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Tech Saturday

“The Magic of WSJT”

March 7, 2026



**Gloucester County
Amateur Radio Club**
W2MMD

Serving Our Community & Amateur Radio For 67 Years

Established In 1959



What is WSJT?

Origins, Purpose & Design Philosophy

WSJT-X

Weak Signal communication by K1JT – Joe Taylor, Nobel Laureate (Physics 1993). Originally developed for moonbounce (EME), meteor scatter, and other extreme weak-signal paths. Now the standard for long-distance DX on minimal power.

Core Philosophy

Narrow bandwidth + long coherent integration + sophisticated DSP = decode signals far below the noise floor. Traditional SSB needs $\text{SNR} \geq +10$ dB. WSJT modes work at -20 dB or lower.

-26 dB

FT8 sensitivity limit (typical)

2.5 kHz

FT8 audio bandwidth — fits 25+ QSOs simultaneously

1993

Nobel Prize — K1JT's pulsar timing research led directly to WSJT DSP techniques

The Magic: Decoding Below the Noise Floor

How WSJT extracts signals that you cannot hear

1. Narrow Bandwidth

FT8 uses only 50 Hz per signal. Noise power is proportional to bandwidth — cutting from 2700 Hz (SSB) to 50 Hz reduces noise by 17 dB before any other processing.

2. Long Integration Time

FT8 transmits over 12.6 seconds. Coherently averaging the signal provides gain proportional to $\sqrt{\text{time}}$. Noise averages toward zero; the predictable signal does not.

3. Structured / Known Format

WSJT messages follow strict formats with only 77 bits of information. The receiver already knows 90%+ of what legal messages can say, enabling powerful error correction.

4. LDPC Error Correction

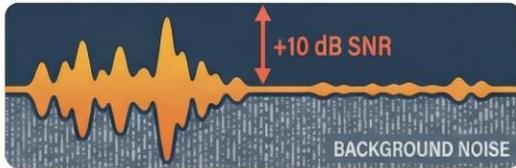
Low-Density Parity-Check codes reconstruct a complete message even when 30–40% of received bits are wrong — extracting intelligible data from what sounds like pure static.

Signal vs. Noise: The Virtual Amplifier

Why digital modes outperform voice by 10,000×

Signal vs. Noise: How Digital Modes Hear the Inaudible

Traditional Voice: The Signal Must Win



Voice Requires a +10 dB SNR

For speech to be intelligible, the signal power must be at least 10 times stronger than the noise.

Modern Digital Modes: Pulling Data From the Noise



Decoding "Invisible" Signals

Digital modes can recover data from signals that are thousands of times weaker than the surrounding noise.



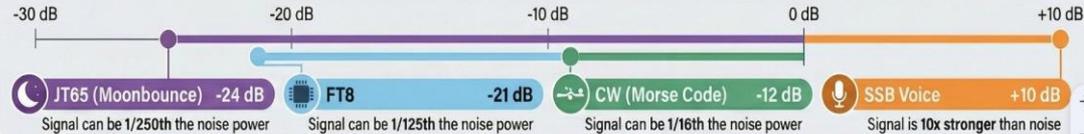
If you can't hear it, the message is lost.

In traditional voice modes, any signal that drops below the level of background noise is effectively gone.



The "Virtual Amplifier" Effect

Switching from voice to a mode like FT8 is equivalent to boosting your power 10,000 times.



© NotebookLM

+10 dB

SSB voice requires signal 10× stronger than noise to be intelligible

-21 dB

FT8 decodes at 1/125th of noise power — a 40 dB improvement over voice

-24 dB

JT65 reaches 1/250th of noise — moonbounce made practical

×10,000

The 'virtual amplifier': switching voice to FT8 equals boosting TX power 10,000×

Bandwidth & SNR: The Physics

$N = kTB$ — why narrower bandwidth equals better sensitivity

Noise Power $N = kTB$

k = Boltzmann's constant · T = temperature (Kelvin) · B = bandwidth (Hz)

WSPR

6 Hz

-28 dB

1.4648 baud — 110.6 sec TX. Automated beacon, ultimate sensitivity.

FT8 / JS8Call

50 Hz

-21 dB

Sweet spot for DX — high sensitivity in a compact 50 Hz slice.

Q65

90 Hz

-26 dB

65-tone FSK for unstable Doppler channels — EME, scatter, microwave.

JT65

180 Hz

-25 dB

84-tone FSK predecessor to Q65 — 1-minute T/R, extreme sensitivity.

MSK144

2.4 kHz

-12 dB

2000 baud — captures complete meteor burst messages in <100 ms.

SSB Voice

2.5 kHz

+10 dB

Full-bandwidth voice — requires signal 10× stronger than noise.

Shannon-Hartley: to increase data rate, you need more bandwidth OR better SNR — you cannot escape this fundamental trade-off.

FT8 — Franke-Taylor 8-FSK

The most popular amateur digital mode in history

USE CASES

- HF DX contacting on all bands 160m–10m
- DXCC, WAS, and contest operations with minimal power
- Grid-square hunting for VHF/UHF awards (6m, 2m)
- Beacon propagation monitoring worldwide

HOW IT'S DESIGNED FOR THE CONDITIONS

- 8-FSK modulation — 8 tones, 6.25 Hz spacing, 50 Hz total BW
- 15-second TX/RX cycles, synchronized to UTC
- 77 bits of user info + 14-bit CRC → 174-bit LDPC codeword
- Signaling interval $T = 0.180$ seconds per symbol
- Sensitivity: -20.8 dB SNR in 2200 Hz reference bandwidth

15 sec

TX period (UTC sync)

50 Hz

Signal bandwidth

-20.8 dB

Min SNR (2200 Hz BW)

77 bits

User payload + 14-bit CRC

FT8 Deep Dive: Modulation Architecture

8-tone CPFSK — how 50 Hz carries a complete QSO

8-Tone Structure (fc = carrier frequency)

Tone 0	fc + 0.00 Hz	bits: 000	Gray
Tone 1	fc + 6.25 Hz	bits: 001	Gray
Tone 2	fc + 12.50 Hz	bits: 011	Gray
Tone 3	fc + 18.75 Hz	bits: 010	Gray
Tone 4	fc + 25.00 Hz	bits: 110	Gray
Tone 5	fc + 31.25 Hz	bits: 111	Gray
Tone 6	fc + 37.50 Hz	bits: 101	Gray
Tone 7	fc + 43.75 Hz	bits: 100	Gray

Gray coding: adjacent tones differ by only 1 bit — a mis-decode of one tone corrupts only 1 bit, not 3.

CPFSK — Continuous Phase

No abrupt phase jumps between tones. Continuous phase = minimal spectral splatter, keeping the entire signal inside its 50 Hz slot even when tones switch.

Costas Array Sync [3,1,4,0,6,5,2]

This 7-tone sequence appears at start, middle, and end of every TX. It lets the receiver lock timing and frequency even at -24 dB SNR where the signal is completely inaudible.

Gaussian Smoothing (GFSK)

A Gaussian filter rounds tone transitions, eliminating spectral sidelobes. Without this, each tone change would splatter energy into neighboring 50 Hz slots and interfere with other stations.

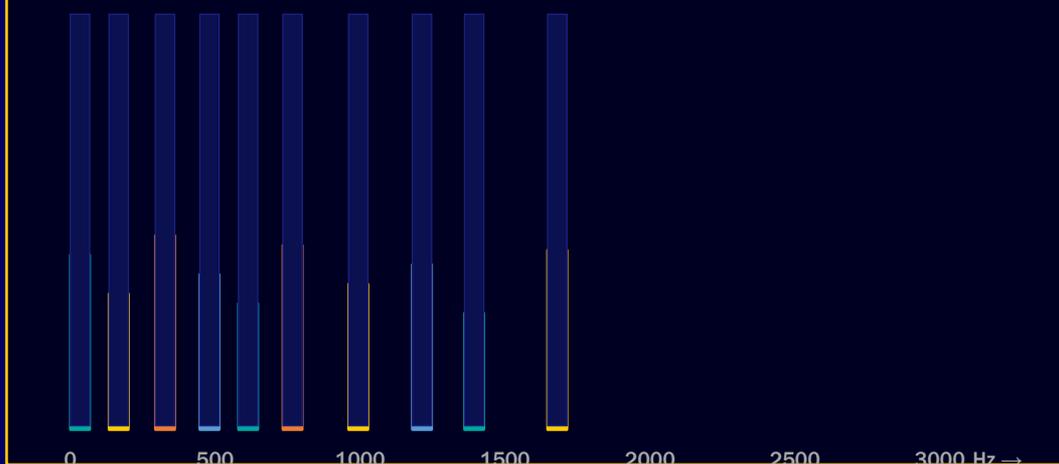
Analogy: an 8-note scale played precisely in a 1-inch pipe — the narrow pipe filters room noise; the known melody survives.

Wide-Band Monitoring: How WSJT-X Hears Everyone

Decoding 25+ simultaneous signals in a single 3 kHz passband

WSJT-X monitors the full 3 kHz audio passband simultaneously — it decodes every valid FT8 signal it finds, all at once, every 15 seconds.

Audio Waterfall — 0 to 3000 Hz



↑ Each colored bar = one FT8 station, 50 Hz wide

FFT — The Secret Weapon

WSJT-X applies a Fast Fourier Transform to the entire audio stream 200 times per second, producing a precise frequency map. Every 50 Hz slot is monitored simultaneously — no tuning required.

25+ Signals at Once

Because each FT8 signal occupies only 50 Hz, the standard 2.5 kHz FT8 segment on any band fits approximately 50 simultaneous signals. WSJT-X decodes all of them in the same 15-second window.

Synchronized Decode Burst

At the end of every 15-second period, WSJT-X processes all received audio simultaneously. Within 1–2 seconds it presents every decoded station — callsign, grid, and SNR — in the decode window.

Global Network Effect

PSKReporter.info aggregates spots from thousands of simultaneous receiving stations worldwide. Your single receiver contributes to a real-time global propagation map updated every 15 seconds.

Q65 — 65-FSK with QRA64 Coding

Optimized for VHF, UHF, microwave, and EME paths

Q65 targets propagation paths with rapid, random phase and frequency variations — ionospheric scatter, EME Doppler, aircraft scatter, and rain scatter. FT8 assumes a relatively stable channel; Q65 does not.

JT65 vs Q65 — Understanding Both Modes

JT65 (older predecessor — 84 tones)

Tones: 84-tone FSK **SNR:** -24.8 dB **Period:** 60 sec

FEC: (63,12) Reed-Solomon code **T:** 0.5715 sec/symbol

Note: Designed for EME. More tones = each symbol narrower = better Doppler tolerance, but slower.

Q65 (modern replacement — 65 tones)

Tones: 65-tone FSK **SNR:** -26 dB **Period:** 15–300 sec

FEC: QRA64 erasure codes **Spacing:** selectable

Improvement: Wider tone spacing → better Doppler resistance + selectable period for EME.

65-FSK — Wider Tone Spacing

65 tones with selectable spacing. Wider gaps between tones resist Doppler-induced smearing — critical for EME where the moon return arrives ± 300 Hz shifted from transmitted frequency.

Selectable Period

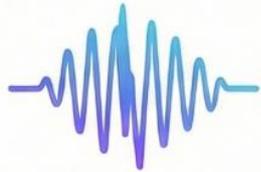
15, 30, 60, 120, or 300 second T/R periods. Longer periods = more integration gain. EME operators use 60 sec to accumulate energy traveling 384,000 km each way.

QRA64 Erasure Codes

Designed to handle burst erasures — entire chunks of signal wiped out by rapid ionospheric fades. Unlike LDPC which corrects bit errors, QRA64 reconstructs missing blocks entirely.

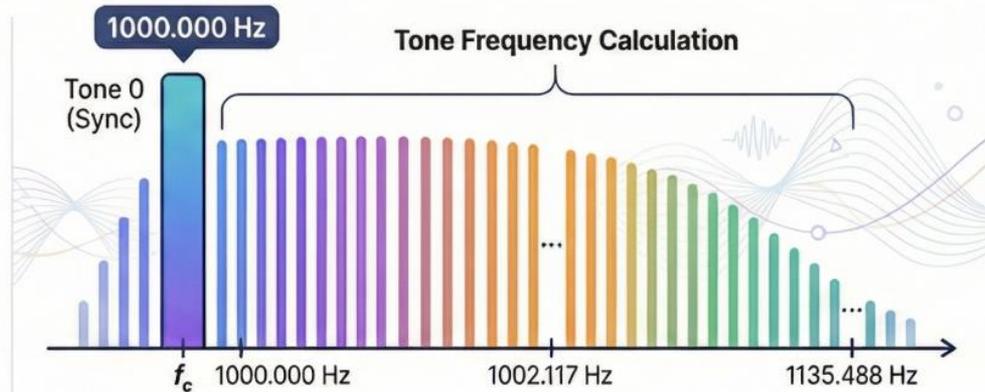
Anatomy of a Q65 Digital Signal

Signal Composition



Built from 65 Discrete Tones

The signal is composed of 64 tones for data and one dedicated tone for synchronization.



Tone Frequency Calculation Example (Q65-30A, $f_c = 1000$ Hz, Spacing = 2.117 Hz)

1 Tone 0 (Sync)

Base Frequency (f_c)

1000.000 Hz

2 Tone 1

$f_c + (1 \times 2.117 \text{ Hz})$

1002.117 Hz

3 ...

...

...

4 Tone 64

$f_c + (64 \times 2.117 \text{ Hz})$

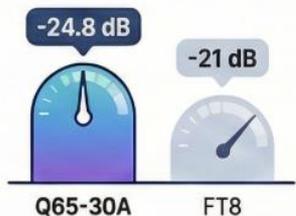
1135.488 Hz

Key Performance Features



Robust Synchronization

A dedicated sync tone allows the receiver to lock on, even with frequency shifts (Doppler).



Superior Sensitivity

Q65-30A decodes signals down to -24.8 dB, which is significantly more sensitive than FT8 (-21 dB).

MSK144 — Minimum Shift Keying 144

Purpose-built for meteor scatter bursts on VHF

THE CHALLENGE

Meteor scatter reflections last milliseconds to a few seconds — a blip of ionized trail as a meteoric particle burns up 80–120 km overhead. Traditional modes like RTTY miss the window entirely.

USE CASES

- 6-meter and 2-meter DX contacts up to 2,300 km
- Shower events: Perseids, Leonids, Geminids
- Random scatter outside major showers
- Grid-square and distance records on weak paths

77 bits + 14-bit CRC

Message payload — identical structure to FT8 user info

2,000 baud symbol rate

2.4 kHz bandwidth — 50× faster than FT8 to capture <100 ms bursts

(174,91) LDPC Block Code

Same FEC family as FT8 — tolerates bit errors in burst fragments

Rapid burst averaging

Receiver scans every few ms; averages partial bursts to reconstruct message

MSK144: Mastering the Meteor Scatter "Ping"

Specialized digital protocol for decoding extremely short radio transmissions using high-speed frames and advanced error correction.

Engineered for Speed and Reliability



250 Characters Per Second

This high rate is the practical limit for standard 2500 Hz SSB transceivers.

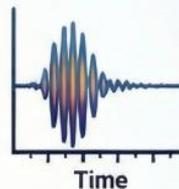


72ms Ultra-Fast Frames

Standard 144-bit message frames last only 0.072 seconds to fit within brief pings.



Specialized Features for Short Transmissions



20ms Optional Short Format

Specialized 20ms frames enable communication even when pings are too short for standard frames.



Coherent Frame Averaging

The decoder sums up to 7 identical frames to gain up to 8.5 dB sensitivity.



(128, 80) LDPC Coding

Uses state-of-the-art Low Density Parity Check codes for high-performance error correction.

Frame Format Comparison

	Standard Frame	Short-Message Format
Frame Duration	72 ms	20 ms
Total Bits	144 bits	40 bits
Typical Use	Initial Call Sign Exchange	Reports & Acknowledgments



0.1 Second Decode Threshold

Reliable decodes are possible from signal bursts lasting only one-tenth of a second.



WSPR — Weak Signal Propagation Reporter

Automated global propagation mapping — milliwatt scale

USE CASES

- Propagation research — see which bands are open to which grids
- Antenna and transmitter comparison at equal power
- QRP experiments — reports at 1 mW (0 dBm) are common
- Automated 24/7 beaconing — no operator interaction required
- WSPRnet.org: all spots stored, searchable, mappable

-28 dB

SNR threshold — deepest sensitivity of any WSJT mode

2 min

Transmission period — extreme sensitivity via slow baud rate

The 4-FSK signal transmits at only 1.4648 baud — one symbol every 680 ms. A complete message takes 110.6 seconds. This extreme slowness allows massive coherent integration gain. The narrow 6 Hz/tone spacing and 200 Hz total bandwidth reduce noise further, pushing sensitivity to -28 dB SNR — detecting a signal 630× weaker than the noise.

WSPR Deep Dive: The 4-Tone System

How 4-FSK and 6 Hz bandwidth achieve -28 dB sensitivity

4-Tone Map (fc = 1500.0000 Hz example)

Tone 0 1500.0000 Hz
fc (base carrier)

Tone 1 1501.4648 Hz
fc + 1.4648 Hz

Tone 2 1502.9297 Hz
fc + 2.9297 Hz

Tone 3 1504.3945 Hz
fc + 4.3945 Hz

Total span = 4.3945 Hz
Signal occupies only 6 Hz

50 bits of information

Each transmission encodes exactly: callsign + 4-digit Maidenhead grid + transmitter power in dBm. Nothing more — maximum efficiency.

1.4648 baud signaling rate

One symbol every 683 ms. The extreme slowness enables massive coherent integration. The receiver averages energy over the full 110.6-second window.

~30 signals in 200 Hz

At 6 Hz per signal with 1.4648 Hz tone spacing, ~30 simultaneous WSPR transmissions fit in the standard 200 Hz band segment without degradation.

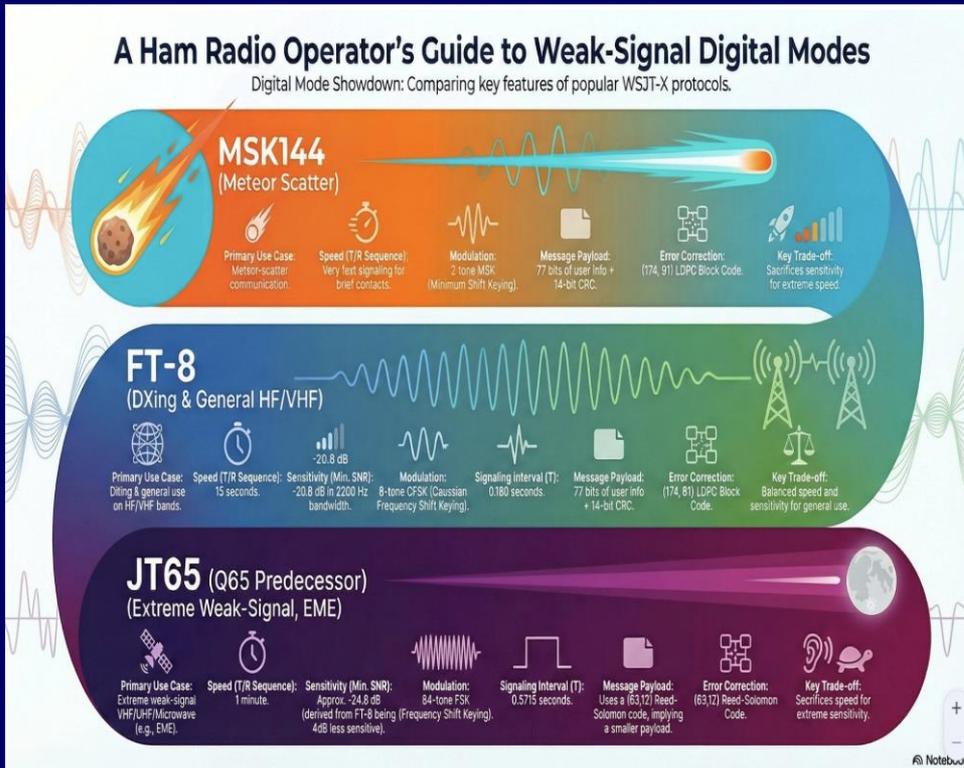
UTC-synchronized start

Every transmission begins exactly 1 second into an even UTC minute, enabling worldwide synchronized monitoring and WSPRnet.org auto-upload.

Analogy: a digital lighthouse humming 4 precise notes — the receiver filters everything else out, hearing the beacon even from the other side of the planet.

Mode Showdown: MSK144 vs FT8 vs JT65 vs WSPR

Speed, sensitivity, and modulation compared



Mode	Mod.	Speed	SNR
MSK144	2-tone MSK	Fast / brief bursts	-12 dB*
FT8	8-tone CPFSK	15 sec	-20.8 dB
JT65/Q65	84-tone FSK	60 sec	-24.8 dB
WSPR	4-tone FSK	110.6 sec	-28 dB

- MSK144:** Speed over sensitivity — captures meteor bursts other modes miss.
- FT8:** Balanced sweet spot — worldwide DX with modest equipment.
- JT65/Q65:** Sensitivity over speed — EME and extreme weak-signal paths.
- WSPR:** Maximum sensitivity — beacon only, no two-way QSO.

* MSK144 trades sensitivity for speed — captures meteor ionization trails other modes miss entirely.

Mode Comparison at a Glance

Selecting the right WSJT mode for the job

Mode	Modulation	Period	Min SNR	Bandwidth	Primary Use
FT8	8-FSK CPFSK	15 sec	-20.8 dB	50 Hz	HF DX, VHF grid hunting
Q65	65-FSK	15-300 sec	-26 dB	90 Hz	EME, scatter, microwave
MSK144	2-tone MSK	15 sec	-12 dB*	2.4 kHz	Meteor scatter VHF/UHF
WSPR	4-FSK	2 min	-28 dB	6 Hz	Propagation beacon

* MSK144 sensitivity is lower by design — the mode trades sensitivity for speed to capture brief meteor bursts.

Getting Started with WSJT-X

Equipment, software, and first steps

Hardware You Already Have

Any HF or VHF transceiver with an audio interface (Signalink, RigBlaster, or built-in USB audio), computer running Windows/Mac/Linux, and a CAT control cable for frequency and PTT.

Software — Free & Open Source

Download WSJT-X from physics.princeton.edu/pulsar/k1jt. Also install JS8Call (message mode built on FT8), GridTracker (real-time map), and PSKReporter for global reception reports.

Frequency & Time

Tune to standard dial frequencies (e.g., 14.074 MHz for 20m FT8). Synchronize your PC clock to within ± 1 second using Windows Time Service or Meinberg NTP — sync is essential.

Making Your First Contact

Set your callsign, grid square (e.g., FM29), and maximum power. Click CQ in WSJT-X. The software handles timing, encoding, and decoding automatically. You will see decoded calls appear in seconds.

Summary & Resources

WSJT Suite — Gloucester County Amateur Radio Club

Key Takeaways

- N = kTB: narrower bandwidth = lower noise floor = better sensitivity
- FT8: 8-tone CPFSK, Gray coding, Costas sync, GFSK smoothing — the all-around mode
- Q65: 65-tone FSK with QRA64 coding for Doppler-unstable paths and EME
- MSK144: 2000 baud MSK — captures meteor bursts other modes miss entirely
- WSPR: 4 tones, 6 Hz, 1.4648 baud, -28 dB — the ultimate propagation beacon
- All modes: free, open-source, any shack PC, no special hardware required

Resources

WSJT-X Home

physics.princeton.edu/pulsar/k1jt

PSKReporter

pskreporter.info

WSPRnet.org

wsprnet.org

GCARC Club Website

www.w2mmd.org