

WSJT: Digital Communication in Extreme Conditions

Mike Hasselbeck
WB2FKO

Socorro Hamfest
15 October 2016

WSJT: A software package for digital radio communication

Weak **S**ignal communication by Professor **J**oe **T**aylor (K1JT)

Uses computer soundcard via a computer-radio interface

Upper sideband

Introduced in 2001

Development is still going strong in 2016



A free open-source download!

Two general use scenarios:

1) Meteor scatter on VHF

Ionization in the E-layer by random meteors
Propagation path exists for < 1 second

2) Sustained paths on VHF and HF

Signals may be ultra-weak and fluctuating
Can work when voice and cw fail

**Exploring the limits of radio communication
with state-of-the-art technology**

VHF CONTEST ROVER



2003 ARRL January VHF Contest

**GRID SQUARE DM73
(North of White Sands)**

12 WSJT QSOs on 144 MHz

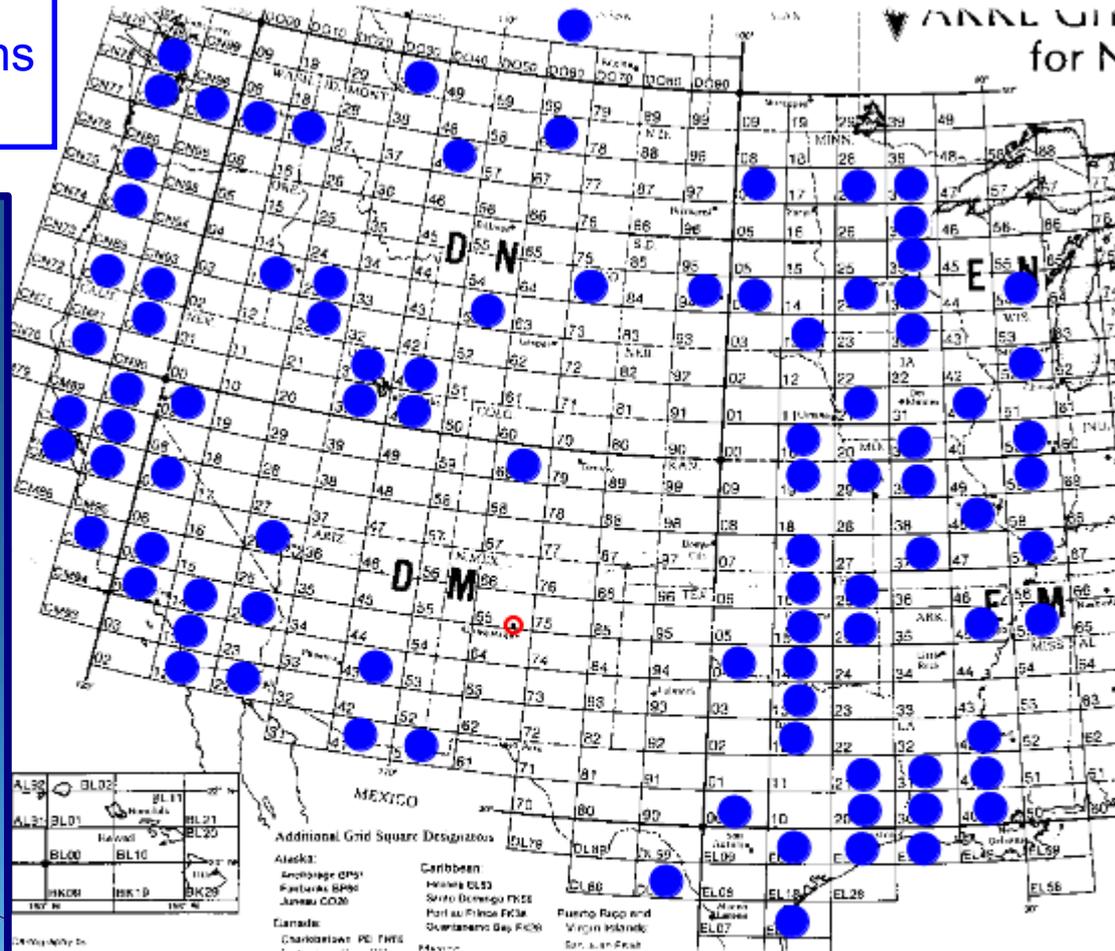
NM, AZ, CA, ID, TX, MN

VUCC grids worked by WSJT meteor scatter on 144 MHz

93 grids

Most in non-shower conditions

Best DX: 1278 miles CN88



2m and 6m beams at WB2FKO

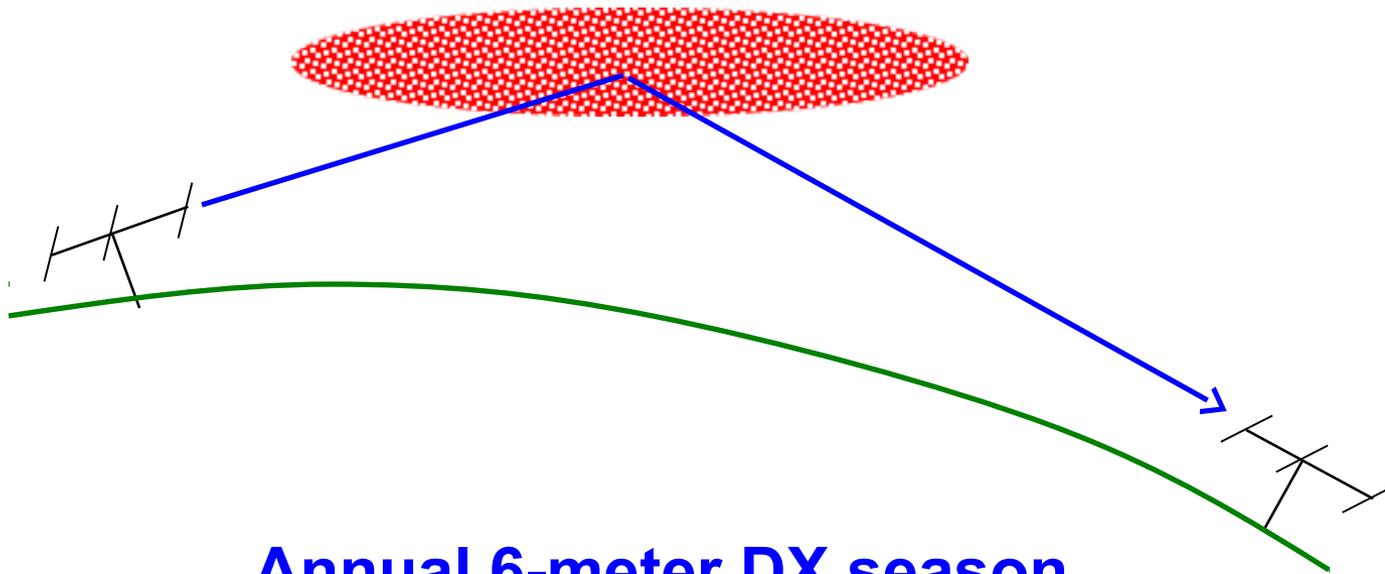
WSJT is not plug and play

Considerable operator skill is required

Skill increases with practice and experience

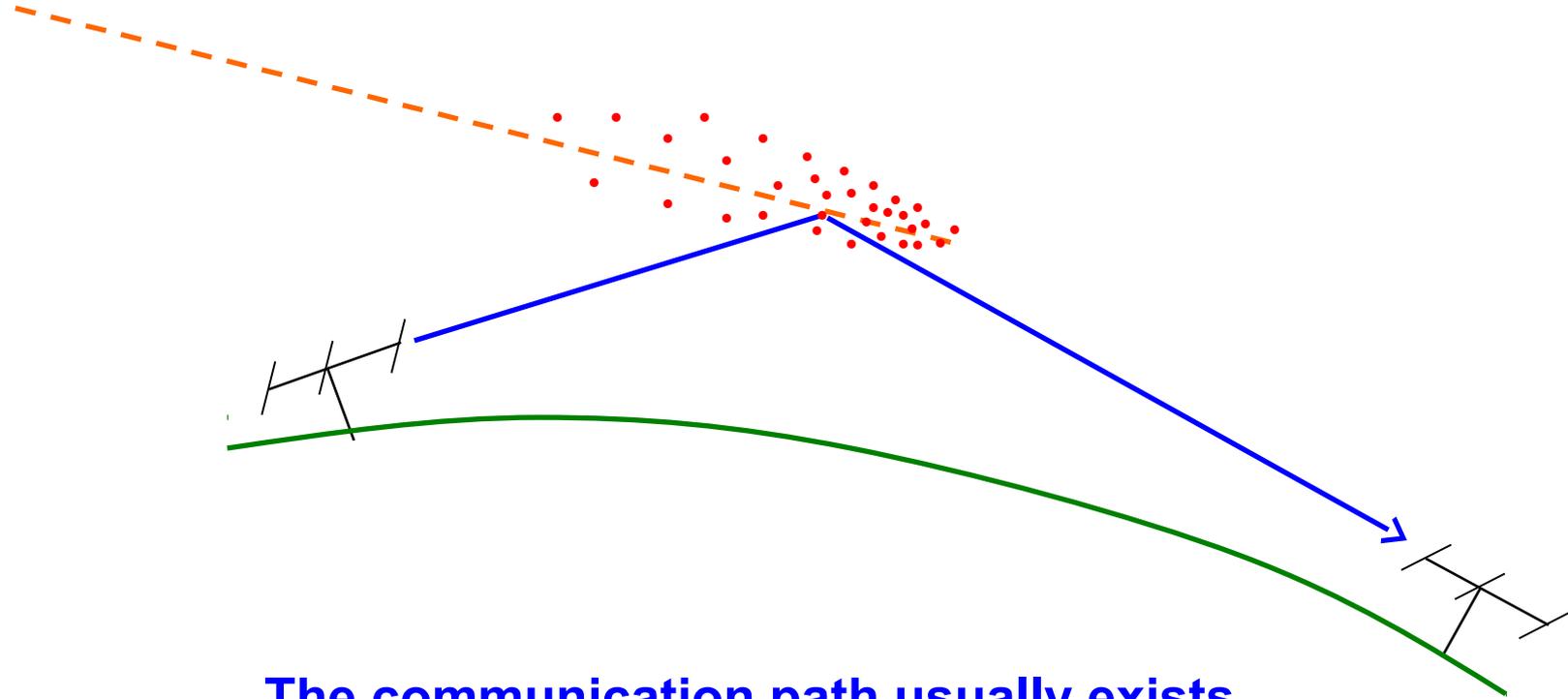
**VHF meteor scatter:
Propagation via the E-layer**

Es: sporadic ionization of the E-layer
Height above ground: ~ 60 miles



Annual 6-meter DX season
Openings last for hours

Meteor scatter: Momentary ionization of the E-layer



**The communication path usually exists
for a fraction of a second**

Meteors:

Size of sand grains or dust specks

Speed is in the range 10 – 70 km/s

Cause ionization trails in E-layer

Ionization trails reflect radio waves

VHF DX is possible at 500 – 1300 miles



PROBLEM: Except in major meteor showers, ionization trail disappears very quickly!

Short-lived ionization trails are called *PINGS*

Typical *PING* lifetime:

- < 1 second at 50 MHz
- < 0.3 seconds at 144 MHz
- < 0.1 seconds at 432 MHz!

Meteor pings are too short to support an ssb QSO

Pings are present in the E-layer 24/7

High speed communication is possible!

WSJT meteor scatter: What's needed?

Cheap computer + radio/soundcard interface

Almost always requires skeds

Skeds can be lengthy: 30 minutes is customary

More time needed if QRP or low gain antennas are used

Pingjockey.net Online real-time scheduling of meteor scatter contacts

Ping Jockey Central.



Relief page	Skeds in-progress	CQ Announcements	JT65 Link
Refresh	Look back	Distance/Bearing Locator	Who's Earwiggling?
Update User details	AA1YN Callsign database	Mike, WB2FKO NM DM65rc	Refreshed 30Sep 15:03

This page is to be used only for the purposes of discussing matters related to amateur radio meteor scatter communications. **Any** non-meteor scatter use is strictly prohibited.

That means **DO NOT USE THIS PAGE TO WORK JT65 or for General chit-chat.**

Remember, in North America, 50.260MHz and 144.140MHz are calling not operating frequencies.

Exchanging any contact details on here before you're complete, invalidates the contact, and, if it's not HIGH-SPEED METEOR SCATTER, it doesn't belong here!

Enter your message here

Go!

DDMMM UTC

30Sep 15:03 Test anyone on 6M? ([W0VB/6M/2M/QRO](#) Terry MN EN34qb 162.255.232.22)

30Sep 15:03 i like how these computer run when you get all the crap off them ([K0TPP/2/6/222/](#) Larry MO EM48rj 71.10.182.149)

30Sep 15:02 K0TPP, Larry, V7123 is now history here,,,,, on v7111 now. Test? ([W0VB/6M/2M/QRO](#) Terry MN EN34qb 162.255.232.22)

30Sep 15:01 I'm just messing around some while waiting to go to an appointment. ([AG0N/6](#) Gary NE DN81fv 65.161.181.76)

30Sep 15:01 Tried CW too ([AG0N/6](#) Gary NE DN81fv 65.161.181.76)

30Sep 15:00 nobody home mabe i reload win onm one of the shack computer clean it up give me some to do ([K0TPP/2/6/222/](#) Larry MO EM48rj 71.10.182.149)

30Sep 15:00 SSB old fashioned mouth noises..... ([W3XS](#) Bill OR CN86ce 107.77.97.50)

30Sep 15:00 I'm hearing bits and pieces.. ([KC5WX/6/2/432](#) Gene TX EM13rs 24.119.48.110)

30Sep 15:00 RR Gary,,think i heard you faintly... ([W5LDA](#) Larry OK EM15xu 72.169.80.204)

30Sep 14:59 Hear you now and then Larry. ([AG0N/6](#) Gary NE DN81fv 65.161.181.76)

30Sep 14:57 SSB? Watsat? What tab is that under, Larry? ([AG0N/6](#) Gary NE DN81fv 65.161.181.76)

30Sep 14:54 rr ([W5LDA](#) Larry OK EM15xu 72.169.80.204)

30Sep 14:54 ssb? ([W5LDA](#) Larry OK EM15xu 72.169.80.204)

30Sep 14:54 ssb ([WQ0P](#) Greg KS EM19wf 216.147.226.27)

30Sep 14:53 W5LDA want to try 50.130? ([WQ0P](#) Greg KS EM19wf 216.147.226.27)

30Sep 14:53 WQ0P Greg,,Can you call me?? 918-292-9030 ([W5LDA](#) Larry OK EM15xu 72.169.80.204)

30Sep 14:52 I've got almost every old version for the last few months. ([AG0N/6](#) Gary NE DN81fv 65.161.181.76)

30Sep 14:50 I saved it from previous install. ([AG0N/6](#) Gary NE DN81fv 65.161.181.76)

30Sep 14:49 where do I get 7115? ([WQ0P](#) Greg KS EM19wf 216.147.226.27)

30Sep 14:48 Yep, tx ok now ([AG0N/6](#) Gary NE DN81fv 65.161.181.76)

30Sep 14:48 7115 is good, Greg. ([AG0N/6](#) Gary NE DN81fv 65.161.181.76)

30Sep 14:47 trying to get 7111 working... no CAT, no audio in, no PTT out... WSJT version 10 worked great... I am about to give it up.. ([WQ0P](#) Greg KS EM19wf 216.147.226.27)

30Sep 14:46 Couldn't find any new error files,so will just roll back. He had a routine to save a spl file in the version I tested while looking for the QRA problem

30Sep 14:44 7115 working good ([K0TPP/2/6/222/](#) Larry MO EM48rj 71.10.182.149)

30Sep 14:43 yes same problem here ([K0TPP/2/6/222/](#) Larry MO EM48rj 71.10.182.149)

30Sep 14:43 yep. I'm looking for the error file before reloading older version. Will send to Joe if it is in this vers. ([AG0N/6](#) Gary NE DN81fv 65.161.181.76)

30Sep 14:42 garv i had it loaded early on both mach was crashing on both went back to 7115 ([K0TPP/2/6/222/](#) Larry MO EM48ri 71.10.182.149)

WSJT meteor scatter: Procedure

30 second sequences (transmitting & listening)

Western-most station transmits at **:00. Other station listens

Eastern-most station transmits at **:30. Other station listens

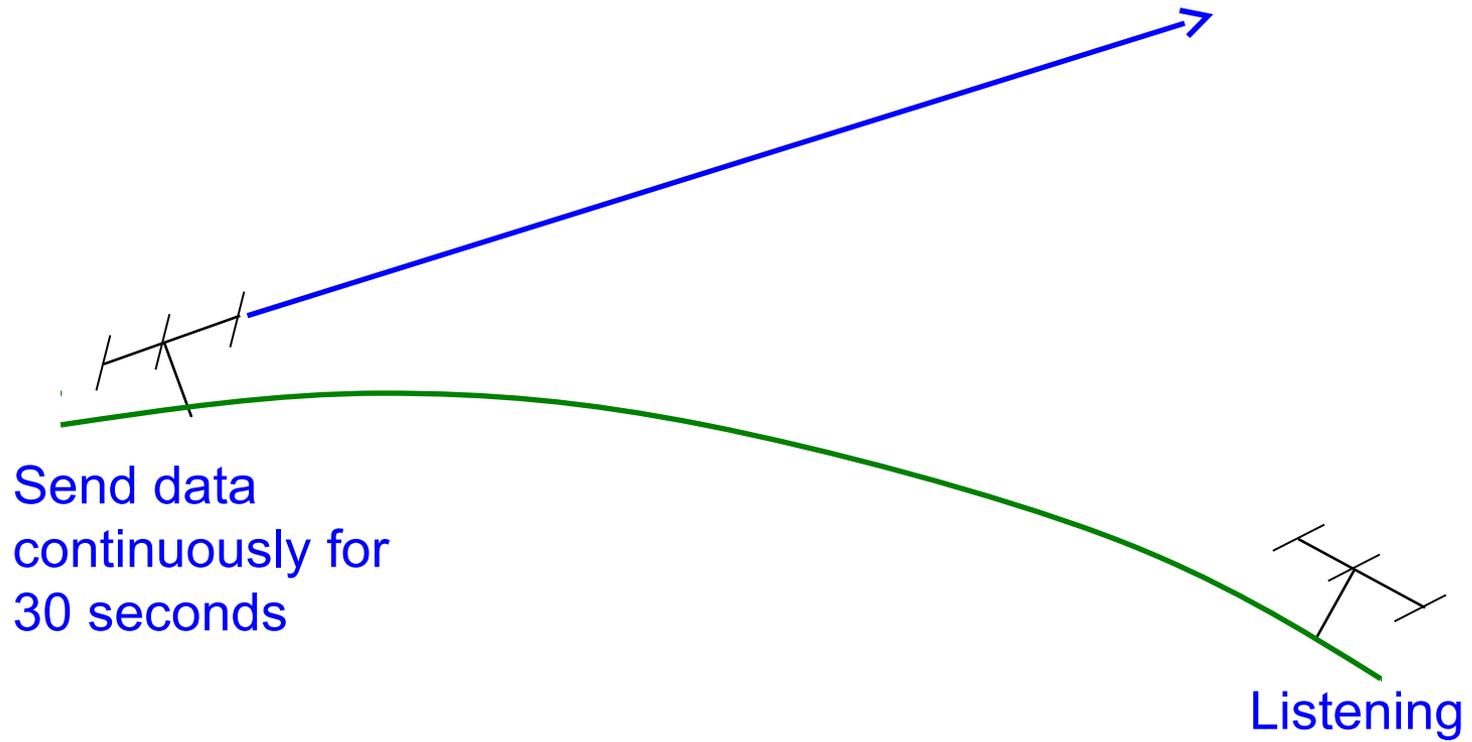
Stations are synched by accurate clocks (eg. GPS or Internet)

Minimum information on both sides to complete QSO:

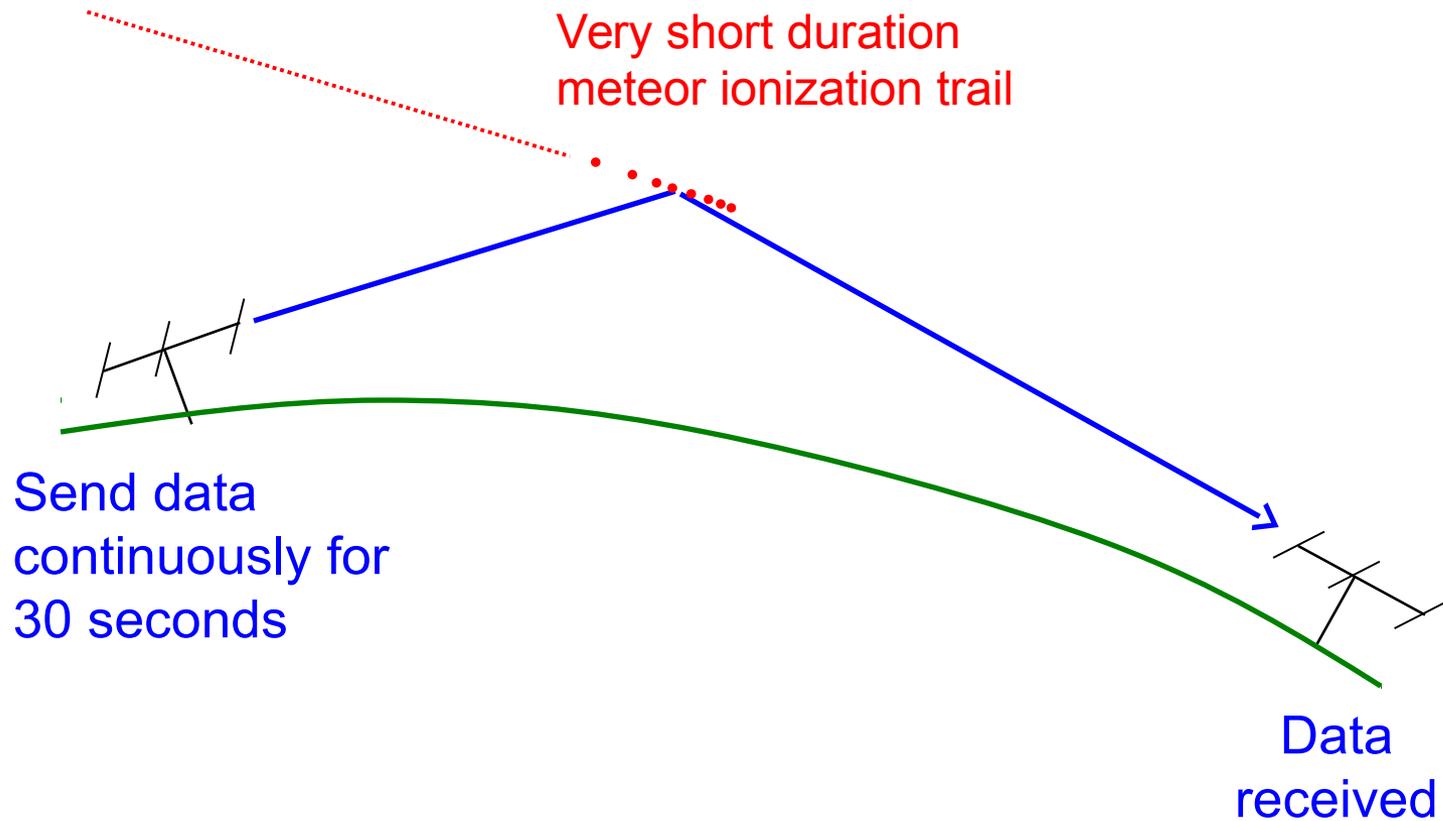
Both callsigns + Report + Roger

Operators use WSJT to decode any pings that are detected

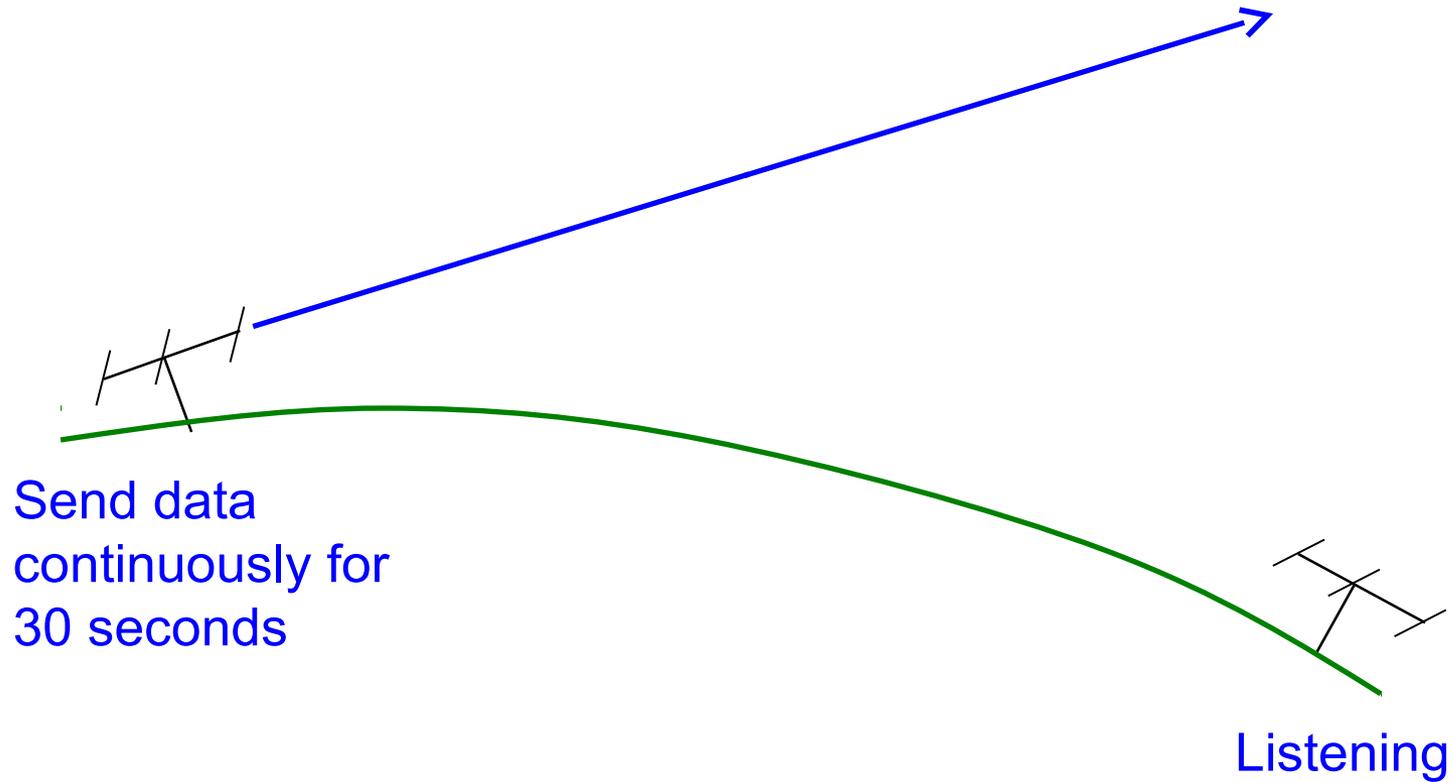
What happens



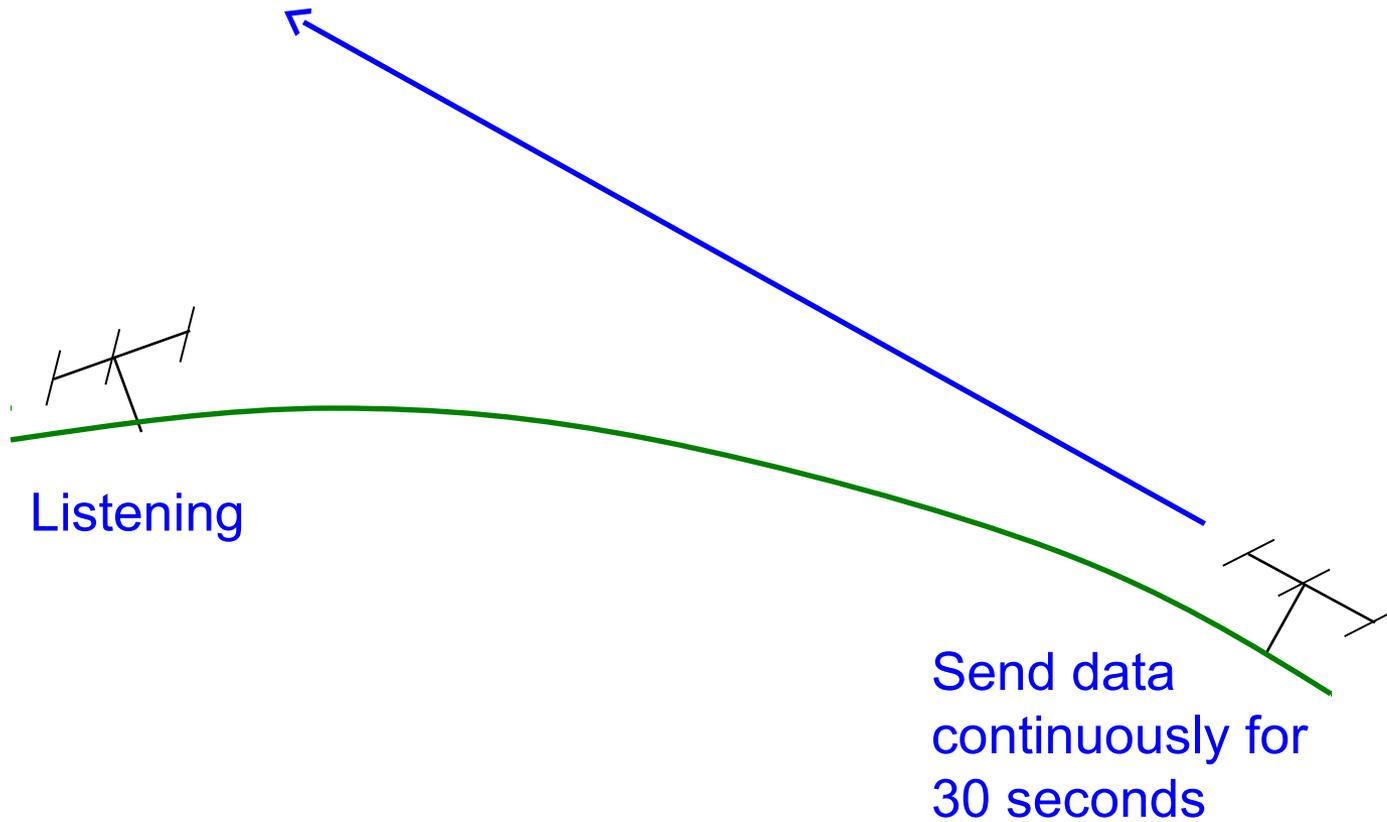
What happens



What happens



What happens



How it works

Frequency Shift Keying at 441 baud (FSK441)

Four tones define the alphabet: 3 tones per character

Tone 0: 882 Hz

Tone 1: 1323 Hz

Tone 2: 1764 Hz

Tone 3: 2205 Hz

Each character (3 tones) requires 0.0068 seconds

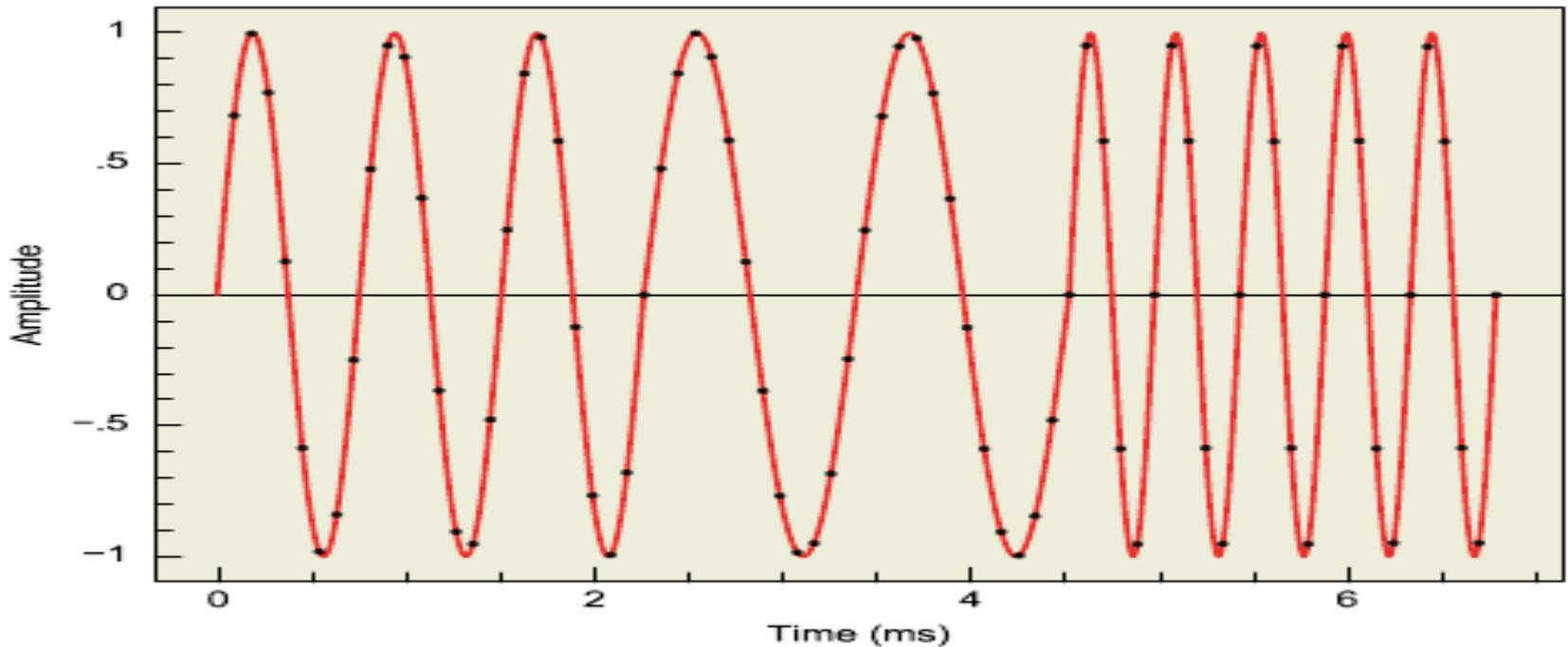
Tones are generated by computer soundcard and transmitted by radio on upper-sideband

The letter C in FSK441

TONE 1

TONE 0

TONE 3



← 6.8 ms →

KG5FHU WB2FKO

033123113011112120211033213102002112123133033

This message is sent **315 times** in
one 30 second transmit interval

Equivalent to 1765 wpm cw

KG5FHU WB2FKO

03312311301112120211033213102002112123133033



Decode algorithm MUST identify a space character

033

to unscramble the tones and display text

123113011112120211033213102002112123133
K G 5 F H U W B 2 F K O

← 88.4 ms →

The **033** space character provides unambiguous synchronization

Must be in every message

Partial decodes are possible *provided*
the **033** space character is present

111121202110332131020021
F H U W B 2

← 50 ms →

211212313303312311301
F K O K G

← 48 ms →

Patient operators can assemble a complete message
with a sufficient number of very short pings



First decoded ping: 144 MHz Albuquerque west mesa November 17, 2002

WSJT by K1JT

File Setup Mode Save Help

0 19.5 Time (s) WA5UFH_021117_232430 30

0 1 2 3 Freq (kHz)

File ID	T	Width	dB	Rpt	DF			
232430	19.5	160	1	26	152	WB2FKO	EL19	WA5UFH EL19EL
232430	19.5	180	5	26	152	TB2FKO	EL19	WA5UFH EL19EL19

Record Monitor Play Stop Save Last Erase

Single-Tone Msgs T/R Period **30** TX First

To radio: **WA5UFH** Grid (6-digit): **EL19pa** W - + Decode Again S - + ST - + Report: **DM65** QRN - + Reset Defaults Tol - +

El: 6 723 mi 1163 km

WA5UFH WB2FKO < Send 1 FSK441
WA5UFH DM65 WB2FKO DM65DM65 Send 2
RDM65 < Send 3 TX Stop

**WA5UFH in
Edna, Texas
720 miles**

Why FSK? Why not PSK? Or high-speed CW?

Tolerant of fast fading and Doppler shifts typical of meteor pings

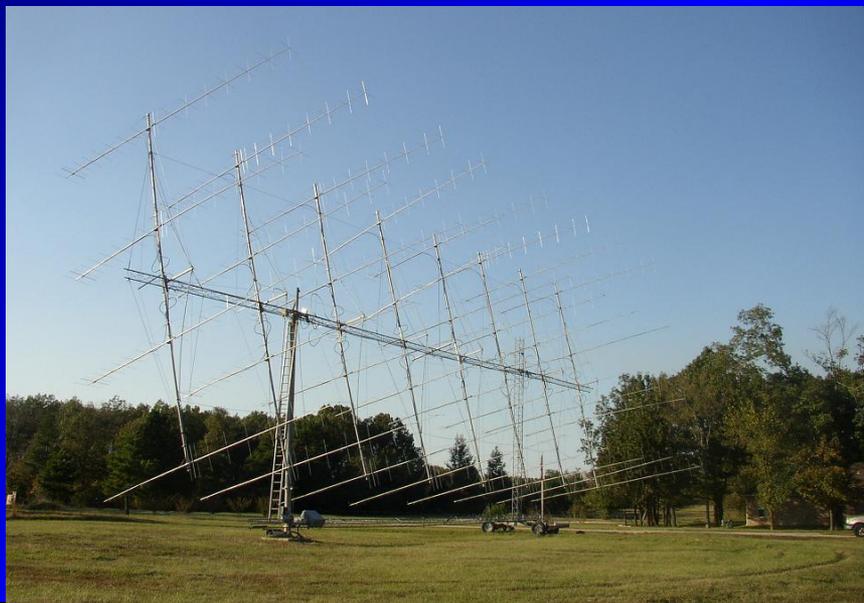
Phase-continuous frequency shifts consume minimal bandwidth:
Signals fit nicely in audio passband of receiver (~ 2.4 kHz)

Very immune to nonlinear amplification, even Class-C

BUT...

The two stations can't be separated by more than 400 Hz
or else no decoding is possible

JT65: ultra-weak but sustained propagation



Developed for Earth-Moon-Earth

**Now widely used for terrestrial
on HF, VHF, UHF, and microwave**

Frequency Shift Keying with 65 tones

More efficient than CW

More tolerant to QSB than PSK

COMPACT and EFFICIENT: 72 bit protocol

KG5FHU WB2FKO DM65

**71 bits in JT65
> 170 bits in CW**

COMPACT and EFFICIENT:

**72 bits also defines any arbitrary message
up to 13 characters:**

73 TNX OLIVIA

FOWARD ERROR CORRECTION:

The crucial enhancement CW does not have

Modems

Hard drives

CDs

DVDs

Blue-Ray

Digital TV

Satellites

Deep-space probes

FOWARD ERROR CORRECTION

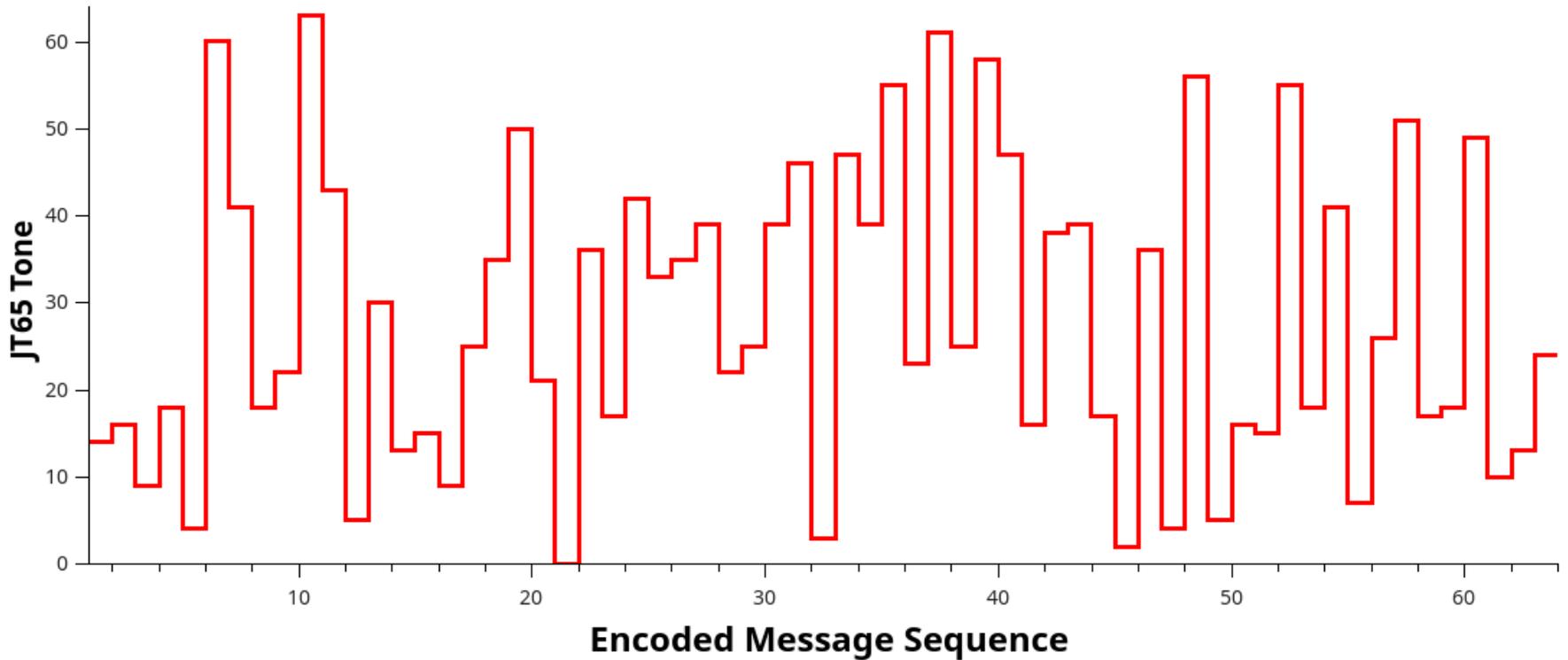
**Each 72 bit message is augmented with
306 Forward Error Correction bits**

81% of the message length are FEC bits

**378 bits then mathematically encoded
into a unique 63 character string
represented by sequence of tones**

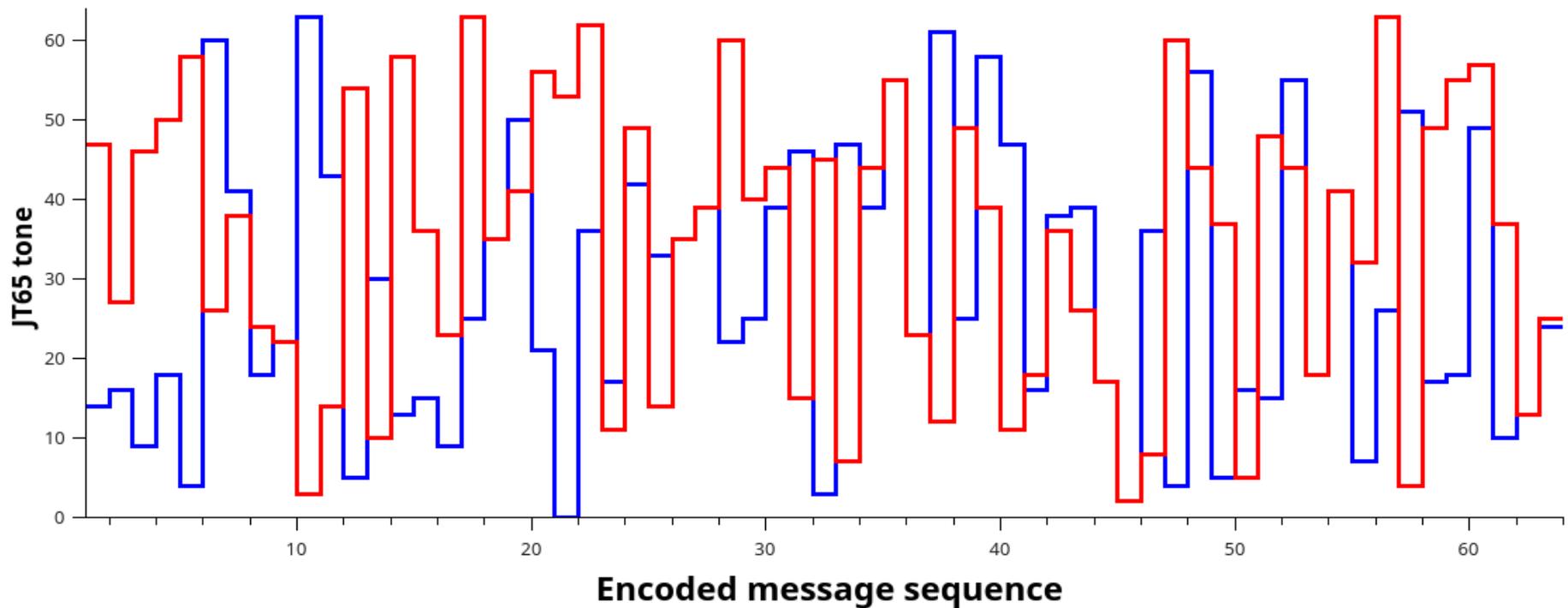
Sequence of JT65 Tones in 63 intervals define a message:

G3LTF DL9KR JO40



Just one character difference radically changes the encoded message tone sequence

G3LTF DL9KR JO40
G3LTF DL9KR JO41



A JT65 message has 126 time intervals

Each interval is 0.372 seconds

Total message duration: 47.8 seconds

63 intervals allotted for the message

63 intervals allotted for time **SYNCHRONIZATION**

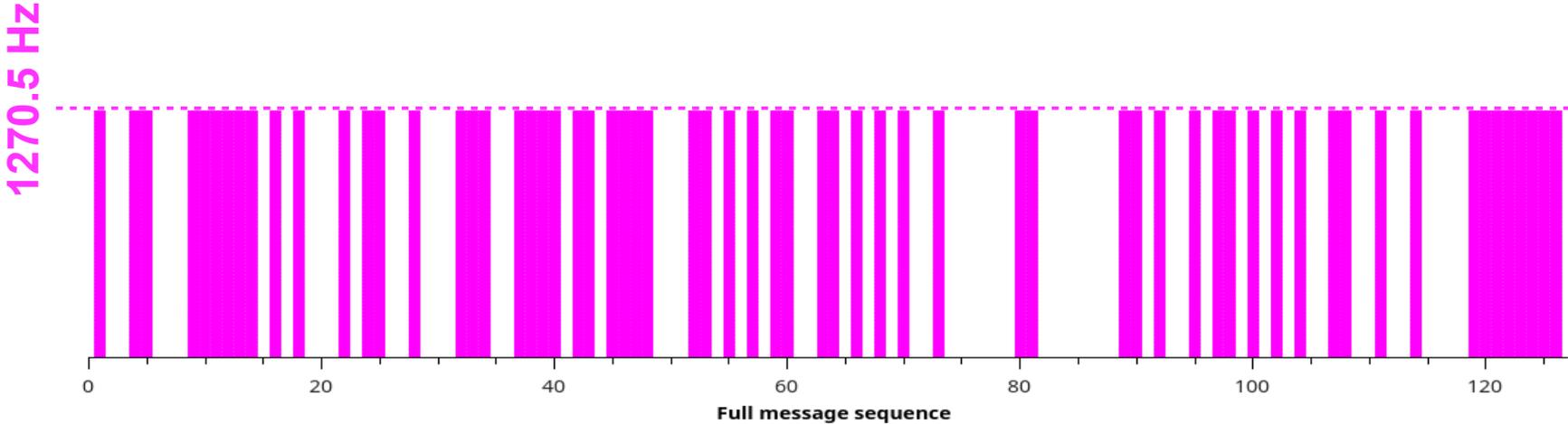
SYNCHRONIZATION IN JT65

The decoder requires an accuracy ≤ 0.03 seconds

Can't accomplish this with amateur gear

The message must supply its own synch signal

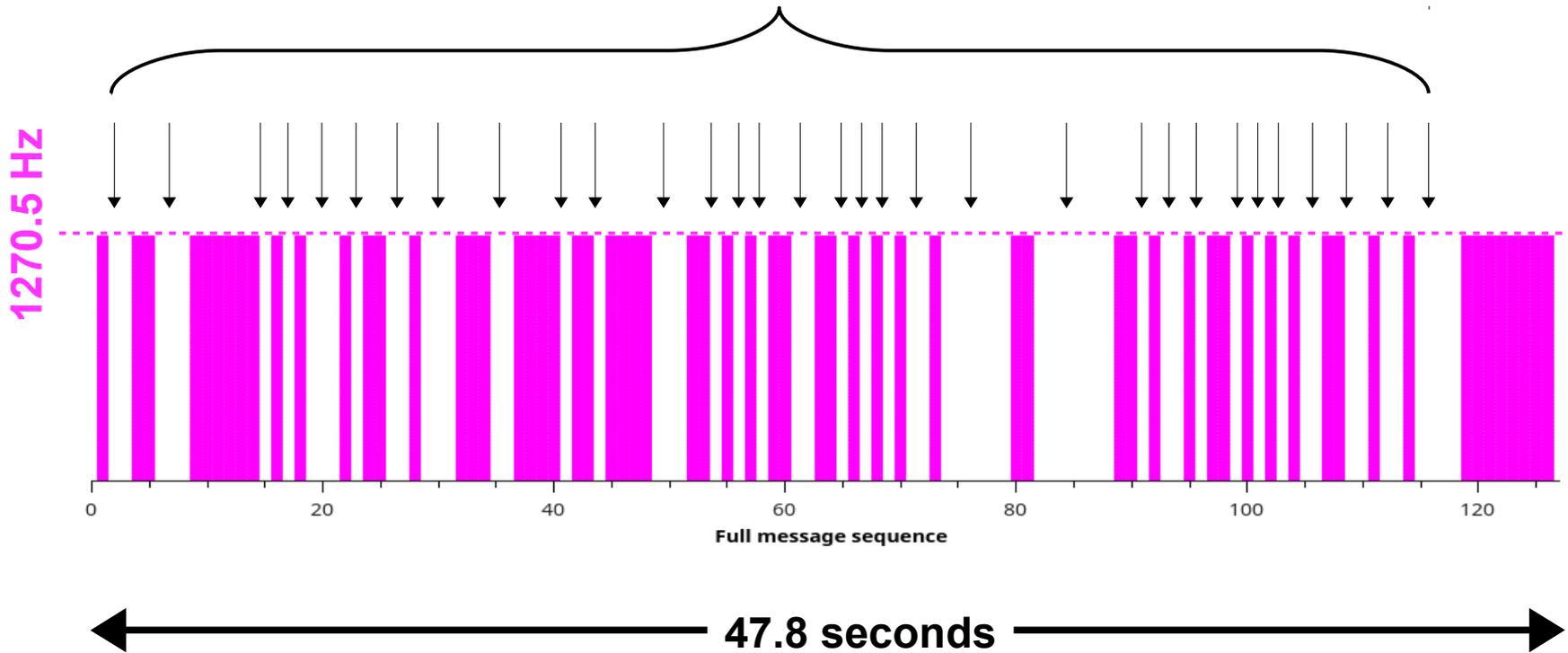
Half of each message is used for synchronization
Synch tone at 1270.5 Hz



47.8 seconds

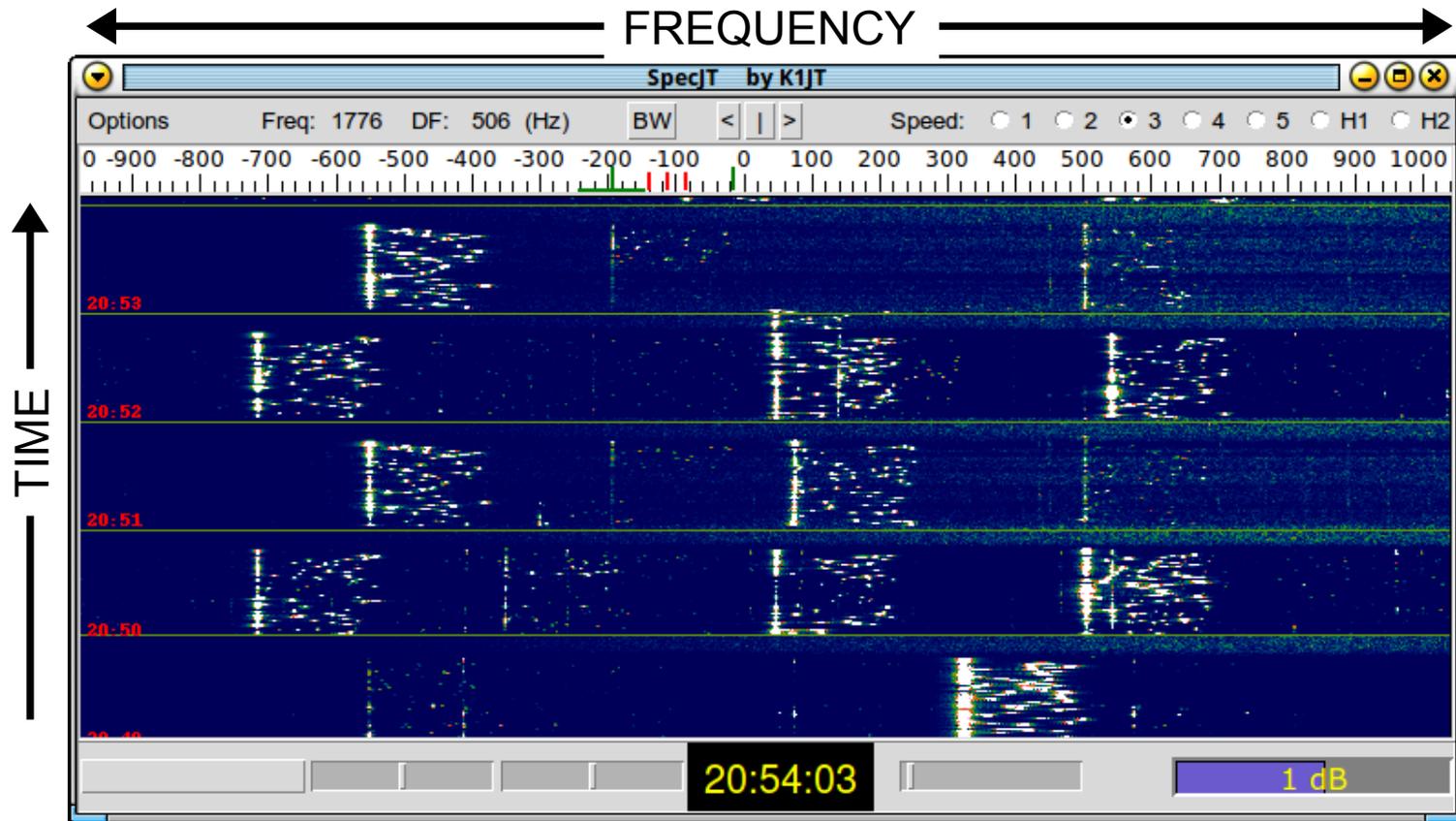
**Half of each message is used for synchronization
Synch tone at 1270.5 Hz**

Encoded message is in the remaining 63 time intervals



JT65 signals on 6 meters

August 2016



Many signals in receiver bandwidth
Prominent synch traces are visible
Frequency stability important for decode reliability

Maintaining absolute stability of amateur equipment gets harder as frequency increases

JT65A: HF – 50 MHz (most sensitive)

JT65B: 144, 222 MHz

JT65C: 432 MHz and up (least sensitive)

The price paid: *TIME!*

Even with perfect decodes a
WSJT QSO requires at least 4 minutes

Best use of time in a contest?

If the path supports SSB or CW,
use these modes instead



The Challenge:
Albuquerque to Las Vegas, Nevada
144 MHz direct using JT65

W7OJT --- WB2FKO: *475 miles*

**The Challenge:
Albuquerque to Las Vegas, Nevada
144 MHz direct on JT65**

**Oooops,
It's W5UN!**



The Accidental EME QSO

Dave Scroggins, W7OJT, and Mike Hasselbeck, WB2FKO

Do you think radio communication by moon reflection is the exclusive playground of megabuck stations with big amplifiers and enormous antenna arrays? That used to be the case, but with the availability of Joe Taylor's *WSJT* software, this is no longer true. I recently became a believer, and then only by complete accident!

WSJT stands for Weak Signal communication by Joe Taylor, K1JT. The software can be conveniently separated into two general modes. The *FSK441* mode uses very high data rates to allow communication via reflection from short-lived meteor ionization trails that randomly light up the upper atmosphere. These meteor bursts are called pings. The *JT65* mode of *WSJT* uses advanced signal processing techniques to decode very weak but generally steady signals that are often inaudible to the ear. This mode was designed primarily with EME (earth-moon-earth) communication in mind and is now in worldwide use for this purpose. The *WSJT* software is free and can be downloaded from pubs.princeton.edu/~joe/K1JT/.

By the end of 2004, I was getting the knack of *FSK441*, having made dozens of contacts with stations throughout the western United States via meteor scatter on 144 MHz. Most of these were accomplished in non-shower conditions, using meteor pings that randomly but constantly enter the Earth's atmosphere. I have a fairly modest station at my Las Vegas, Nevada location: a single 10 element beam and a brick amplifier.

We Try to Span the 500 Miles Between Us

Most meteor scatter QSOs are arranged by schedule on a Web site appropriately called "Ping Jockey" (www.pingjockey.net/cgi-bin/pingtalk). Late one winter evening, coauthor Dave, W7OJT, spotted his friend (and coauthor) Mike, WB2FKO, in Albuquerque, New Mexico, on Ping Jockey. We had previously worked each other on *FSK441* meteor scatter, but we had been trying for several weeks to cover the 488 mile path between us using *JT65*. This

While trying to set up a meteor scatter contact, the authors instead discover EME!



Coauthor Dave Scroggins, W7OJT, shows off the modest 10 el beam he used to make contact with world-class EME op Dave Blaschke, WBUN.

mode is well suited for long-haul contacts like this, where the signals are extremely weak. *JT65* is very effective at pulling information out of the white noise.

Without the aid of meteors, tropo-scatter enhancement or sporadic E, we found the Las Vegas to Albuquerque path to be a formidable challenge on 2 meters. The miles of tall mountains in northwest Arizona are probably the largest factor preventing us from completing a *JT65* QSO. But we continued to try, making several attempts.

Using the chat site, Dave asked Mike if he'd like to attempt a QSO. He agreed and we moved to the *JT65* page of Ping Jockey to choose the operating parameters. Both *WSJT* modes require the two

stations to be appropriately synchronized—you have to be listening when your QSO partner is transmitting, and vice versa. In *JT65*, it is necessary to have the two stations' computer clocks closely synchronized. This is accomplished using one of a variety of time references on the Internet or a handheld GPS. You also have to agree on who transmits when—in *JT65* you alternately transmit and receive every other minute.

We set the sequences and began to scan the band for a quiet frequency. Mike suggested 144.130 MHz, but I had a birdie there. *Birdie* is the general term describing a carrier or other noise from various electrical sources such as pagers, cordless phones, poorly filtered home entertain-

What else?

WSJT-X: New experimental modes in development

WSPR: Weak Signal Propagation Reporter

Help: WSJT Yahoo Users Group

What else?

WSJT-X: New experimental modes in development

WSPR: Weak Signal Propagation Reporter

Help: WSJT Yahoo Users Group

New Mexico VHFers Unite!
Join us at **NMvhf.org**