VHF Contesting in the Age of Digital Disruption

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Introduction

Like many in the current VHF operator community I was bitten by the radio bug at an early age. It started innocently enough. Building a few simple receivers, learning to fix TV's, and spending hours listening to signals from faraway lands emanating from my grandfather's shortwave radio. I received my novice ticket at age 15 just before Christmas and had one of the best holidays of my life making contacts at 10 WPM and marveling at the miracle of wireless communication.

After spending a few years experiencing the thrill of working DX stations near and far using homebrew and Heathkit equipment connected to handbook design dipole wire antenna's, my life changed forever when I accepted a 6M AM transceiver from a local ham that wanted to find a good home for an old trusted rig. It didn't take long before I was well on my way down the dark path - spending endless hours in a basement lab building transverters, amplifiers, Yagi's and inevitably participating in contests, particularly the January VHF SS, for these past 43 years.

VHF contesting has seen many changes over the decades. Grid squares, rovers, new operating categories and ever changing operating procedures have all been met with some initial resistance but soon were embraced providing increased participation and a larger stack of contest certificates mailed out by the league each year. New technology has also played a major role with logging programs, low noise preamps, computer modeled antennas and readily available transverter kits allowing serious VHF and above operators to increase their station band count up to 10 GHz and supercharge their grid totals and cumulative contest scores.

The latest technology innovations, software defined radio and WSJT digital modulation modes, are once again challenging everything we thought we knew about amateur radio communication. FT8 the latest digital format introduced by Joe Taylor K1JT, Steven Franke K9AN, and the WSJT development team has reinvigorated the HF bands including 6 meters and, as evidenced by this year's January VHF SS, dramatically changed VHF contesting from this point forward.

The Evolution of Digital Modes

A Brief History of Digital Protocols

Modern radio began as a form of digital communication with CW transmissions using Morse code on-off keying (OOK). CW is still a popular mode for both ragchew and contest contacts. High speed CW (100 WPM and higher) has been used for VHF meteor scatter contacts while high power low speed CW was the previous standard for the majority of EME contacts.

Landline telegraphy printers that were originally developed in the mid 1800s were reincarnated as radio teleprinters first by the US Navy in the early 1920s and then commercially starting in 1932. Radioteletype (RTTY) using a modified Baudot code and frequency shift keying (FSK) modulation saw expanded usage during WWII and became the digital mainstay of amateur radio following the war as Model-15 teletype machines were retired by AT&T Western Electric and quickly entered the surplus market.

The next digital mode evolution occurred with the introduction of PSK31 in December 1998. PSK31 was developed and named by Peter Martinez G3PLX. It uses 31 Baud Binary Phase Shift Keying of an SSB audio modulated carrier. PSK31 operation became wildly popular since it only required a personal computer (PC) with a sound card and an easy to use freeware program. PSK31's symbol rate of 31.25 Hz was selected because it roughly matches the normal typing speed of 50 words per minute and because it aligned with the 8 KHz sample rate commonly used in sound cards at that time (8000/256 = 31.25). The narrow bandwidth allows approximately 20 simultaneous PSK31 contacts within a 2.7 KHz channel. The low bandwidth and spectrum efficiency of PSK31 enables low power stations to work DX even on a crowded band but with limitations due to its slow speed and limited error correction capability.

PSK31 allows conversational contacts and works well with typical QSB fading. But multi-path propagation can disrupt the signal phase reducing its effectiveness at VHF frequencies. PSK31 is still in use today exclusively on the lower HF bands. However, the number of stations available to work has greatly decreased from its heyday in the early 2000's.

The advent of using a PC sound card connected to a standard radio transceiver generated a number of similar programs and modes such as Hellschreiber, and Olivia MFSK. It has also breathed new life into RTTY which continues to be a popular contest mode.

WSJT was originally released in 2001 with a new digital mode designed for weak signal meteor scatter operation. FSK441 employed multi-frequency shift keying using 4 tones at a data rate of 441 baud allowing a message to be transmitted in 122 milliseconds. The protocol is self-synchronizing eliminating the need for a separate synchronization tone but requiring accurate time calibration of the PC being used to generate and decode messages. FSK441 was ideally suited for 2 meter MS contacts but could be used at almost any time of day to make a long distance contact in the presence of a signal scattering condition.

In 2002, JT6M a meteor scatter mode optimized for 6 meter operation was released. This version also used MFSK modulation but with 43 data tones plus one synchronization tone allowing the full alphanumeric character set and additional symbols to be transmitted. JT6M has a symbol rate of 21.53 baud although the actual data rate is 14.4 characters per second due to the transmit signal encoding.

JT65 was the next major revolution in weak signal digital communication for amateur radio. Initially released in 2003, JT65 was designed for extremely weak but slow varying signals that are typical in troposcatter and EME propagation. JT65 continues the use of MFSK modulation with 65 tones. Its relatively slow data rate and narrow per-tone bandwidth (~ 4 Hz) allows contacts that are below the noise floor. JT65 increases the probability of accurate decodes by incorporating Reed-Solomon (RS) forward error correction (FEC).

Digital signal processing techniques such as Reed-Solomon enhance data reliability by including error correcting code used by a predetermined algorithm in the encoded message prior to transmitting. The message bits are sent multiple times per transmission since an error could occur in any of the samples during reception. Because of the FEC process, messages are either correctly decoded or not decoded at all.

JT65 dramatically improved EME QSO success even for operators using minimal antenna gain and modest transmit power levels. Unexpectedly, its real overwhelming popularity was achieved on the HF bands where operators with severe antenna restrictions and a typical 100 watt multi-band transceiver soon discovered that JT65 allowed them to work DX that was previously unattainable.

Table 1 – JT65 Minimum Usable Signal Levels

JT65 Message Type Minimum S/N	dB
Arbitrary message, including plain text	-24
Call sign in database (Deep Search)	-28
Arbitrary message, with averaging	-29
Message synchronization	-30
Shorthand RO, RRR, 73	-32

From 2004 through 2012 WSJT was packaged as a compilation of different modes with continuing updates and major adaptations. WSJT version 4.7 through 10.0 saw significant changes with each release as K1JT, K9AN and others on the development team experimented and optimized parameters for different propagation types. Fast modes (MSK, JT9, ISCAT) favored Ionospheric and meteor scatter propagation while slow modes (JT65, JT4, JT9, WSPR) worked best with troposcatter, sporadic-E and low Tx power EME contacts.

In 2012 word of WSJT-X began to emerge as the next generation in amateur radio digital code design. By 2016 large scale testing was under way with over 4000 users worldwide. At year end the first full release of WSJT-X v1.7 was announced. It included a new mode - MSK144.

MSK144 was the first major WSJT-X update for meteor scatter communication. It employs the latest LDPC forward error correction coding to improve decoding reliability and was optimized for 6 Meters due to the nature of MS reflections. The duration of a reflected ping has an inverse square relationship to the transmitted frequency. As a result a 2M received ping is only 1/8 as long as a 6M ping. The longer 6M pings allowed the use of coherent demodulation which in turn greatly increases the sensitivity of the detector. MSK144 also included a contest mode and a short message mode to speed up contact completion with short pings (which also helps mitigate the 144 MHz issue described previously).

FT8 followed in July 2017 with the release of WSJT-X v1.8. The new FT8 mode provided sensitivity down to -20 dB, QSOs 4 times faster than JT65 or JT9, auto-sequencing and an option to respond automatically to first decoded reply to your CQ. FT8 is a primary focus of this paper and will be described in greater detail in subsequent sections.

FT8 v1.8 was immediately followed with v1.9 in early 2018 and updated again with v2.0.0-rc1 in September and the 2.0 Full Release at year end. The latest revision, 2.0.1, was released February 26, 2019.

<u>A graphic view of WSJT Protocols</u>

WSJT provides a wide range of modes optimized for different propagation characteristics. The latest WSJT-X modes use the most efficient FEC codes available today which increases the probability of a correct decode.

Low-Density Parity-Check (LDPC) codes were first invented by Robert Gallager in 1963 but were soon forgotten as the computing capabilities of that time were incapable of implementing them. LDPC was rediscovered in 1996 when researchers began looking for an enhancement to the turbo codes used in deep space and satellite applications.

FT8 is designed for terrestrial weak signal contacts. Its short transmission duration and narrow occupied bandwidth also make it spectrally efficient. Up to 20 FT8 stations can simultaneously occupy the same 2.7 KHz channel.

MSK144 designed for meteor scatter has lower effectiveness as frequency increases limiting its usefulness to the lower VHF bands. Although it can be used for random contacts, MSK144 is most effective in a scheduled contact where both operators know the frequency and antenna pointing for the other station.

Along with accurate time calibration, WSJT modes require a stable channel frequency. Most modern amateur radio transceivers provide more than adequate stability at HF and low VHF frequencies. Older and homebrew UHF / microwave band transverters however typically use local oscillator multiplier factors of 30X and higher which can create significant drift with even minor internal temperature changes. An ovenized LO or preferably a GPS locked or other time referenced oscillator is required to achieve reliable frequency stability for the higher bands.

Multi-path propagation which is common at 10 GHz can also severely impact FT8 decodes. Wider BW WSJT fast modes such as JT9G and JT9H have been reported to be very reliable for 10 GHz operation while all other WSJT-X modes were unsuccessful.

Tables 2 and 3 below provide a side by side comparison of the key characteristics for each of the WSJT digital modes. Table 2 groups together the so called “slow modes” which have low Baud rates and longer transmission times. While Table 3 groups together the “fast modes” which have higher Baud rates and typically short transmission times. Figure 1 below shows the waterfall visual displays for a few of the most popular digital modes.

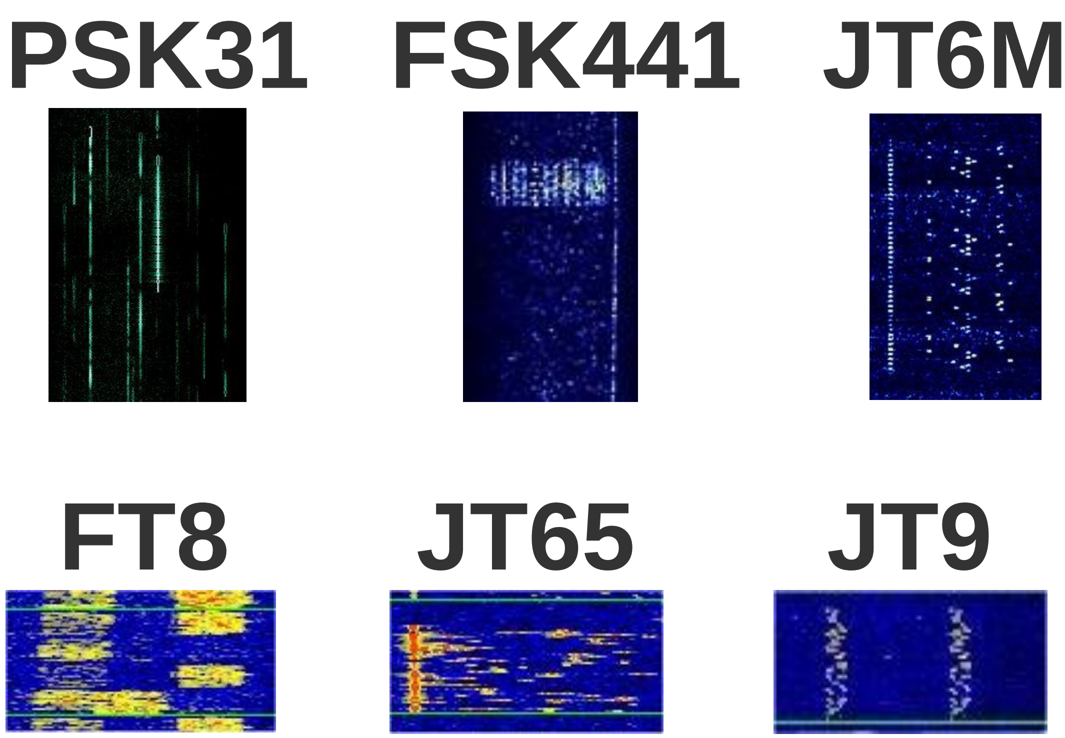

Figure 1 – Waterfall plots of popular digital modes

Table 2. Parameters of WSJT Slow Modes

Mode	FEC Type	Block Code (n,k)	Q	Modulation type	Keying rate (Baud)	Occupied Bandwidth (Hz)	Tx Duration (s)	S/N Threshold (dB)
FT8	LDPC, r=1/2	(174,91)	8	8-FSK	6.25	50.0	12.6	-21
JT4A	K=32, r=1/2	(206,72)	2	4-FSK	4.375	17.5	47.1	-23
JT9A	K=32, r=1/2	(206,72)	8	9-FSK	1.736	15.6	49.0	-27
JT65A	Reed Solomon	(63,12)	64	65-FSK	2.692	177.6	46.8	-25
QRA64A	Q-ary Repeat Accumulate	(63,12)	64	64-FSK	1.736	111.1	48.4	-26
WSPR	K=32, r=1/2	(162,50)	2	4-FSK	1.465	5.9	110.6	-31

Table 3. Parameters of WSJT Fast Modes

Mode	FEC Type	Block Code (n,k)	Q	Modulation Type	Keying rate (Baud)	Occupied Bandwidth (Hz)	Tx Duration (s)	S/N Threshold (dB)
ISCAT-A	-	-	42	42-FSK	21.5	905	1.176	
JT9E	K=32, r=1/2	(206,72)	8	9-FSK	25.0	225	3.400	-23
JT9F	K=32, r=1/2	(206,72)	8	9-FSK	50.0	450	1.700	-22
JT9G	K=32, r=1/2	(206,72)	8	9-FSK	100.0	900	0.850	-21
JT9H	K=32, r=1/2	(206,72)	8	9-FSK	200.0	1800	0.425	-20
MSK144	LDPC	(128,90)	2	OQPSK	2000	2400	0.072	0
MSK144 Sh	LDPC	(32,16)	2	OQPSK	2000	2400	0.020	0

Digital Operating on the HF Bands

The Terrestrial Revolution

Within a few years of its release, JT65 signals began appearing on the HF bands and quickly gained popularity as the digital mode of choice for casual operators. JT65 calling frequencies were established for all bands from 160M to 6M. The open source nature of WSJT spawned a number of alternative software programs that focused on JT65 operating. While a few of these freeware programs had serious bugs, the better ones provided added features and ease of use that allowed even first time users of JT65 to make successful contacts.

The only drawback with JT65 is the length of time needed to complete the full exchange of information and finish the contact. At 60 seconds per transmitted message a complete QSO from CQ to signal report to QSL/73 could take 5 to 7 minutes even with good conditions. This extended time per QSO is acceptable for casual contacts but limits the QSO rates in contest operation so JT65 never achieved serious momentum in the various HF or VHF contests.

FT8 was initially announced in 2012 and the first stable release v1.8 was available in mid-2017. The FT8 transmission period is 15 seconds allowing a complete contact to take place in as little as one minute. Message sequencing was improved and automated which also helped to speed up QSO confirmation and completion.

FT8 Is Eating the World

In short order FT8 started dominating the HF digital channels. Its superior performance provided reliable, efficient DX contact capability in a quarter of the time needed with the previous JT65 mode. Not long after even the most devout "never digital" operators were displaying FT8 contacts on their QRZ log page. In late spring 2018 updates aimed at optimizing FT8 operation for DXpedition use were being rolled out touting a reduced sequence to minimize the number of transmissions needed for a legal contact.

JT65 designated channels have now essentially gone silent as the activity shifted to FT8 and new alternative freeware software such as JTDX are now following the same path as their earlier JT65 predecessors.

Digital Operating on the VHF Bands

VHF Contests – The Problem with Rovers

Early versions of FT8 still were not completely compatible with VHF contest operation. The contest protocol of a 4 digit grid square exchange instead of a signal strength report was available but rover or portable identification was not possible in all cases due to the limited number of bits per transmission. FT8 assumed a 1X2, 2X2, or 2X3 call sign. The number of bits needed to append /R were not available in the early version protocol.

The WSJT-X development team worked tirelessly to modify the protocol by adding two additional bits and other enhancements plus Beta test the new revision 2.0 code before its target release date in early December 2018. A significant downside of the code modifications was that the new 2.0 code would not be compatible with the prior releases. All operators would need to upgrade to the new WSJT-X revision and get familiar with the changes in the roughly six weeks remaining before the January VHF SS contest weekend.

A major information campaign was launched in advance to alert every one of the upcoming release and the need to change over as quickly as possible. Word of the FT8 v2.0 update's availability was well publicized and to their credit the v2.0 code had no significant reported issues. Adoption was almost immediate.

FT8 v2.0 Impact on the VHF SS

The 2019 January VHF Sweepstakes weekend saw poor propagation conditions along with freezing rain and heavy snow across most of the northern and northeast areas of the country. Just a few hours after the contest commenced it became obvious that all of the bands were quieter than normal. This phenomenon continued throughout the contest and was even more pronounced on the higher UHF and microwave bands. Even enhanced E's propagation to southern Florida produced little activity in the CW/SSB portions of 50 MHz.

In the meantime FT8 activity on 50.313 MHz was booming. Record grid counts on 6 meters boosted the score total for many stations that normally can't compete with the high power and better equipped contest stations. The sum total of at least 95% of the RF energy being transmitted at any one moment for the remainder of the contest was concentrated in a single 2.7 KHz bandwidth channel. The other 5% was also using FT8 but on 144.174 MHz. Everything else was negligible.

The release of FT8 v2.0 occurred only a few weeks before the January VHF SS. There was little time to adjust to the overwhelming shift from the previous dominance of CW/SSB activity to almost all FT8 activity that transitioned only a few hours after the contest began. Without experience or guidance non-assisted contest operators had no way to move stations to higher bands. 10 band super stations continued to call CQ but only received a dribble of random contacts above 222 MHz.

At the end of the weekend event most operators realized that they had just witnessed a paradigm shift in amateur radio contesting. Many of the top tier contesters also realized that their cumulative score was considerably lower than past years. Table 4 illustrates the impact of this year's changes in operating behavior on contest scores. The Mount Airy VHF Radio Club better known as the Packrats have dominated the unlimited club category of the VHF SS contest for many years both in number of participants and total score. The 2019 final tally was 40% lower than previous years going back a decade even though the number of logs entered was 18% higher than last year.

Table 4 – Packrat January Contest Scores for the Past 10 Years

Mt. Airy VHF Radio Club January VHF SS Previous Aggregate Claimed Scores		
Year	**Logs Submitted**	**Score**
2019	71	1,138,372
2018	60	1,911,495
2017	65	1,998,637
2016	70	2,238,450
2015	68	2,065,073
2014	68	2,277,747
2013	65	2,659,242
2012	77	2,491,702
2011	67	2,156,784
2010	70	2,699,809
2009	58	1,891,225

Was it the result of conditions, the unforgiving weather, or the single minded obsession to run with the activity on 6M FT8 that caused the drop in scores? It will probably take a few years to truly answer this question since one year does not make a trend. But it is also safe to say that FT8 was and will be a major disrupter of the status quo.

Band Plans

WSJT was originally conceived and developed to optimize contacts in narrowband, specialized propagation modes such as meteor scatter and EME. Joe Taylor K1JT has commented in numerous articles and presentations that the widespread adoption of WSJT modes for HF troposcatter and point to point contacts was an unexpected surprise. This is the reason why all HF frequencies including 160, 80, and 40M use USB instead of LSB.

As each new digital mode (PSK31, RTTY, JT65, FT8, etc.) has taken hold, a single SSB channel slice has been designated for each unique mode. This method of sharing the band makes sense as long as the predominance of CW/SSB modulation continues. FT8 may end up tilting that balance particularly on the VHF bands where a single sideband voice operator typically needs a large antenna and higher power to be successful. FT8 allows lower power, antenna restricted stations, to level the playing field. Therefore the everyday use adoption of FT8 has been much more noticeable on 50 MHz.

As this trend continues it no longer makes sense to pack every station on the band into a single 2.7 KHz channel. The VHF/UHF bands have hundreds of kilohertz of spectrum already specifically assigned for audio modulated signals like WSJT modes. Coordinating expanded band segments for these digital modes will relieve the congestion during contests and provide guidance to operators as they look for contacts on higher bands. Table 5 below shows the currently allocated plans for each band from 50 MHz through 10.5 GHz. The highlighted segments are available for FT8 and other WSJT modes. A consensus plan approved by a designated advisory board or other established body is needed to get ahead of the curve and increase the spectrum and effectiveness of digital mode operating.

Table 5 – FCC / ARRL Band Plans for the VHF and Above Frequencies

6 Meters (50-54 MHz)

50.0-50.1	CW, beacons
50.060-50.080	beacon sub band
50.1-50.3	SSB, CW
50.10-50.125	DX window
50.125	SSB calling
50.3-50.6	All modes
50.6-50.8	Non voice communications

2 Meters (144-148 MHz)

144.10-144.20	EME and weak-signal SSB
144.200	National calling frequency
144.200-144.275	General SSB operation

1.25 Meters (222-225 MHz)

222.10-222.15	Weak-signal CW & SSB
222.15-222.25	Local coordinator's option; weak signal, ACSB, repeater inputs, control

70 Centimeters (420-450 MHz)

432.10-432.30	Mixed-mode and weak-signal work
432.30-432.40	Propagation beacons
432.40-433.00	Mixed-mode and weak-signal work

33 Centimeters (902-928 MHz)

902.075-902.100	CW/SSB	Weak signal	
902.100	CW/SSB	Weak signal calling	Regional option
902.100-902.125	CW/SSB	Weak signal	
903.000-903.100	CW/SSB	Beacons and weak signal	
903.100	CW/SSB	Weak signal calling	Regional option
903.100-903.400	CW/SSB	Weak signal	

23 Centimeters (1240-1300 MHz)

1296.080-1296.200	CW, SSB	Weak Signal
1296.100	CW, SSB	CW, SSB calling frequency
1296.200-1296.400	CW, digital	Beacons

13 Centimeters (2300-2310 and 2390-2450 MHz)

2304.10-2304.300	3 kHz or less	SSB, CW, digital weak-signal
2304.300-2304.400	3 kHz or less	Beacons
2304.400-2304.750	6 kHz or less	SSB, CW, digital weak-signal & NBFM

3300-3500 MHz

Level I - Major Band Divisions			Level II - Sub-Band Divisions			Level III	Suggested	Suggested	
Frequency Range (MHz)			Frequency Range (MHz)			Specific Freq.	Emission Types	Emission B.W.	
From	To	Width	From	To	Width	MHz	(Note 1)	(Note 1)	Functional Use
						3400.100	CW, SSB, Digital		EME Calling Frequency
3455.500	3457.000	1.5					CW, SSB, NBFM, Digital	6 kHz or less	Terrestrial Weak Signal Band - Legacy
						3456.100		6 kHz or less	Weak Signal Terrestrial Calling Frequency
			3456.300	3457.000	0.1		CW, Digital	1 kHz or less	Propagation Beacons

5 Centimeters (5650.0-5925.0 MHz)

FrequencyRange	**Emission Bandwidth**	**Functional Use**
5760.0-5760.1	< 3kHz	SSB, CW, Digital Weak-Signal
5760.1-5760.3	< 6 KHz	Beacons
5760.3-5760.4	< 3 KHz	SSB, CW, Digital Weak-Signal
5760.4-5761.0	< 6 KHz	SSB, CW, Digital Weak-Signal

3 Centimeters (10000.000-10500.000 MHz)

Frequency Range	**Emission Bandwidth**	**Functional Use**
10367.000-10368.300	6 kHz or less	SSB, CW, Digital Weak-Signal & NBFM
10368.300-10368.400	6 kHz or less	Beacons
10368.400-10370.000	6 kHz or less	SSB, CW, Digital Weak-Signal & NBFM

A Delicate Balance – Saving the UHF and Above Bands

Reactions and Proposals

Immediately following the contest a passionate debate began regarding the impact of FT8 on the future of VHF contests. This argument still continues today on the various email reflectors and forums. The discussion has a number of themes but basically boils down to either the participants proclaiming the benefits and communication enhancements provided by FT8 versus the opposite side proclaiming the collapse of activity on the higher bands caused by FT8 which will spell doom for VHF and above contesting as we know it. Both sides of this debate have very valid arguments and a number of well-reasoned ideas to make FT8 more of an asset in a VHF contest rather than the potential instrument of its demise.

Among the ideas to promote full use of the VHF and above bands were the following:

- Increase the points per contact for CW/SSB QSO's
- Increase the multiplier for 222 and higher bands
- Petition the ARRL to establish FT8/WSJT national calling frequencies for all VHF/UHF bands from 6M to 3cm
- Expand FT8 contest activity bandwidth +/- 5 KHz around the established calling frequency to allow stations to spread out and reduce the receiver overload issue caused by everyone being on the same channel
- Add a QSY UP message to the FT8 protocol to help digital stations run the bands
- Establish 222 and above contest activity hours per band on a national level. This would create a mini-sprint for each band within the contest period and hopefully drive higher frequency band activity

There are most likely many more ideas that should be considered but the driving force must be the members of the VHF community. This topic needs to be discussed within every club and shared with like-minded VHF enthusiasts across the country.

Summary

Digital modes have matured and are now mainstream communication protocols that can enhance and invigorate the amateur radio community.

WSJT-X FT8 is a revolutionary and disruptive enhancement to amateur radio communication. The impact of a contest compatible digital mode has been dramatic and has exposed a number of operating issues that need to be addressed to fully embrace the new digital modes without abandoning the higher frequency bands that we have spent so much effort to explore and cultivate. New guidelines and procedures are required to expand the popularity of this new digital mode across all of the available VHF and above band allocations

The recent 2019 January VHF SS was the first test of FT8 in a major VHF contest and should be studied to determine the potential changes need to be made.

The VHF community must work together in conjunction with the ARRL to define new band plans and recommendations needed to assure that digital modes have the necessary bandwidth to be a useful tool in future contests and everyday VHF / UHF and microwave communication.

Digital mode assimilation is nearly complete and it is more obvious than ever that resistance is indeed futile.

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Mt Air VHF Radio Club, February 2019 “CheeseBits”

http://www.arrl.org/band-plan

Acronyms:

EME Earth-Moon-Earth communication	PSK Phase Shift Keying
FEC Forward Error Correction	RS Reed-Solomon
FSK Frequency Shift Keying	Tx Transmitter
LDPC Low Density Paraty-Check	WSJT Weak Signal Joe Taylor
MFSK Multi - Frequency Shift Keying	
MS Meteor Scatter	
OOK On-Off Keying	
PC Personal Computer	