Amateur Radio Using Digital Modes

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Summary

You want to play with wireless communications and heard that getting an Amateur Radio license expands the spectrum available to you to transmit on? That's great but experimenting is all you want to do and any communication with another "ham" you'd like to keep "short and sweet" and to the experiment at hand. You want to have fun but not join a cult. Playing with the various digital modes of communications used in Amateur Radio can be a good starting point to ease into the hobby both cheaply and at a comfort zone of human interaction desired.

This document is a tutorial introducing Amateur Radio Digital modes. We will first start with understanding the technical fundamentals, describe various digital modes and their uses, and then provide a list of exercises that guide you through using some digital modes with a simple setup you can build with a laptop, open-source software, and around $65 USD in hardware.

The assumption is you have an interest in Amateur Radio and have recently attained (or will be testing for) an Amateur Radio Technician class license (US) or similar license in your home country that permits you to use the digital modes described and the frequencies covered in this guide.

This document and other materials to help you prepare as well as use during the workshop are available at the following URL:

http://amateur-radio.io/hope-workshop

Before you begin and other Disclaimers

To perform any of the exercises within this tutorial you either MUST have an FCC Technician Class license or greater or perform the exercises under the supervision of someone holding an FCC Technician Class license or greater agreeing to act as control operator.

Workshop attendees are also required to have the pre-requisite hardware listed at this Amazon Idea List Link. Know the workshop has been tested with this kit.

We may have extra pieces of radio equipment for use by those without an FCC issued Amateur Radio license under the supervision of an FCC licensed Amateur Radio operator serving as control operator.

Finally, the material within does not present itself as a detailed authoritative guide on the topic of Digital Modes. In some cases, we take the most expedient route in conveying an idea at the sacrifice of some technical detail to avoid confusion. This material is structured as an introductory workshop providing a path of least resistance to experience using Digital Modes and plant the seed of self-discovery to continue your own investigation.

Enjoy !

- Joe, NE2Z

Overview of Amateur Radio

Let's first ground ourselves on what our limitations are when it comes to the purpose of Amateur Radio and permitted content for the spectrum we are using.

- Amateur Radio is a popular hobby and service that brings people, electronics, and communication together.
- It uses radio frequencies designated for licensed amateur radio operators for non-commercial exchange of messages, wireless experimentation, self-training, private recreation, contesting, and emergency communications.
- Encryption is not generally permitted.
- Is the only hobby governed by international treaty.

Illustration 1: Technician Class Privileges for VHF/UHF

While the FCC regulates what frequencies and where modes are used by Amateur Radio operators, this gets broken down further as informal agreements among Amateur Radio operators as to where specific modes are used. These informal agreements are referred to as Band plan or Considerate Operators Guide.

2 Meters (144-148 MHz)

144.00-144.05	EME (CW)
144.05-144.10	General CW and weak signals
144.10-144.20	EME and weak-signal SSB
144.200	National calling frequency
144.200-144.275	General SSB operation
144.275-144.300	Propagation beacons
144.30-144.50	New OSCAR subband
144.50-144.60	Linear translator inputs
144.60-144.90	FM repeater inputs
144.90-145.10	Weak signal and FM simplex (145.01,03,05,07,09 are widely used for packet)
145.10-145.20	Linear translator outputs
145.20-145.50	FM repeater outputs
145.50-145.80	Miscellaneous and experimental modes
145.80-146.00	OSCAR subband
146.01-146.37	Repeater inputs
146.40-146.58	Simplex
146.52	National Simplex Calling Frequency
146.61-146.97	Repeater outputs
147.00-147.39	Repeater outputs
147.42-147.57	Simplex
147.60-147.99	Repeater inputs

Notes: The frequency 146.40 MHz is used in some areas as a repeater input. This band plan has been proposed by the ARRL VHF-UHF Advisory Committee.

Illustration 2: 2 Meter Band plan

Radio Communication

There are numerous choices in what digital modes to use. To understand their differentiation let's start with some radio communication fundamentals to understand what digital modes are best used where and why.

Modulation

Continuous Wave (CW)

Communication starts off with a radio wave carrier signal (aka carrier signal) that we impart an intelligence onto. The simplest form of intelligence we can impart is simply turning the carrier on and off in some rhythmic fashion. CW is the simplest form of communication with the on-off rhythm being Morse Code. CW is arguably the original digital mode.

Amplitude Modulation (AM)

While turning a carrier on and off rhythmically gets the job done albeit slowly, we could instead impart an audio signal on top of the signal. Varying the amplitude of the carrier signal with audio is AM. A refinement of AM that makes efficient use of power and bandwidth is Single-Sideband (SSB.) More about this mode will be discussed in the next section.

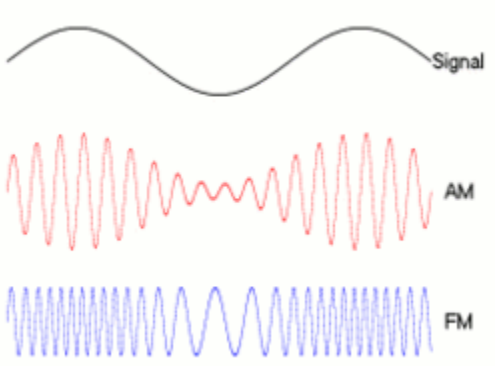

Illustration 3: Audio signal carried by AM and FM (source: Wikipedia)

Frequency Modulation (FM)

Varying the frequency of the carrier signal with audio is FM. Each has advantages/disadvantages according to the radio spectrum they are used on.

Bandwidth

Another dimension to our communication is how wide our resulting signal is measured as bandwidth. AM modulation produces upper and lower sidebands on either side of the carrier signal which can lead to a total bandwidth twice the highest audio signal, around 6 KHz.

SSB is a refinement of AM that makes efficient use of power and bandwidth by suppressing the carrier signal and one of the side-bands sending either Lower Sideband (LSB) or Upper Sideband (USB.)

To give you context on bandwidth sizes, here is a list of modes and their average bandwidth.

- FM 15 KHz
- AM 6 KHz
- SSB 3 KHz
- CW 100 Hz

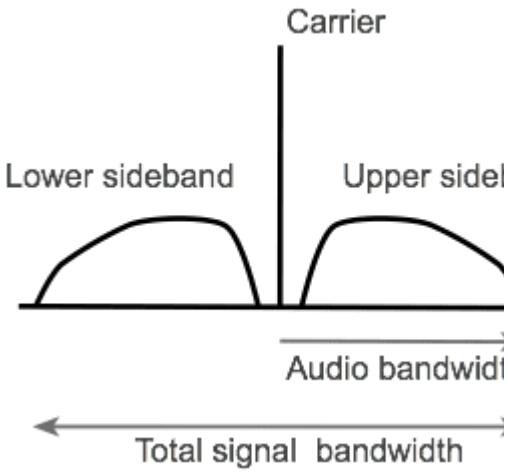

Illustration 4: AM Signal Bandwidth

With radio spectrum a precious limited resource, the bandwidth of a signal limits how many simultaneous communications can occur within a given piece of spectrum.

Performance

Radio waves travel across an atmosphere fraught with natural and man-made phenomenon that can impact the integrity of that signal. If you've listened to AM radio before/during/after a thunderstorm you hear various noises interfering with your ability to hear a song or what is being said. Listen in the evening anf you may hear signals fade in and out according to upper atmospheric conditions. Mind you, these radio stations are using kilowatts of power using Amplitude Modulation consuming significant bandwidth.

When we talk about performance in Amateur Radio communications, we are looking at the best way to communicate intelligence expediently and reliably without loss of integrity across varying atmospheric conditions using minimal power and making efficient use of radio spectrum. Performance is where digital modes excel.

Digital Mode Modulation

Digital communications is rooted in our ability to communicate 1's and 0's in some fashion. Methods include:

- Keying a signal on and off as with CW
- Shifting the frequency of a signal with one frequency represent 0's and another representing 1's
- Differing audio tones upon a signal with one tone representing 0's and another representing 1's

Let's dig into this further.

Frequency Shift Keying (FSK)

FSK is a frequency modulation scheme in which intelligence is transmitted digitally as frequency changes in a carrier signal. One frequency may represent 1's (referred to as the MARK frequency) and the other frequency as 0's (referred to as the SPACE frequency.)

The first digital mode to employ this method was Radio Teletype (RTTY.) RTTY was an evolution in the 1920's of early landline teleprinter communications that began in the mid-1800's. For RTTY the signal is shifted 170 Hz. More about RTTY later.

Audio Frequency Shift Keying (AFSK)

AFSK is a modulation scheme in which intelligence is transmitted digitally as audio pitch changes on a carrier signal whether it be AM or FM. Audio often transitions between two tones representing 1's and 0's respectively.

AFSK vs FSK

While AFSK allows you the flexibility to use sound cards on computers to generate tones as used by various digital modes, you need to insure your audio levels (sending and listening) are set correctly to insure you do not overdrive audio and generate distorted signals. When levels are set correctly, AFSK gives you the same signal as FSK.

All of the digital mode usage in this workshop will use AFSK.

Quick Overview of some Digital Modes

Modulated Continuous Wave (MCW)

We mentioned CW as the first digital mode whose method of communicating intelligence is simply turning the carrier on and off in the motion of Morse Code. Another method of sending Morse Code is using Modulated Continuous Wave. With MCW we send an on/off audio tone in the rhythm of Morse Code. An example of MCW on FM is hearing a VHF/UHF repeater ID in Morse Code.

Though MCW is switching between audio tone and off as compared to two different tones, you could consider MCW a form of AFSK. Important to note that within the US, MCW cannot legally be used on HF bands but can be used on VHF and higher frequencies.

Radio Teletype (RTTY)

As mentioned RTTY is an evolution of early landline teleprinter communications that began in the mid-1800's. RTTY began around the 1920's using FSK with a signal that shifted 170 Hz. One frequency represents a 1 (referred to as the MARK frequency) and another frequency as 0 (referred to as the SPACE frequency.)

Illustration 5: Teletype from the 1950's. Out of view is Modem and Radio

As a method of keyboard-to-keyboard communication, RTTY used a five-bit code called Baudot to represent letters, numbers, punctuation, and some control characters. Since the output was printed on rolls of teletype paper, some of the control characters were necessary to signify carriage return and linefeed of the paper. There was control character for ringing a bell on a teletype as well.

Over time teleprinters were replaced with terminals and then eventually with PCs the use of ASCII replacing Baudot. Since AFSK gives you the same signal as FSK, dedicated RTTY modems of the past became replaced with sound cards on PC's. As a reminder when using AFSK, audio levels are critical for proper reception and clean transmission of signals.

Phase Shift Keying 31 Baud (PSK31)

Many of the digital modes that are popular today are born as PC implementations using sound card and radio interfaces rather than implements as dedicated hardware devices like CW and

RTTY. PSK31 uses amplitude and phase modulation converted to audio. We say phase modulation because the phase shift of the signal determines whether you are sending a 0 or a 1 (180-degree phase shift and no phase shift respectively.)

PSK31 is designed as a keyboard-to-keyboard communication protocol so its data rate of 31 baud is designed to be close to typing speed. The mode is very efficient as we will learn during our lab exercises.

MT63

Up till now we've been covering modes used mostly on HF that are slow and have no error correction. MT63 is a digital mode used on VHF/UHF by Amateur Radio Emergency Services organizations for message handling. The mode provides Forward Error Correction (FEC) and 2 KHz of bandwidth providing transfer rates of 1 KB/minute. I know the transfer rate does not sound like much compared to a WiFi connection but the range at this rate with an omni-directional antenna depending on terrain, go from tens of miles to almost one hundred.

Franke-Taylor design, 8-FSK modulation (FT8)

FT8 is a popular FSK mode designed for weak signal communication despite unfavorable conditions such as low solar activity, high RF noise, or low transmit power (often referred to as operating QRP.)

Beyond the software used to operate this mode, attributes that contribute to this performance is time synchronization and use of fixed time windows - 77-bit message blocks transmitted in regular 15-second periods, consisting of 12.64 seconds of transmission time and 2.36 seconds of decode time, giving a digital data rate of 6.09 bits/sec. In essence each window is sending short, structured text messages (up to 13 characters.) Messages containing callsigns, reports and locators.

Other Digital Modes

You may wonder why there is no mention of (INSERT-TRENDY-MODE) here. That is because to best learn digital mode fundamentals it is best to start by referencing established modes (RTTY and PSK31), modes where asynchronous services have been standardized on (MT63), and emerging synchronous modes and their dependencies (FT8.) Understanding the fundamentals of these modes will help you evaluate future modes and protocols that come along.

Since this is an introductory workshop to digital modes, Packet Radio has been deferred as a more advanced topic, given the depth of material to cover.

About the Workshop

Goal

It's great when things just work right of the box. The goal of the workshop is to help you quickly achieve success in using and building experience in digital modes with minimal investment and effort.

Approach

We start with students building simple VHF/UHF Amateur Radio stations using hardware they have purchased in advance of the workshop. Then students install and familiarize themselves with open-source software packages used for encoding/decoding digital modes. Students will use digital modes to communicate with an instructor station and other student stations. Lab exercises will help students:

- Develop familiarity with popular modes by hearing what they sound like
- Understand the strength and weaknesses of each digital mode.
- Learn relationship between data rates and bandwidth amongst digital modes.

Popularity, availability, low cost, and re-use is why the Baofeng UV5-R was the radio chosen for the workshop. This way if you decide Amateur Radio digital modes is something you do not want to pursue, your investment in radio gear is the same as a freshly minted Technician – an HT for local repeater use.

Caveats

Getting sound levels correct is CRITICAL to success digital modes using AFSK. The software we will be using will give us visual aid in tweaking levels accordingly. Using the VHF/UHF spectrum and low power eliminates band conditions as a variable to be considered in lab exercises. But since we will be using FM, we will be subject to a phenomenon known as the capture effect[1] ,which will interfere with our ability to show how multiple signals simultaneously share a carrier frequency as done on HF with SSB.

1 https://en.wikipedia.org/wiki/Capture_effect

References

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