FT-8 HF Data Mode

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WMARC Mt Washington Valley, NH **SPARC** St Petersburg, FL

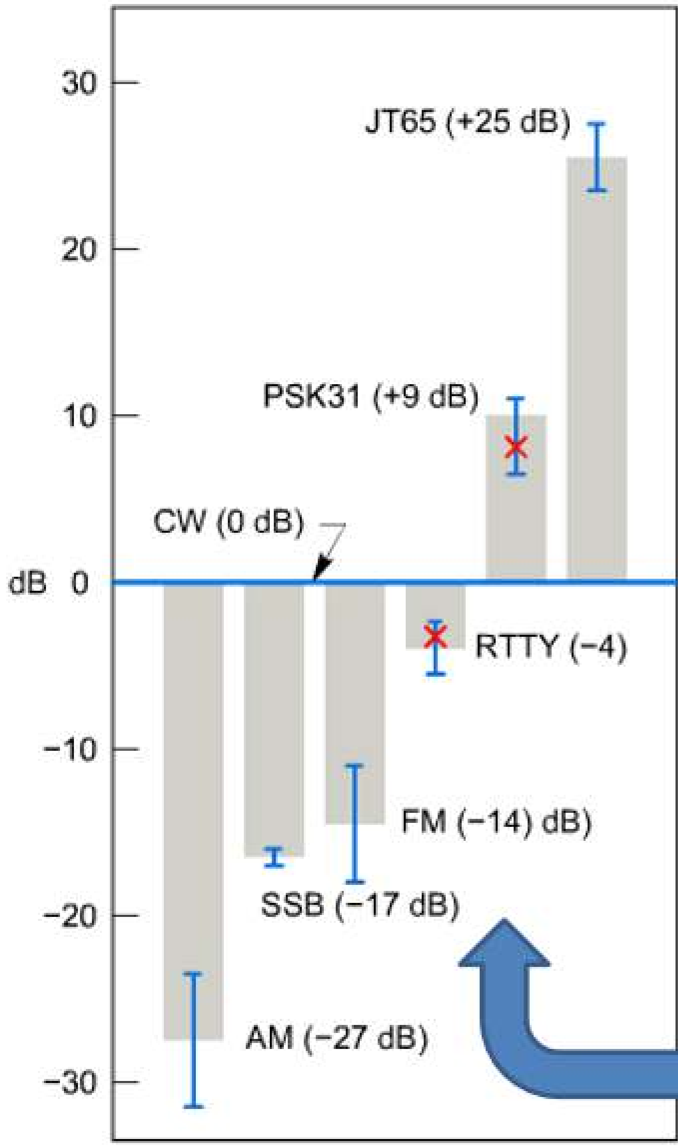
From August 2018 QST:

FT8 Activity Bumping Up at Some Expense to Other Modes

Despite largely dismal HF conditions recently, there is no doubt that the recent FT8 digital protocol has hams on the air. The mode has caught on so quickly that co-developer Joe Taylor, K1JT, expressed surprise last fall at the rapid uptake of FT8 for making contacts on HF bands. Judging by Logbook of The World (LoTW) data, more than 2.3 million FT8 contacts were uploaded in 1 month — a net gain of 1.2 million contacts on all modes over the same month last year, ARRL Radiosport Manager Norm Fusaro, W3IZ, said. Over the same period, activity in some of the other modes has declined.

Fusaro said that while some feel that FT8 is "taking over the world," overtaking all other modes, that's not the case. "Activity in the traditional modes of SSB and CW has decreased only slightly, by 10%," he said. "The *real* decrease is in RTTY and PSK activity and in the other *WSJT*-X modes. I believe poor propagation would have cut into SSB and CW activity, regardless of the new mode." Anecdotal reports support Fusaro's numbers, with wall-to-wall signals surrounding the FT8 watering holes.

How Much "Punch" Can You Get from Different Modes



QST Dec 2013, P30-32

"You can target the DX station's operating mode more confidently when you know CW can out perform unprocessed SSB by 17 dB and RTTY can out perform SSB by 11 dB. If you can't get them on phone, try RTTY or better still, try CW."

Table 1
Average Power for 100 W PEP Transmitter

Mode	Average Power (W)	Compared to CW (dB)
AM	25	–2.5
SSB	25	–2.5
FM	100	+3.6
RTTY	95	+3.3
CW	44	ref: 0
PSK31	75	+2.3
JT65	100	+3.5

Table 2
Average Receiver Sensitivities

Mode	Receiver Sensitivity (microvolts)	Receiver Sensitivity (dBm)	Compared to CW (dB)
AM	0.72	–109.9	–25.1
SSB	0.22	–120.3	–14.7
FM	0.29	–117.7	–17.3
RTTY	0.096	–127.3	–7.7
CW	0.040	–135.0	ref: 0
PSK31	0.023	–139.8	+7.1
JT65	0.0035	–156.2	+21.2

FT-8 digital mode for HF

Weak signal digital mode

FT-8 is available in WSJT-X software

- Created by Joe Taylor, professor at Princeton University
- WSJT "Weak Signal Joe Taylor"
- JT modes first developed for weak signal earth-moon-earth (EME)
- FT-8 developed for HF, poor path (QSB), short duration E-skip
- Operational behavior: similar to JT-9 & JT-65
- Multi-decoder: finds and decodes all FT-8 signals in pass band
- Auto-sequencing after manual start of QSO

FT-8 digital mode for HF

Why FT-8?
A faster mode was needed for HF.
A better dig mode for DXpeditions.
Automation required by the speed of the exchanges.

Important characteristics of FT-8:

- T/R sequence length: 13.48s. Four transmissions per minute.
- FEC code: LDPC (174,87)
- Modulation: 8 tone FSK, keying rate = tone spacing = 5.86 Hz
- Waveform: Continuous phase, constant envelope
- Occupied bandwidth: 47 Hz
- Synchronization: three 7x7 Costas arrays (start, middle, end of Tx)
- Decoding threshold: -21 dB [-24dB]

Total occupied bandwidth, decoding sensitivity and band usage:

Mode	Band	BW Hz	Sensitivity dB	Range dB	Transmit cycle seconds
JT-9	HF	15.6	-27	-50 to +49	60
FT-8	HF	47.0	-20	-50 to +49	15
JT-65A	HF	177.6	-25	-30 to -1	60
JT-65B	2m	355.3	-24	-30 to -1	60
JT-65C	80cm	710.6	-23	-30 to -1	60

Signals become visible on the waterfall around S/N = –26 dB and audible (to someone with very good hearing) around –15 dB.

- At the user level, the modes have nearly identical message structures.
- JT-65 signal reports are constrained to the range –1 to –30 dB. This range is more than adequate for EME purposes, but not enough for optimum use at HF.
- By comparison, JT-9 & FT-8 allow for signal reports in the range –50 to +49 dB.
- JT-9 is an order of magnitude better than JT-65 in spectral efficiency (bandwidth). On a busy HF band the conventional 2.5-kHz-wide JT-65 sub-band is often filled with overlapping signals. Ten times as many JT-9 signals can fit in the same bandwidth without collisions.

*

What do we want to exchange in the QSO?

Just the QSO Essentials

- When CW or SSB signals are strong and communication is essentially error free, it is easy to judge whether a QSO has taken place.
  - Calls & signal reports are exchanged
- When a rare one shows up or in a contest, rapid-fire QSOs in the pile-up generally proceed something like the following exchange:

1. **CQ N2ESP**
2. **NZ1Q**
3. **NZ1Q 599**
4. **599 TU**
5. **73 N2ESP**

- In the above QSO NZ1Q never sends the call sign of the station he is working, because the situation has made this information clear.
- After the exchange has taken place, both stations confidently enter the QSO in their logs.

The FT-8 QSO

Following those guidelines, the FT-8 QSO proceeds like this:

W1MWV sends:

- CQ NY4I FN44
- NZ1Q NY4I -05
- NZ1Q NY4I RR73

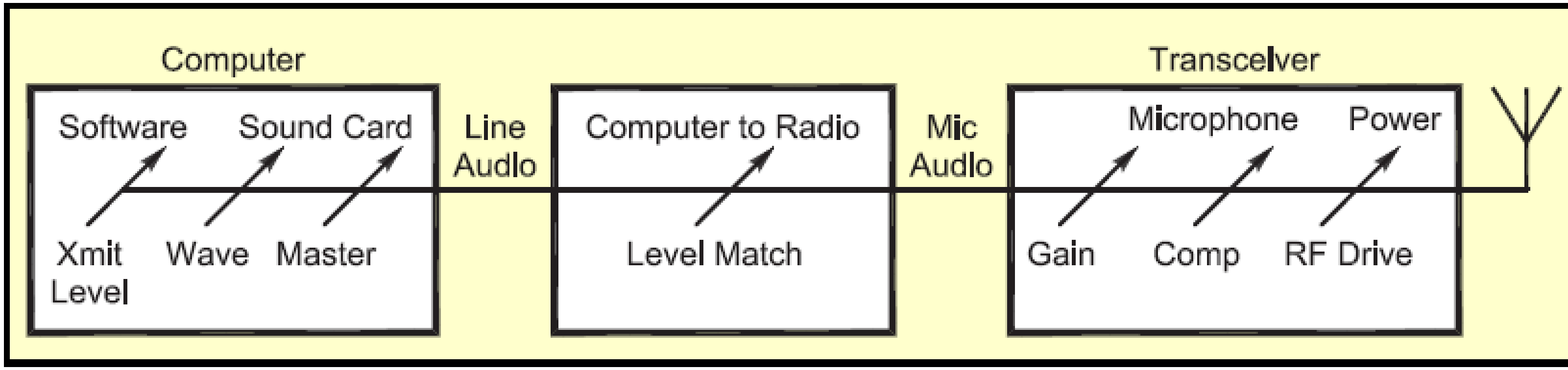
NZ1Q sends:

- NY4I NZ1Q EL87
- NY4I NZ1Q R-03
- NY4I NZ1Q 73

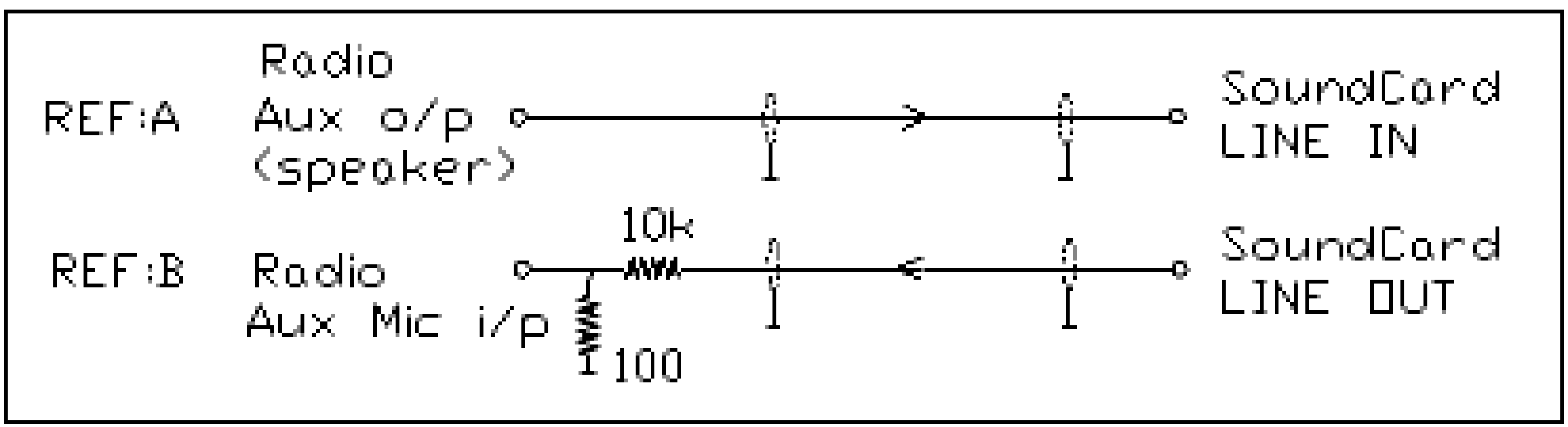
What do you need to start?

- **SSB station**
  - Minimal power, 40w is good, 5w works
  - Any type antenna
  - Any band
- **PC**
  - Sound card or Interface
    - Signal Link, Rig Blaster, etc.
  - Cables for audio, PTT, etc.
  - WSJT-X software (free)
    - "Weak Signal Joe Taylor"

Typical Hardware Setup

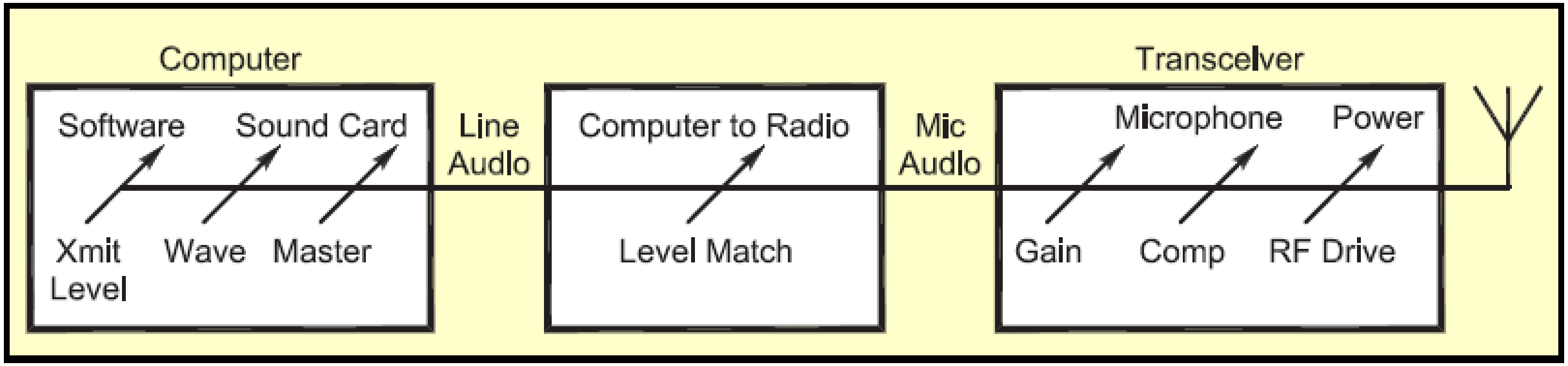


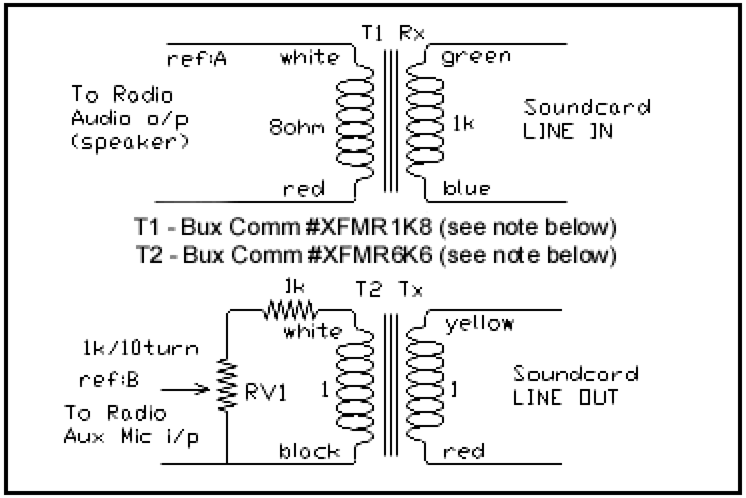
·An example of daisy-chained transmit level controls. Note that the controls are in series and the resultant output is affected by each of the prior control settings.



Simple interface between rig and PC

Typical Hardware Setup





Impedance and level matching network.

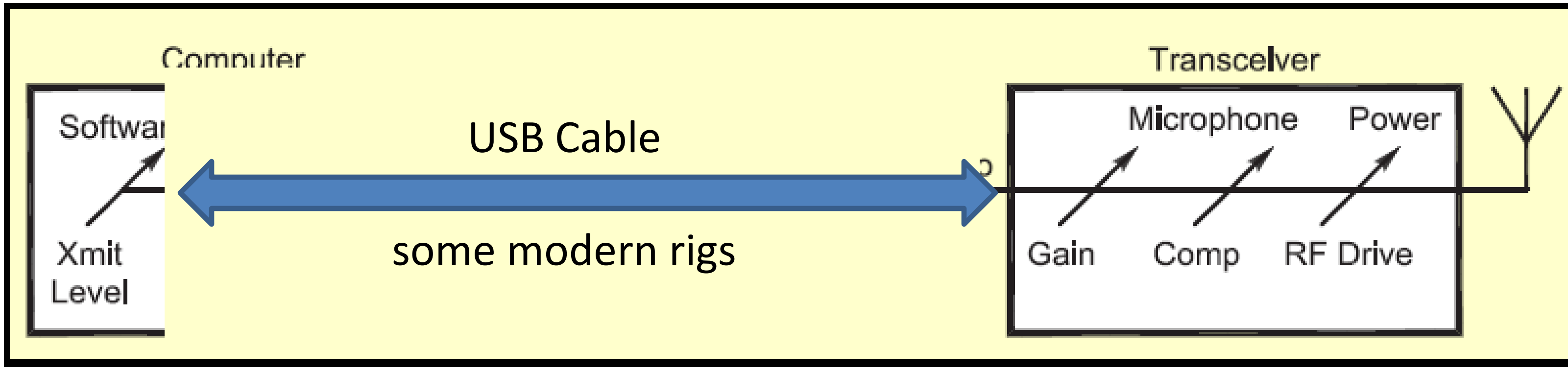
Typical Hardware Setup

An interface device like the SignalLink or RigBlaster is a good way to connect the rig to the PC.

A USB connection is used between the PC and the interface box.

Instead of using the PC sound card, the sound card is built into the interface.

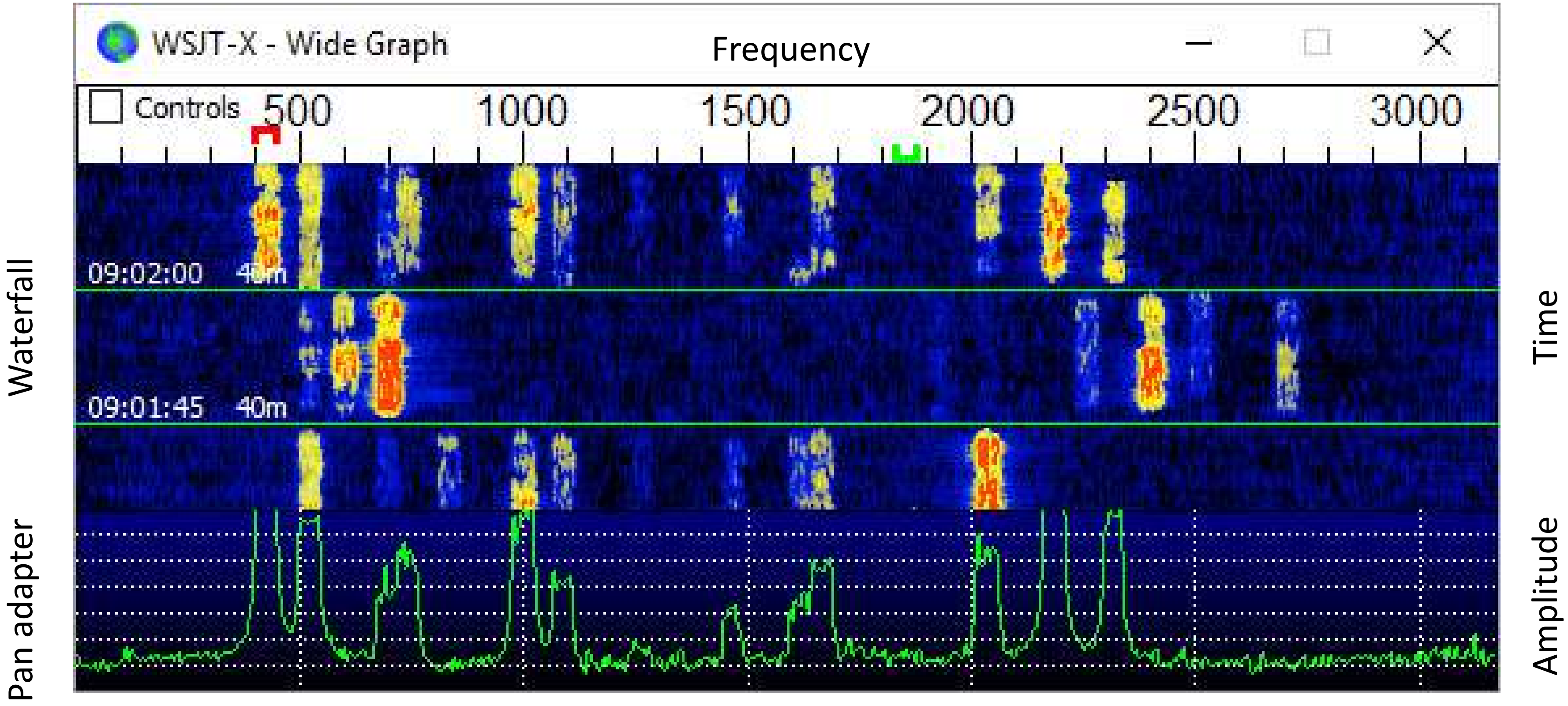
Typical Hardware Setup



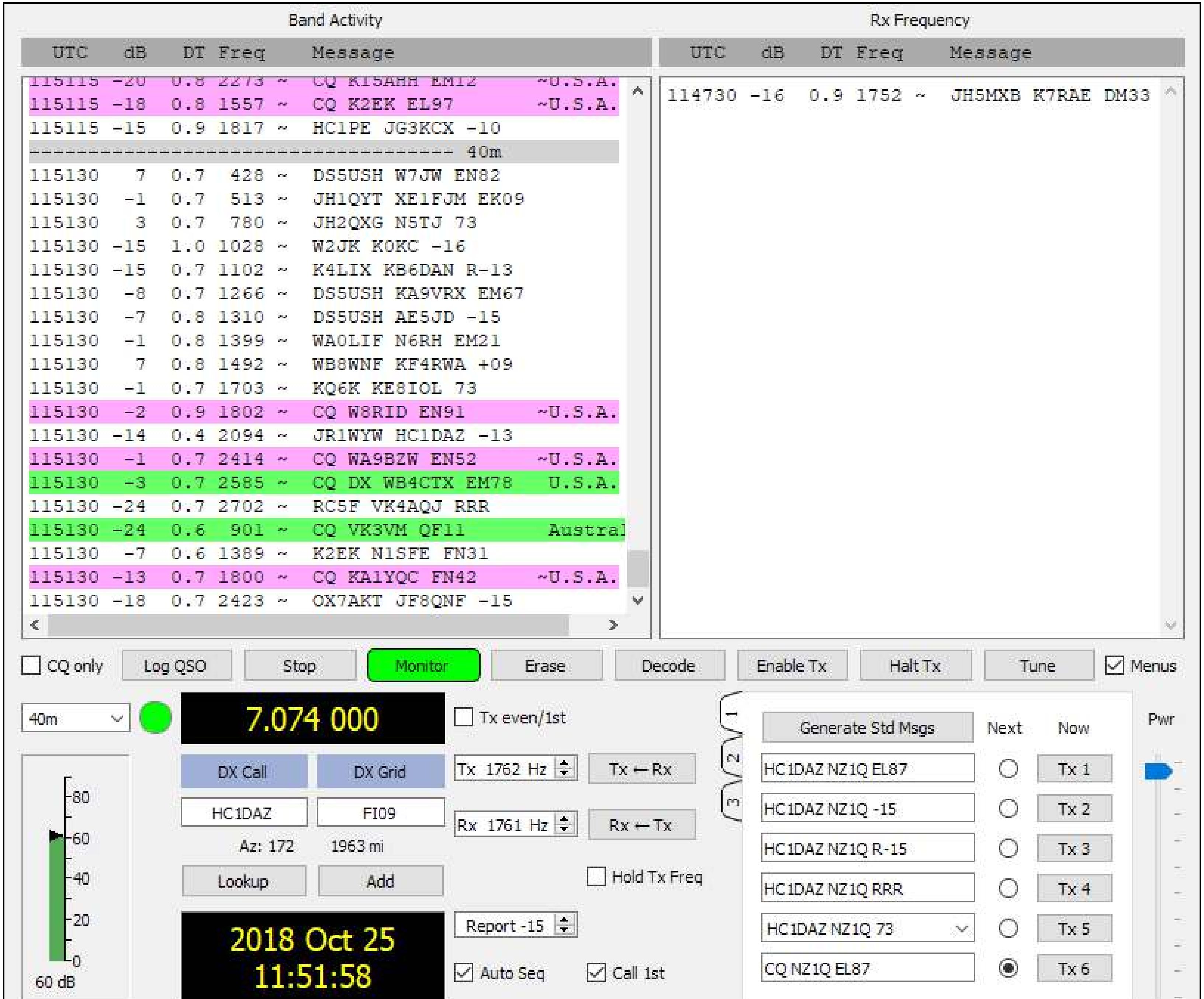
Modern rigs use a direct USB cable between the rig and the PC since the sound card is built into the rig itself.

This is the easiest way to connect and have the software program communicate with the rig.

What do FT-8 Signals Look Like



Messages alternate between stations every 15 seconds.



Band Activity
Rx Frequency
UTC dB DT Freq Message
115115 -18 0.8 1557 ~ CQ K2EK EL97 ~U.S.A.
115115 -15 0.9 1817 ~ HC1PE JG3KCX -10
40m
115130 7 0.7 428 ~ DS5USH W7JW EN82
115130 -1 0.7 513 ~ JH1QYT XE1FJM EK09
115130 3 0.7 780 ~ JH2QXG N5TJ 73
115130 -15 1.0 1028 ~ W2JK K0KC -16
115130 -15 0.7 1102 ~ K4LIX KB6DAN R-13
115130 -8 0.7 1266 ~ DS5USH KA9VRX EM67
115130 -7 0.8 1310 ~ DS5USH AE5JD -15
115130 -1 0.8 1399 ~ WA0LIF N6RH EM21
115130 7 0.8 1492 ~ WB8WNF KF4RWA +09
115130 -1 0.7 1703 ~ KQ6K KE8IOL 73
115130 -2 0.9 1802 ~ CQ W8RID EN91 ~U.S.A.
115130 -14 0.4 2094 ~ JR1WYW HC1DAZ -13
115130 -1 0.7 2414 ~ CQ WA9BZW EN52 ~U.S.A.
115130 -3 0.7 2585 ~ CQ DX WB4CTX EM78 U.S.A.
115130 -24 0.7 2702 ~ RC5F VK4AQJ RRR
115130 -24 0.6 901 ~ CQ VK3VM QF11 Austral
115130 -7 0.6 1389 ~ K2EK N1SFE FN31
115130 -13 0.7 1800 ~ CQ KA1YQC FN42 ~U.S.A.
115130 -18 0.7 2423 ~ OX7AKT JF8QNF -15
UTC dB DT Freq Message
114730 -16 0.9 1752 ~ JH5MXB K7RAE DM33
CQ only
Log QSO
Stop
Monitor
Erase
Decode
Enable Tx
Halt Tx
Tune
Menus
40m
7.074 000
Tx even/1st
DX Call
DX Grid
Tx 1762 Hz
Tx ← Rx
HC1DAZ
FI09
Rx 1761 Hz
Rx ← Tx
Az: 172
1963 mi
Lookup
Add
Hold Tx Freq
80
60
40
20
0
60 dB
2018 Oct 25
11:51:58
Report -15
Auto Seq
Call 1st
1
2
3
Generate Std Msgs
Next
Now
Pwr
HC1DAZ NZ1Q EL87
Tx 1
HC1DAZ NZ1Q -15
Tx 2
HC1DAZ NZ1Q R-15
Tx 3
HC1DAZ NZ1Q RRR
Tx 4
HC1DAZ NZ1Q 73
Tx 5
CQ NZ1Q EL87
Tx 6

Links

WSJT-X website
http://physics.princeton.edu/pulsar/K1JT/wsjtx.html

WSJT manual
http://physics.princeton.edu/pulsar/K1JT/wsjtx-doc/wsjtx-main-1.9.1.html

PC to Rig interfacing for WSJT (look for KA4IOX file)
https://www.sparc-club.org/test-page-pdf-links/

JTAlert for real time "needed stations," worked before info & log program interface
http://hamapps.com/

PSK Reporter quickly shows your world wide propagation
https://pskreporter.info/pskmap.html

DX Maps shows band activity + grid squares
https://www.dxmaps.com/spots/mapg.php

Net Time Protocol for accurate PC time
https://www.meinbergglobal.com/english/sw/ntp.htm#ntp_stable

FT-8 Demo

Notes and References Follow

Hints & Kinks

Once receiver audio is reaching the Pc & software waterfall decoding can be a bit tricky . There are several things to look for:

1. The audio level in WSJT-X should be set to around 30 dB on the left bottom scale during a no signal period. The slider will let you set this, it is not critical.
2. Timing is important. The PC clock needs to be off by less than 2 sec to Internet Time, best when exactly right on. That will let you decode more signals that may vary + or – a second or two. This can ne easily done by updating the time in Windows Clock.
3. For decoding, the Monitor button should be green (active - click if not).
4. The piece of the spectrum being received from the rig needs to be at least 3 kHz wide and better at 5 kHz wide. This will help in decode and also give the waterfall's lower display (amplitude) a flatter response curve across the display.
5. The PC needs reasonable computing power. My old laptop of 10 years just can't handle the processing required during the decode period after the 47 sec xmissions.
6. "Mode" in the pull down menu should be JT-65 to start.

S-unit vs. dB vs. uV

S-reading	HF	
	µV (rms, Relative to 50Ω)	dBm
S9+10dB	160.0	-63
S9	50.2	-73
S8	25.1	-79
S7	12.6	-85
S6	6.3	-91
S5	3.2	-97
S4	1.6	-103
S3	0.8	-109
S2	0.4	-115
S1	0.2	-121

Signal strength	Relative intensity	Received voltage		Received power (Z_c = 50 Ω)	
S1	–48 dB	0.20 µV	–14 dBµV	790 aW	–121 dBm
S2	–42 dB	0.40 µV	–8 dBµV	3.2 fW	–115 dBm
S3	–36 dB	0.79 µV	–2 dBµV	13 fW	–109 dBm
S4	–30 dB	1.6 µV	4 dBµV	50 fW	–103 dBm
S5	–24 dB	3.2 µV	10 dBµV	200 fW	–97 dBm
S6	–18 dB	6.3 µV	16 dBµV	790 fW	–91 dBm
S7	–12 dB	13 µV	22 dBµV	3.2 pW	–85 dBm
S8	–6 dB	25 µV	28 dBµV	13 pW	–79 dBm
S9	0 dB	**50 µV**	34 dBµV	50 pW	–73 dBm
S9+10	10 dB	160 µV	44 dBµV	500 pW	–63 dBm
S9+20	20 dB	500 µV	54 dBµV	5.0 nW	–53 dBm
S9+30	30 dB	1.6 mV	64 dBµV	50 nW	–43 dBm
S9+40	40 dB	5.0 mV	74 dBµV	500 nW	–33 dBm
S9+50	50 dB	16 mV	84 dBµV	5.0 µW	–23 dBm
S9+60	60 dB	50 mV	94 dBµV	50 µW	–13 dBm

decibel conversions			
x factor	**+ factor**	**x factor**	**+ factor**
1 000 000 000	+90	0.000 000 001	-90
100 000 000	+80	0.000 000 01	-80
10 000 000	+70	0.000 000 1	-70
1 000 000	+60	0.000 001	-60
100 000	+50	0.000 01	-50
10 000	+40	0.000 1	-40
1 000	**+30**	0.001	-30
100	+20	0.01	-20
10	**+10**	0.1	-10
4	+6	0.25	-6
2	**+3**	0.5	-3
1	**0**		

JT-65 FEC

- After being compressed into 72 bits, a JT65 message is augmented with 306 uniquely defined error-correcting bits. The FEC coding rate is thus *r = 72/378 = 0.19; equivalently one might say that each message is transmitted with a "redundancy ratio" of 378/72 = 5.25. With a good error-correcting code, however, the resulting performance and sensitivity are far superior to those obtainable with simple five-times message repetition. The high level of redundancy means that JT65 copes extremely well with QSB. Signals that are discernible to the software for as little as 10 to 15 s in a transmission can still yield perfect copy.*
- The source of this seemingly mysterious "coding gain" is not difficult to understand. With 72 bits the total number of possible user messages is 2^{72}, slightly more than 4.7×10^{21}. The number of possible patterns of 378 bits is a vastly larger number, 2^{378}, in excess of 6×10^{113}. With a one-to-one correspondence between 72-bit user messages and 378-bit "codewords," or unique sequences of 378 bits, it is clear that only a tiny fraction of the available sequences need to be used in the code. The sequences chosen are those that are "as different from one another as possible," in a mathematically rigorous sense.

Drive level

After your computer and your radio are set, you should adjust your sound card interface audio level to drive the transmitter to 50 percent power output or less. There are two reasons for doing this—to eliminate production of a wide and distorted signal and to prevent overheating of the transmitter's power amplifier. Less than full power output ensures that you won't overdrive the transmitter, cause distortion and overtax the amplifier.
Most digital mode duty cycles are continuous and full power operation for an extended time can overheat the transmitter.

According to K1JT, the *WSJT software modes contain only single* tones at any instant and cannot easily produce intermodulation distortion (IMD), although IMD is possible with other digital modes if drive levels are excessive.

Signal coding technique: JT65 was designed for making minimal QSOs via EME (“moon-bounce”) on the VHF and UHF bands. A detailed description was published in QEX for September-October, 2005. Briefly stated, JT65 uses 60s T/R sequences and carefully structured messages. Standard messages are compressed so two callsigns and a grid locator can be transmitted in just 71 information bits. A 72^{nd} bit serves as a flag to indicate that a message consists of arbitrary text (up to 13 characters) instead of callsigns and a grid locator. Special formats allow other information such as add-on callsign prefixes (e.g., ZA/K1ABC) or numerical signal reports (in dB) to be substituted for the grid locator. The basic aim is to compress the most common messages used for minimally valid QSOs into a minimum fixed number of bits. After compression, a Reed Solomon (63,12) error-control code converts 72-bit user messages into sequences of 63 six-bit channel symbols.

JT65 requires tight synchronization of time and frequency between transmitting and receiving stations. Each transmission is divided into 126 contiguous tone intervals or “symbols” of length 4096/11025 = 0.37s. Within each interval the waveform is a constant-amplitude sinusoid at one of 65 pre-defined frequencies (tones). Frequency steps between intervals are accomplished in a phase-continuous manner. Half of the channel symbols are devoted to a pseudo-random synchronizing vector interleaved with the encoded information symbols. The sync vector allows calibration of time and frequency offsets between transmitter and receiver. A transmission nominally begins at t = 1s after the start of a UTC minute and finishes at t = 47 seconds. The synchronizing tone is sent in each interval having a “1” in the following pseudo-random sequence:

100110001111110101000101100100011100111101101111000110101011001 101010100100000011000000011010010110101010011001001000011111111

Encoded user information is transmitted during the 63 intervals not used for the sync tone. Each channel symbol generates a tone at frequency 11025 × 472/4096 + 11025/4096 × (N+2) × m, where N is the value of the six-bit symbol, 0 ≤ N ≤ 63, and m is 1, 2, or 4 for JT65 sub-modes A, B, or C. Sub-mode JT65A is always used at HF.

References

The JT65 Communications Protocol
Joe Taylor, K1JT
Abstract. JT65 is a digital protocol intended for Amateur Radio communication with extremely weak signals. It was designed to optimize Earth-Moon-Earth (EME) contacts on the VHF bands, and conforms efficiently to the established standards and procedures for such QSOs. JT65 includes error-correcting features that make it very robust, even with signals much too weak to be heard. This paper summarizes the technical specifications of JT65 and presents background information on its motivation and design philosophy. In addition, it presents some details of the implementation of JT65 within a computer program called WSJT, together with measurements of the resulting sensitivity and error rates.
http://physics.princeton.edu/pulsar/K1JT/JT65.pdf

WSJT-X User Guide version 1.6.0
1. Introduction
WSJT-X is a computer program designed to facilitate basic amateur radio communication using very weak signals. The first four letters in the program name stand for "Weak Signal communication by K1JT," while the suffix "-X" indicates that *WSJT-X* started as an extended (and experimental) branch of the program *WSJT*.
http://physics.princeton.edu/pulsar/k1jt/wsjtx-doc/wsjtx-main-1.6.0.html#INTRO