and lower) will have 25 watts power apiece. **The overall power of the transmitter still remains 100 watts (50+25+25).**

- **The actual bandwidth of an AM signal is 2 times the maximum modulating frequency**. In AM broadcast radio, the maximum modulating frequency is 5 kHz giving a maximum signal bandwidth to 10 kHz. **In amateur radio, the overall bandwidth allowed on most amateur bands is 6 kHz (see RBR-4, column II, Schedule I, page 5).** This allows a maximum modulating frequency of 3 kHz for an AM signal; this should sound fine for voice speech, but would limit the high frequency audio fidelity for good music transmission.

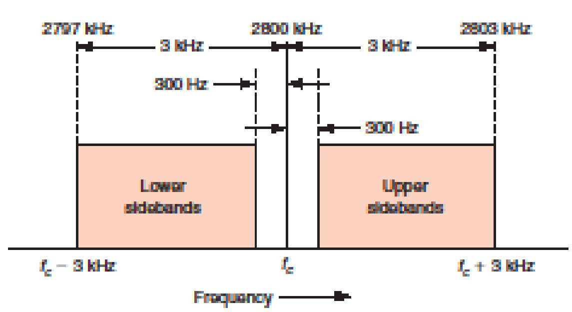
- AM is demodulated easily using a diode detector.



- **AM is no longer popular for amateur radio** communications and has largely been replaced by Single Side Band (SSB) voice.

3. **Double Sideband (DSB suppressed carrier) voice modulation is a derivative of AM.** **<u>DSB is AM with the carrier removed</u>** from the transmission. In a **fully modulated AM signal, 50% of the transmit power is taken transmitting the carrier**. **<u>If that power reserve in the transmitter was used to further amplify and put power into the sidebands, a much more efficient transmitter could be realized.</u>** Simple circuitry can produce a DSB signal. The bandwidth remains the same as an AM signal but the carrier is greatly reduced in amplitude by 40 to 50 dB. **<u>When there is no modulation input to a DSB transmitter, there is essentially no RF output.</u>** For reception, however, **simple diode detection will <u>not</u> do the job**, instead; the **<u>missing carrier</u>** must be **<u>re-inserted by the receiver</u>** by an oscillator called the **<u>Beat Frequency Oscillator (BFO)</u>** similarly needed for reception of CW signals.
   Understanding DSB is necessary for <u>Question: B-003-012-006</u>

4. **<u>Single Sideband (SSB) is a further improvement to DSB</u>**. SSB is the most popular analogue voice mode of modulation used by amateurs radio operators on the HF bands. **SSB is like DSB but removes not only the AM carrier, but also one or the other AM sidebands**. This is typically done with highly selective filtering in the transmitter circuitry. **<u>Only one sideband is transmitted and is necessary to convey full voice information.</u>** All of the transmitter RF output power capacity can be applied to the transmitting one **single sideband.** Compared to 100 watt AM transmitter where one and the other of the two sidebands are transmitted to a maximum of 25 watts, a transmitter of the same capacity can then transmit a single sideband at 100 watts if the other components of the AM signal are not transmitted. This gives a **<u>SSB transmission a 6 dB advantage over an AM transmission of the same transmitter power.</u>** Either the Upper or Lower sideband can be transmitted. And compared to an AM or DSB transmission, **<u>only half the bandwidth is required for SSB and 2.7 kHz suffices for good communications voice quality</u>**. This allows **<u>twice as many SSB signals to occupy a given amateur band allocation</u>** providing all that are **<u>using the same band, operate on the same sideband</u>**, that is. all be on Lower Sideband or all be on Upper Sideband. **By convention, Lower Sideband (LSB) should be chosen on the 160, 80 and 40 metre ham bands and Upper Sideband (USB) on the other amateur bands.** On most amateur band transceivers, USB or LSB are selectable by the user.



- **When receiving SSB**, like reception of CW or DSB, **the suppressed carrier** (that would be present in an AM transmission) **must be re-inserted**, this is **the function of the BFO in the receiver.** Switching in this BFO on most modern communications receivers or transceivers is automatic when SSB or CW modes of reception are selected. When tuning in a SSB voice signal, if tuning is not right-on, then there is not the proper separation of the injected signal from the BFO in relation to reception of the desired SSB signal. Such errors in tuning the signal will result in the voice not sounding natural; it may sound too high in pitch or too low. Trying to tune in an SSB Upper Sideband signal while the radio is selected in LSB or vice versa, will not work. The result will be all high frequencies of the voice audio will be low frequencies and vice versa which cannot be resolved as intelligible speech. If you get it wrong, switching sideband selection should make it right.

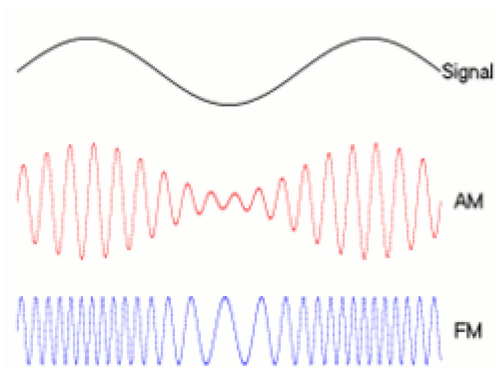
- When in the SSB mode of operation, the frequency dial of the receiver (or transceiver) should show the frequency of the missing carrier of transmission as if you were in AM mode. In the case of using USB, the single sideband voice RF energy will extend upwards by approximately 3 kHz. So, if you **are close to the top edge of the band allocation**, be careful, your dial may indicate you are within the band limit, but **your SSB modulation may be outside the band and that is a violation of the rules**. The same principal would apply to the bottom edge of an amateur band allocation if you were using Lower Sideband. Below illustrates being close to the upper edge of the 20 metre band at 14.350 MHz.

```
          USB Signal out of band
              ^^^^^^^^^
  |--------|--------|
.347   14.350   .353
```

5. Frequency Modulation (FM)

- Frequency Modulation, as the name implies, uses an instantaneous change in frequency **plus and minus** the carrier frequency of the transmitter that follows the modulating waveform frequency. The **amount of the frequency change** called **deviation** is determined by the instantaneous amplitude of the modulation signal. The **louder you talk, the greater the deviation** within the **maximum limits** imposed by the **deviation control setting** on the FM radio transmitter.

  This animation shows the difference between AM and FM. (cont'l click to see animation)



- In amateur radio, FM is popular on the VHF and UHF bands where the rules permit wider emission bandwidth. Most repeaters operate using FM. The bandwidth of FM modulation is determined by the formula 2 x (M + D) where M is the upper most modulating audio frequency for speech which is limited to 3000 Hz, and D is the +/- deviation which is the amplitude of the swing in frequency plus and minus the carrier frequency. For amateur radio communication, the deviation limit is usually set at + / - 5 kHz. Applying the formula results in a Bandwidth calculation for modulation of 16 kHz. This is considered Narrow Band FM (NFM). For broadcast FM radio, much wider bandwidth is required because the deviation is + / - 75 kHz and the upper modulating frequency is 15 kHz (for high fidelity). The required BW for an FM broadcast signal is 180 kHz which is considerably wider than an AM broadcast signal BW of 10 kHz or NarrowBand FM (NFB) used for amateur communications.

- FM transmitters must transmit full carrier power at all times throughout the transmission cycle; this contrasts to SSB transmissions where RF power is only transmitted in response to the amplitude of the audio waveform. In between the syllabic content of the speech, RF power is not transmitted; this makes the drain on batteries for portable operations much less when transmitting Single Sideband compared to FM or AM.

- FM however, has it merits in reception; the receiver has an over-amplified "limiter" stage that effectively distorts the received signal waveform by clipping off the amplitude variations from sources of interference before the FM detector stage. This has no effect on the quality of the recovered audio which is dependent only on frequency variations of the signal; the result is a considerable reduction of interference from noise that may otherwise be on the received signal without the limiter stage. As well, the **signal to noise** ratio (SNR) is much improved over AM depending on the modulation level and deviation of the FM signal. For voice communications, FM compared to AM has a 5 to 15 dB improvement in SNR ratio.

- FM communications receivers also have a **squelch circuit** that **mutes the speaker** (or headphones) **when the receiver is not receiving a signal**. Because of the overly high amplification in the limiter stage, considerable internal receiver noise is received between the active reception of a FM signal. The squelch uses this noise to activate the audio switch for muting the receive audio. When the **FM receiver receives a signal**, the **noise "quiets**" significantly and the squelch circuit responds by opening the speaker circuit for listening to the channel.

6. Digital Modes

- Over the past few decades with the advent of computer and digital technology, amateur radio developers have created many digital modes used by amateur radio operators over the air-waves. One of the pioneer digital modes was RTTY. There are many more digital modes discussed here; however, what follows are the main ones used today, or those addressed on the amateur exam.

RTTY

- RTTY means Radio Teletype. It was originally used by radio amateurs using electo-mechanical teletype machines that became surplus from the Telegram companies like Western Union and CNCP. **RTTY uses a 5 bit "Baudot" code**. For RTTY, the radio amateur would use Frequency Shift Keying (FSK) to transmit the ones and zeros of the **5 bit Baudot** code serially and then at the receiving end, an electronic modem (usually home built at the time) would translate the resulting warbling tone sounds into the necessary electrical pulses for the TTY machine.

Today for RTTY, we use a computer and software to do the same thing; the **modem being the computer sound card**. The over-the-air, two-level FSK signals are known as **mark and space**; these convey the 1's and zeros of the serial code. The FSK shift is 170 Hz and is created by modulating an SSB radio with audio (modem) tones at **2295 Hz tone for Space** and 170 Hz down to **2125 Hz for Mark** and selecting Upper Sideband (USB) mode on transceiver. RTTY with a **170 Hz shift between Mark and Space will occupy less than 500 Hz bandwidth**. ***See question B-003-015-007 .***

- Re **Mark and Space** in text above, ***see question B-003-015-008***

- *A computer RTTY application is MMTTY, available at: http://hamsoft.ca/pages/mmtty.php*

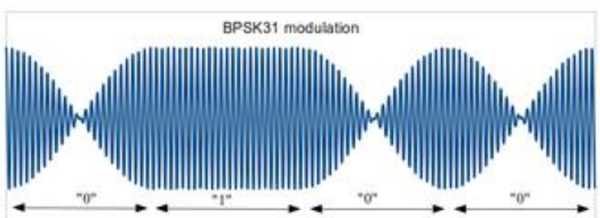
- *RTTY is popular during RTTY specialty contests. Go see : http://www.cqwwrtty.com/*

AMTOR

- **AMTOR** is an improved type of RTTY mode that was popular during the 1980's but is little used by the amateur radio community nowadays. However, there remains one significant question about Amtor in the exam bank of questions***. See question B-003-015-010.*** The ARQ mode referred to in the question would be used to carry on an exchange of communications between the two stations to ensure errors in transmission were detected and data automatically repeated to get it right. More can be read about AMTOR at: *http://en.wikipedia.org/wiki/AMTOR*

PSK 31

- PSK 31 (31 baud) has become a very popular computer-soundcard generated mode used primarily by radio amateurs to conduct real-time keyboard-to-keyboard chat sessions using specified frequencies on HF amateur bands. The mode is very low speed data using a variable length **vari-code for character encoding**. PSK 31 uses **Binary Phase Shift Keying** which means, the phase of the tone used for generating PSK 31 is reversed 180 degrees for a binary data element of **zero** or remains with no phase shift for a binary element **1** for each 32 ms symbol intervals. Each time there is a phase shift, the modulation also reduces to zero in amplitude to eliminate key click interference to other radio users on nearby frequencies. **PSK 31 can be applied to modulate a SSB** radio most typically set to USB. **PSK 31 occupies very little Bandwidth** typically requiring less than 100 Hz; many side by side contacts can happen without mutual interference within the 2.7 kHz bandwidth required for a single SSB voice contact. **PSK 31 works well even at very lower power levels (QRP)**.



- By amateur convention, the following table shows the accepted standard amateur frequencies for PSK 31 operation.

Frequency MHz	Band
1.838	160
3.580	80
7.040	40
10.142	30
14.070	20
18.100	17
21.080	15
24.920	12
28.120	10
50.290	6

- A popular PSK 31 computer application is "DigiPan" available at: http://www.digipan.net/

AX-25 Packet Radio

- Amateur Packet Radio was developed in the early 1980's using an open source AX-25 protocol. This protocol was robust based on error detection and automatic resending of data not received correctly and not acknowledged by return packets much the way the internet works today. AX-25 is a data link layer and works in a similar fashion to the way ethernet networking works.
- The AX-25 protocol has a **"Connected"** mode of operation which supports exclusive terminal to terminal exchange of information between two stations. It also provides a **unconnected** or

"Monitor" mode that allows all to see the AX 25 traffic on the radio channel. ***See questions: B- 003-015-001 and B-003-015-002*** .

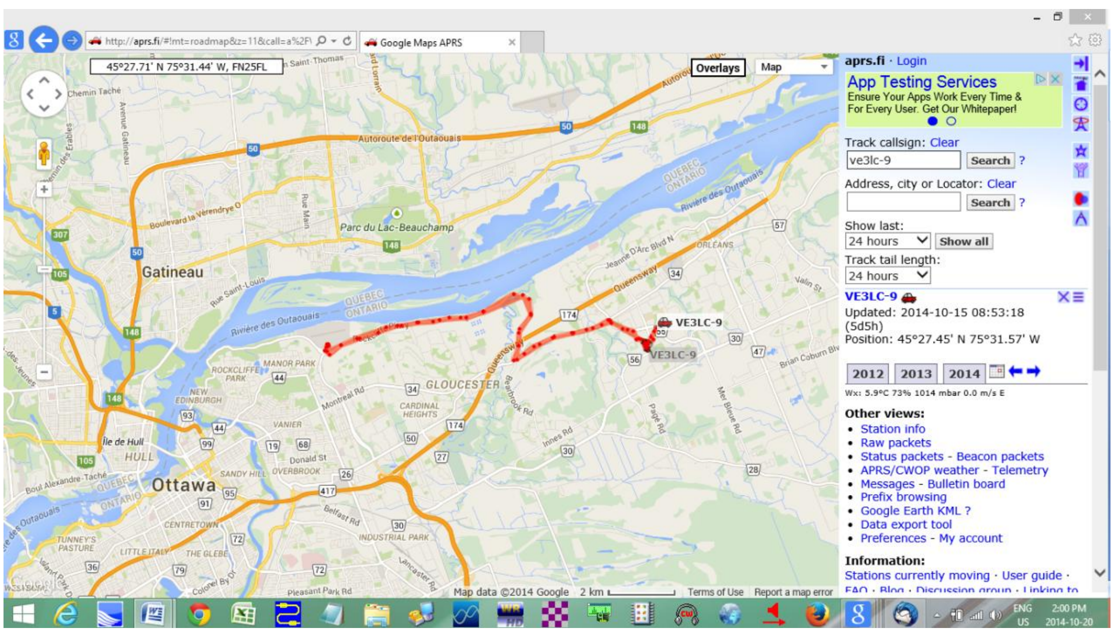
- The AX-25 packet radio protocol incorporates a Network Layer that is a way of connecting packet radio stations so data can be sent (and relayed) from station to station over long distances. The store and forward data through a AX-25 station is known as operating as a **"digipeater".** ***See questions B-003-015-003 and B-003-015-004*** .

- The AX-25 protocol was originally implemented using **smart hardware** called **a TNC (**for **Terminal Node Controller)**. The **TNC** and its internal modem provides **physical connections to the microphone and speaker audio and PTT function of the radio. (see question B-003-015-006)** It also provides connections to the **Terminal** (or computer with Terminal software) using **ASCII**. ASCII is the standard character transmission code for computers communications. **ASCII means "American Standard Code for Information Interchange"**. ***The RTTY Baudot code is NOT used in AX-25 packet radio***. ***See questions B-003-015-008 and B-003-015-009*** .

- The AX-25 protocol can be fully implemented now with software on a PC computer and is part of most Linux releases.

- Today, AX-25 is primarily used now on VHF for **APRS** (meaning **Automatic Packet Reporting System}**. APRS works on a standardized frequency 2 metre band frequency of **144.390 MHz** in North America.. **The over-the-air data rate is 1200 baud**. The system is a network of digital radio repeaters **(called digipeaters)** and radio-internet gateways stations for relaying and transferring the data to select computer servers throughout the world. APRS is used for short text messaging, weather reporting, and position reports using GPS receivers. The entire system is constructed, used and maintained by amateurs for the fun of it. Many amateur radio operators beacon out their position automatically while motoring along; this can be viewed on sites such as ***< aprs.fi >.***

- Here's my track to the Aviation Museum and back home:



- The installation in the car to achieve this position beaconing is a small **AX-25 packet TNC modem** (with the smarts in it, see: http://www.byonics.com/tinytrak4/) that **inputs raw position data from an external GPS** receiver and outputs **unconnected AX-25** structured data to the radio as modem audio tones to the 2 metre FM mobile radio **microphone input** while asserting a PTT function to make the radio transmit as required. ***See questions B-003-015-005 and B-003-015-006 .***

- WinLink Express is an email Client application that works with WinLink system that is a worldwide Email service exclusively for radio users. You must have a radio call sign (amateur or otherwise) to have a Winlink account. I am VE3LC@winlink.org .

- WinLink Express works with a Packet Radio TNC hardware but also provides directly, a HF data mode called Winmor that works through an internal or external computer sound card as a modem to interface with a HF SSB transceiver.

- Many radio amateurs around the world have established "gateway" stations on various HF bands and frequencies that feed the WinLink mail servers through an internet connection. There is a 2 metre packet WinLink gateway here in Ottawa.

- Although the WinLink system can handle email attachments, the data rate is very slow and should be used for short email text messages.

- Of course, like all amateur radio operations, the WinLink service is free of charge.

- For more information and download WinLink Express, goto: *http://www.winlink.org/RMSExpress*

JT 65 and JT 9 Weak Communications (and now FT-8 and FT-4)

- These modes are especially designed for working 25 dB below the noise floor. They occupy a very narrow bandwidth and transmit symbol information based on transmitting and receiving small variations in transmit frequency. These transmission modes are the creation of **Nobel Laureate, Joe Taylor, K1JT** . JT 65 was especially designed for Moon Bounce communications but now has a wide following by QRP enthusiasts on HF. A complete transmission takes 1 minute to transmit up to 13 characters of information. A full exchange between the other party takes 2 minutes and must be time synchronized accurately to UTC time. Transmitting doesn't start until being right on the minute. This mode uses a computer application and interfaces to the radio much the same as other computer software of digital modes communication. The software for JT65 - JT-9 is available at: *http://physics.princeton.edu/pulsar/k1jt/wsjtx.html*

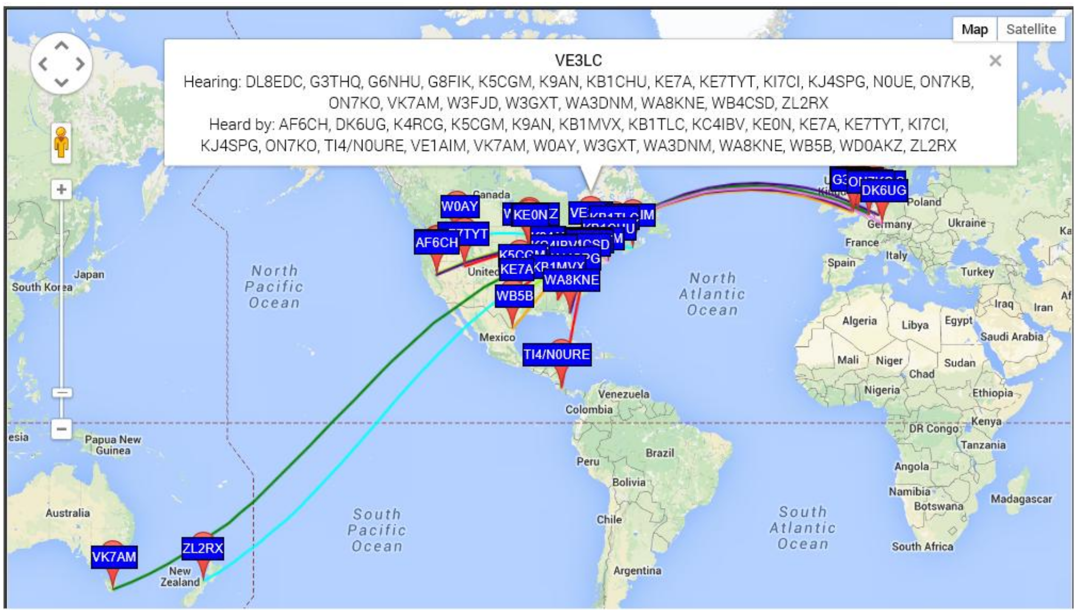
- The JT-65 and JT-9 modes have now been superseded using the same software application by modes called FT-8 and FT-4. The development never stops!

WSPR (Whisper) Weak Signal Propagation Reporter

- Another creation of K1JT is WSPR. This is a one-way beacon mode for low power propagation studies. WSPR stands for Weak Signal Propagation Reporting. *The digital application can be download at: http://physics.princeton.edu/pulsar/k1jt/wsjtx.html*

- You load the application with your call sign, grid square (for location) and the power you are using in dBm. As an example, 5 watts = 37 dBm. Your computer running this application must be accurately time synchronized to UTC within a couple of seconds. The computer running the WSPR software interfaces with your low power (QRP) transceiver and listens on a prescribed WSPR frequency determined by the application through "rig" control of the transceiver. Transmissions are on-the-minute and last 1 minutes and 50 seconds. Receive cycles must coincide exactly to other transmit cycles that must start on-the-minute. For any particular station, transmit and receive cycles are randomized to ensure there are listening stations when there are also transmitting stations. All reception received by your station as well as other stations hearing your transmissions are sent automatically by the WSPR application software over the internet to a WSPRnet server. You can see the results at: http://*wsprnet.org* as to who and where other stations are receiving your signal. It's a great way to see how low you can go in power and still be heard at faraway places around the world.

- Here is a computer screen capture of paths of propagation I had over a 12 hour period on the 20 meter band using my 1 watt Peaberry V2 SDR transceiver using the WSPR mode.



- **<u>Digital Voice</u>**

- Some proprietary digital voice technology is used by the amateur community on amateur band allocations. This includes P-25, D-Star and DMR and Yaesu C4FM which can be investigated separately from information on the net.

- One open source, narrow bandwidth digital voice application that can be used with interface to an HF SSB transceiver is FreeDV. The computer application and information is found at: **freedv.org**

Amateur Television (ATV)

- There is some mention of TV and Amateur TV in the bank of questions. Some exclusive radio amateurs have been involved over the years in transmitting TV imagery over the amateur bands. In the past, this has involved conventional analogue NTSC TV used by the North American broadcasters and only recently, has been converted to the ATSC digital standard. Radio amateurs call this "Fast Scan" TV as opposed "Slow Scan" TV. Enterprising radio amateurs exchanged NTSC video transmissions typically using the 430 to 450 and 902 to 928 MHz amateur spectrum as the rules for these bands permitted the high bandwidth (up to 12 MHz) necessary for real time video. A NTSC transmission takes up to 6 MHz of bandwidth per channel of video.   *Refer to questions B-001-016-009 and B-001-016-010 where there is a mention about fast-scan television and ATV in this regard.*

Slow Scan Television (SSTV).

- In order to transmit imagery on the HF amateur bands with limited bandwidth, a standard for "Slow Speed" television was developed for the amateur community by transmitting a low resolution picture frame over 8 seconds. The bandwidth required was less that 3 kHz and could be easily accommodated in a SSB voice channel. With the advent of computers and digital picture files, software was developed to send and receive the Slow Speed TV standard.

For more information see: http://en.wikipedia.org/wiki/Slow-scan_television. The MMSSTV software is available at: http://hamsoft.ca/pages/mmsstv.php and interfaces to HF SSB radio in a similar fashion as digital modes.

There are frequent SSTV transmission from the International Space Station (ISS) on the 2 metre amateur band using FM modulation. It is good sport to receive this promotional imagery from the ISS as it orbits around the world.

<u>Question B-001-016-010 is the only place in the bank of questions where SSTV is mentioned.</u>

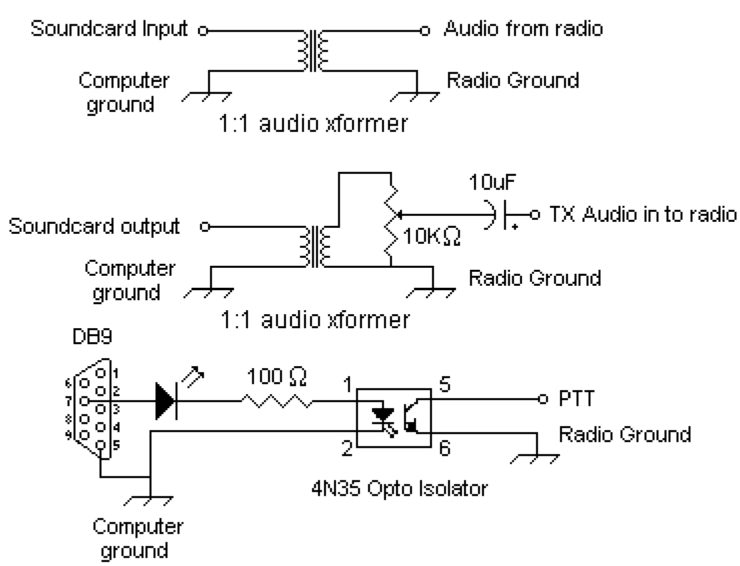
<u>Digital TV.</u>

- There are already amateur radio operators transmitting ATSC and DVB digital TV using SDR (software define radio) technology. There is now a 10 MHz to 6 GHz SDR transceiver available called the "HackRF One" that has been used for DVB video transmissions by local hams operating on the 430 to 450 MHz amateur band. We expect this will be commonplace technology for amateur experimentation and use in the near future. *See: http://www.nooelec.com/store/sdr/hackrf.html*

Interface to the HF SSB transceiver

- Digital modes of operation are most often implemented through Windows, Apple or Linux based computers running appropriate specialty software that has been developed over the last decade or two and is generally available as Free Ware. Some of these have already been identified in this section. For a digital mode to be passed by way of an analogue path of communications such as an SSB transceiver, a **"modem"** (modulator/demodulator) is required to convert digital signals to analogue signals and vice versa and this is nicely handled by the **sound card technology** in consumer computers. Also, software control of a computer **serial "COM" port** can easily be used to provide the necessary **PTT (transmit) function to a radio**. Based on this, a simple circuit interface of computer to HF SSB transceiver is shown:

Computer to Transceiver Interface



- Or, more elegant is to use a product developed for the purpose that includes an external USB coupled sound card circuit for the computer and VOX to assert the PTT function to the radio.

- Many new amateur HF radios now have “sound card” technology as part of their internal design. These modern radio transceivers provide a single USB cable connection to the computer to allow direct interface of radio when using the various digital mode software applications available to the radio amateur.