

# Evolution of the WSJT Digital Modes

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**WB2FKO**

**New Mexico TechFest**  
**25 February 2017**

# **WSJT**: A software package for digital radio communication

**W**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 2017



**A free open-source download!**

# Two general use scenarios:

- 1) Fast modes: Meteor scatter on VHF**  
Ionization in the E-layer by random meteors  
Propagation path exists for  $< 1$  second
- 2) Slow modes: 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**

# WIDE VARIETY OF MODES AVAILABLE FOR DIFFERENT APPLICATIONS

**JT4**

**FSK315**

**JT65**

**JT6**

**FSK441**

**QRA64**

**JT6M**

**ISCAT**

**WSPR**

**JTMS**

**MSK144**

**Echo**

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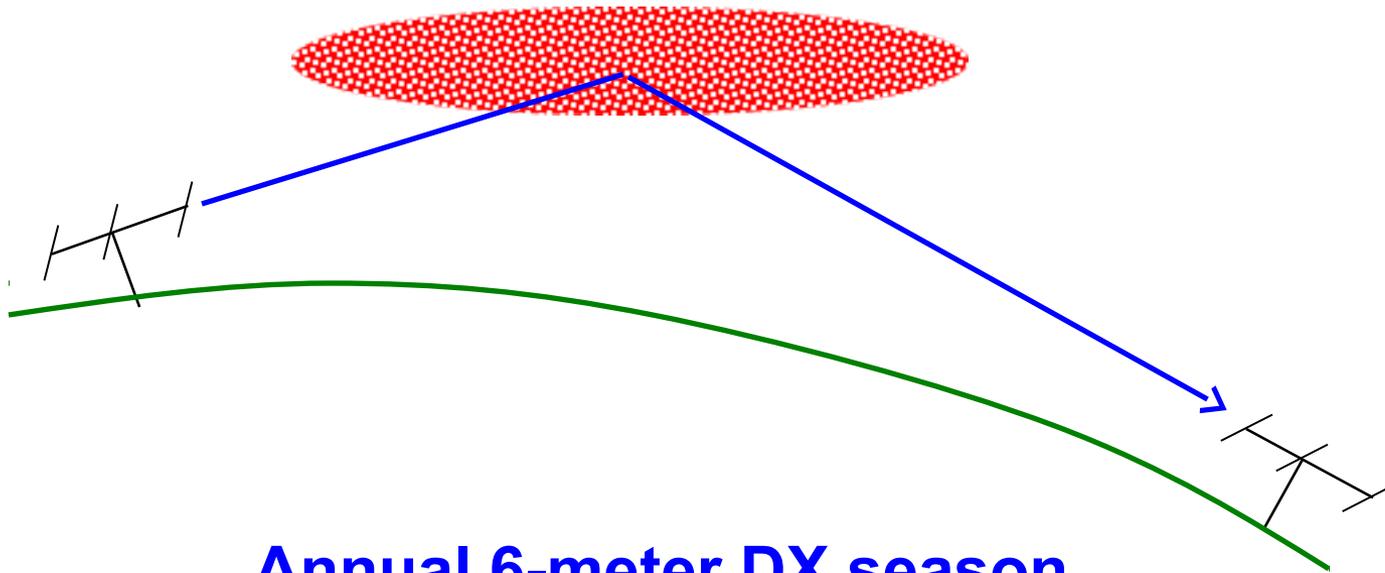
**JTMS**

 **MSK144**

**Echo**

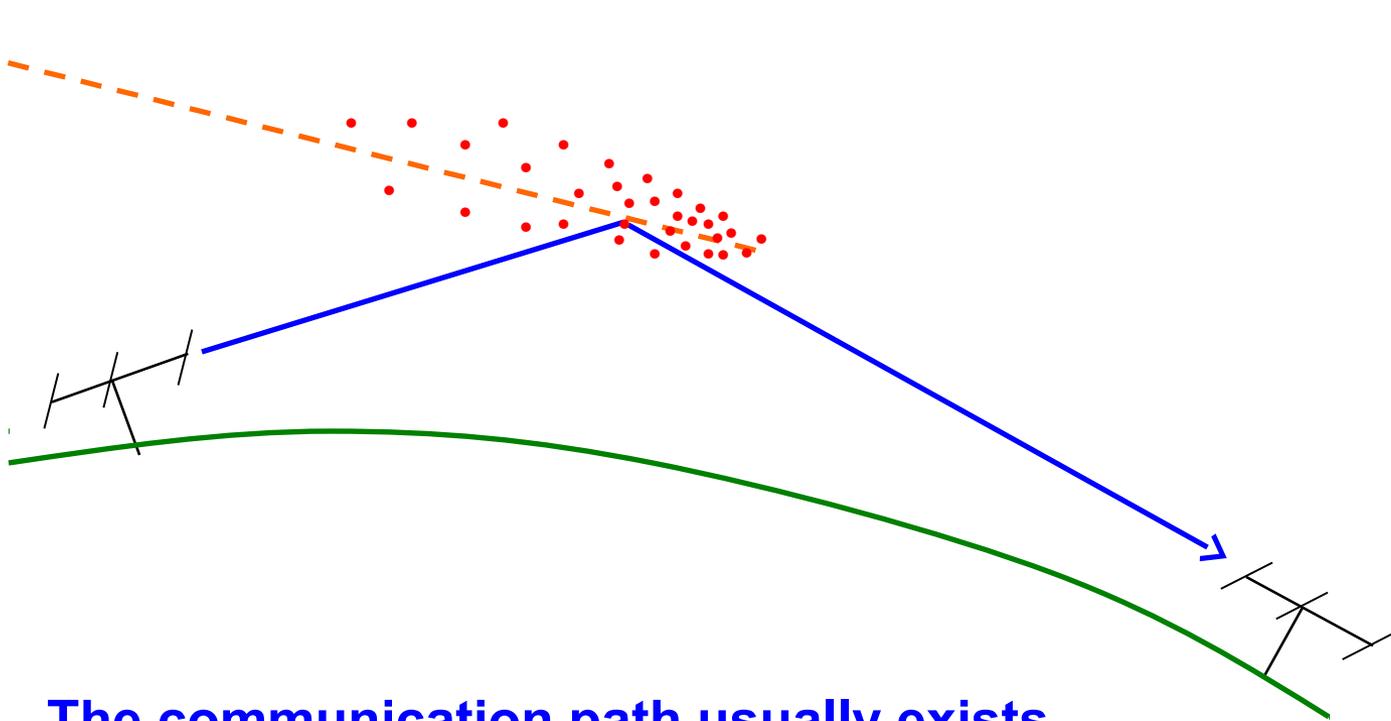
# **VHF meteor scatter: Propagation via the E-layer**

**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?**

**Computer + radio/soundcard interface**

**Usually 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.



<a href="#">Relief page</a>	<a href="#">Skeds in-progress</a>	<a href="#">CQ Announcements</a>	<a href="#">JT65 Link</a>
<a href="#">Refresh</a>	<a href="#">Look back</a>	<a href="#">Distance/Bearing Locator</a>	<a href="#">Who's Earwiggling?</a>
<a href="#">Update User details</a>	<a href="#">AA1YN Callsign database</a>	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)

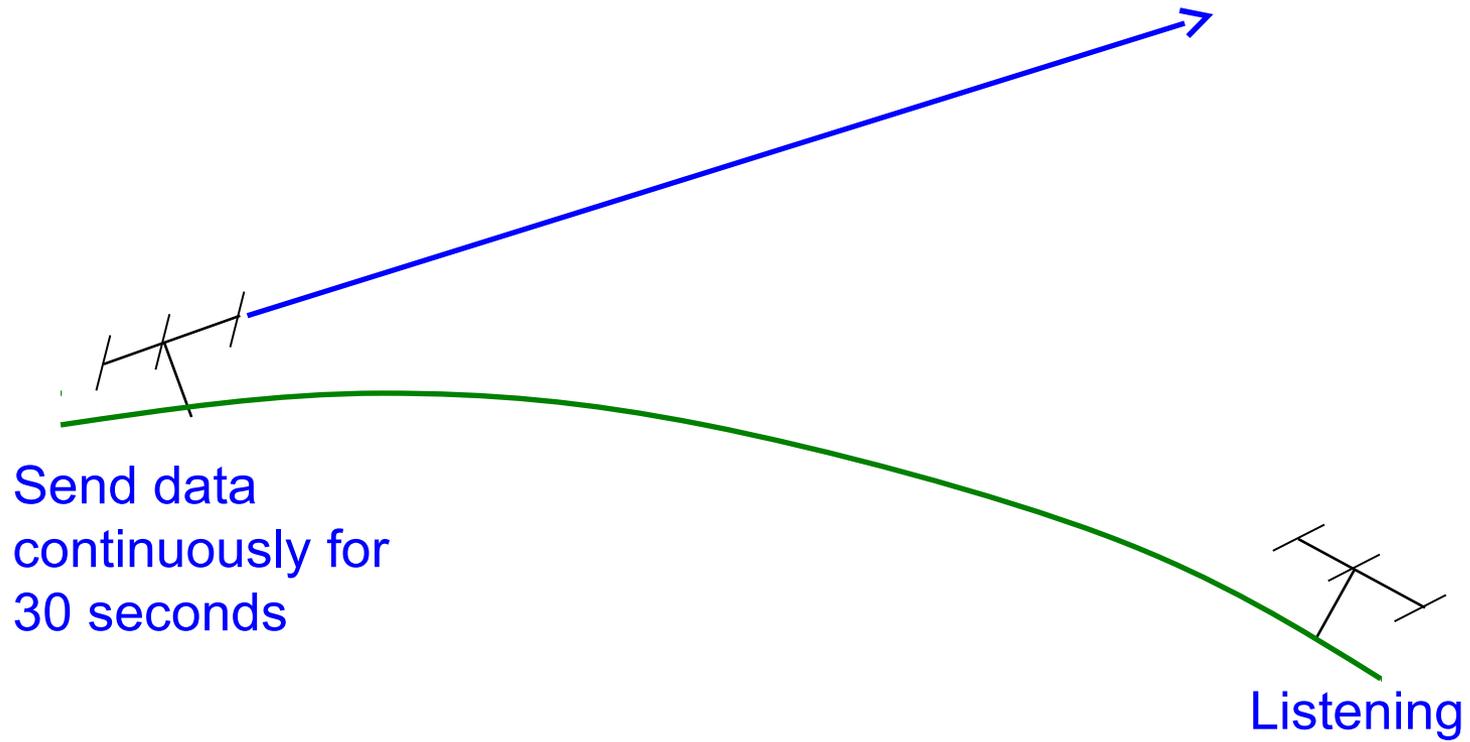
Minimum information on both sides to complete QSO:

Both callsigns + Report + Roger

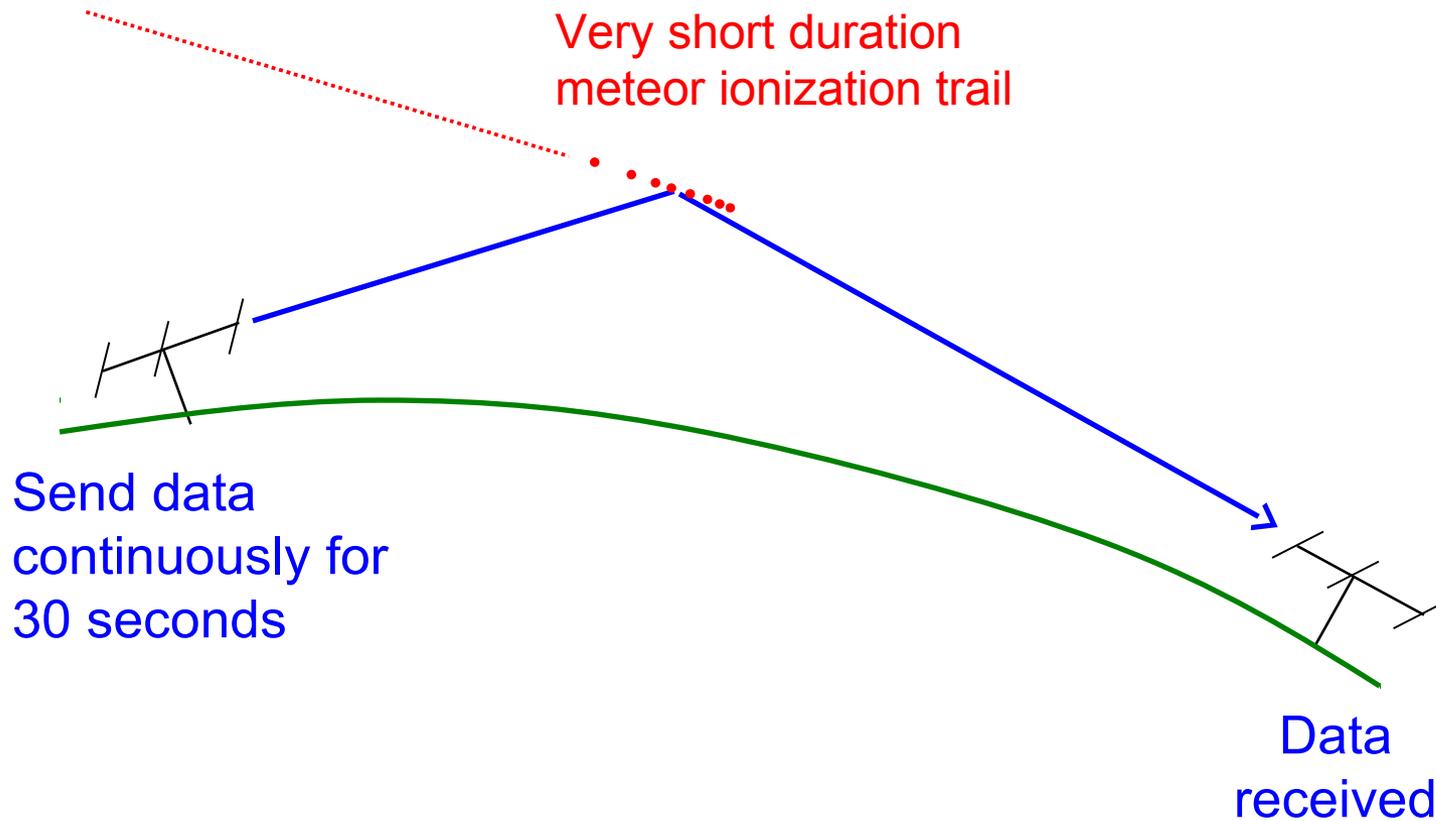
Operators use WSJT to decode any pings that are detected

**As of Fall 2016, North America now using  
15 second sequences**

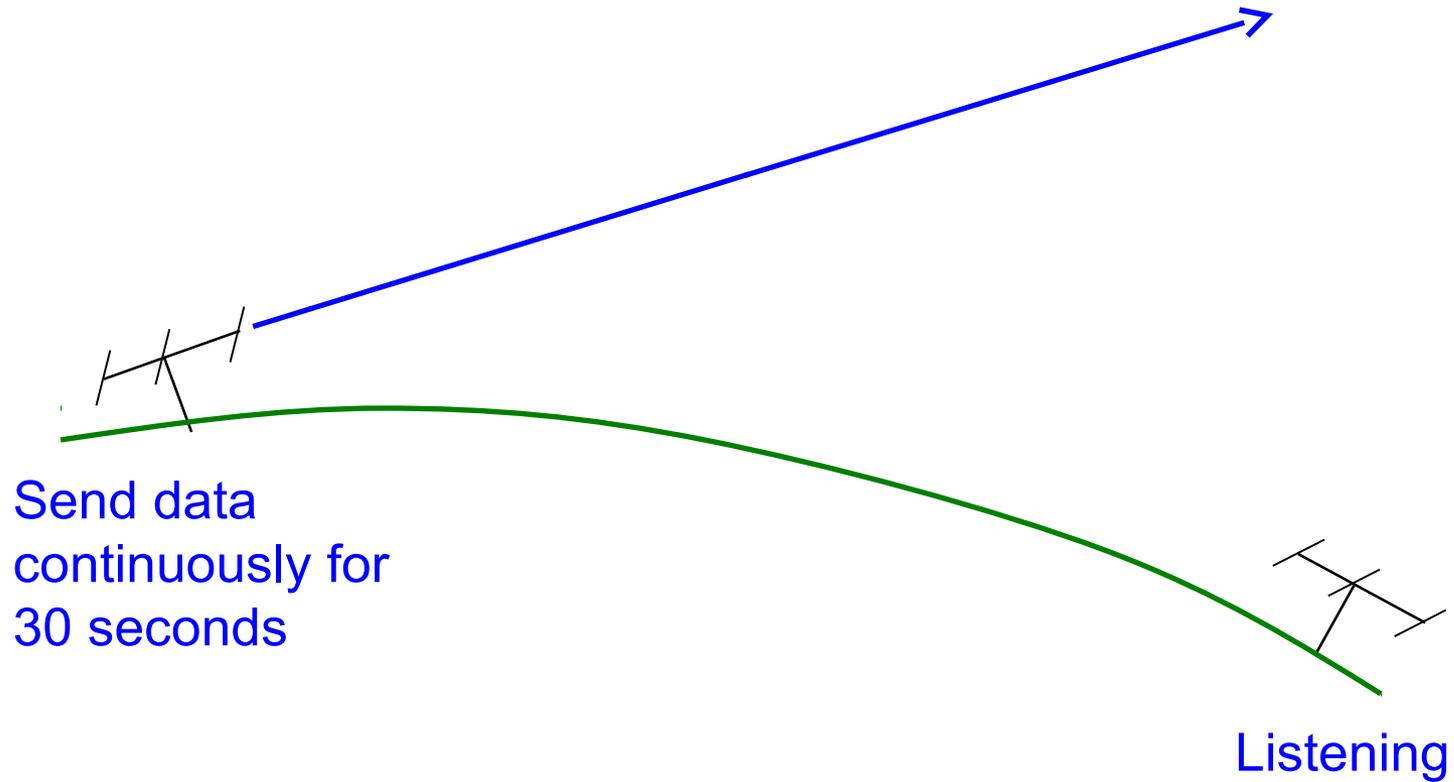
# What happens



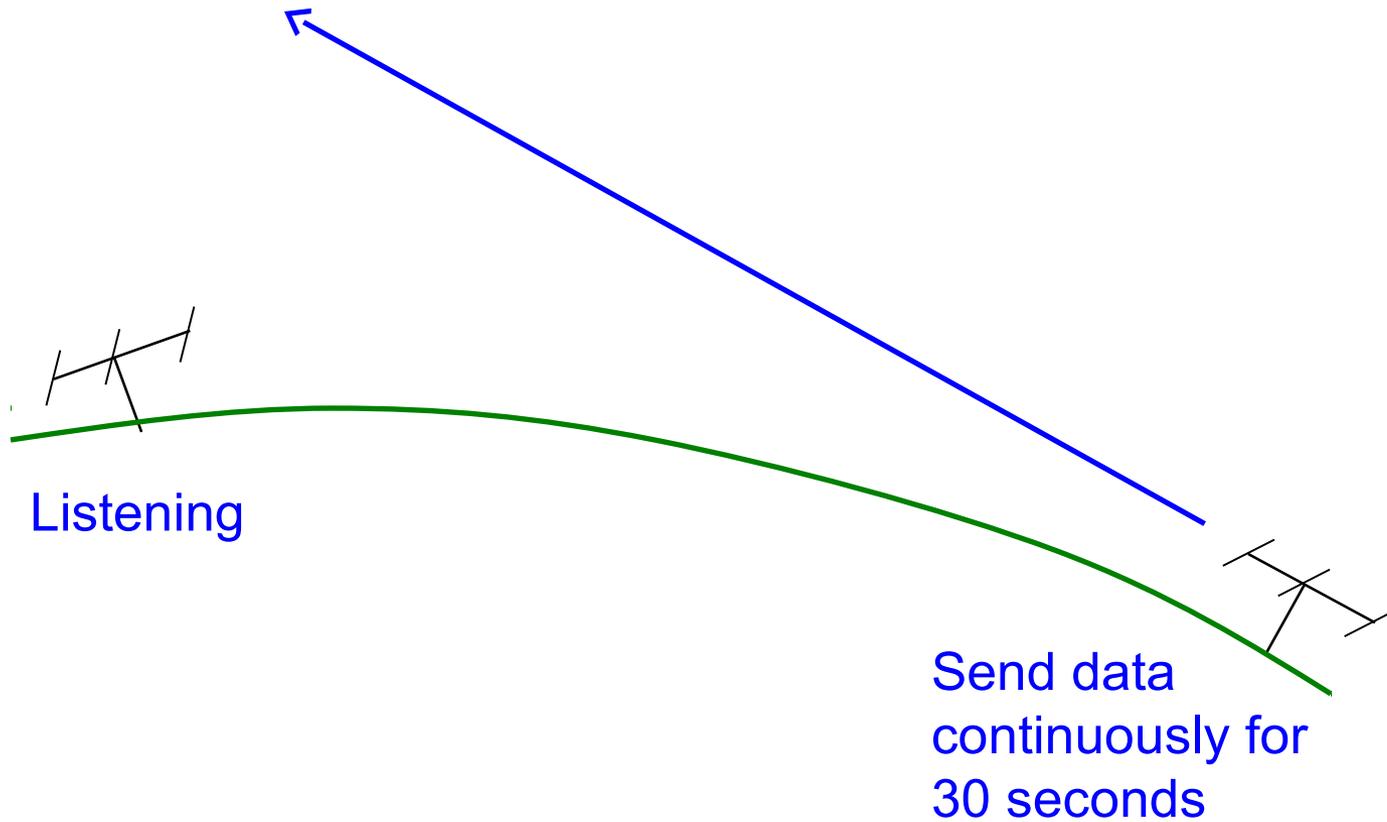
# What happens



# 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 sine wave

Tone 1: 1323 Hz sine wave

Tone 2: 1764 Hz sine wave

Tone 3: 2205 Hz sine wave

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

**Computer sound card serves as A-D converter to generate the tones**

**A-D sampling at 11025 samples/second**

**Exactly 25 samples/tone**

**Each tone requires ~ 2.3 ms → 441 baud**

**Tone 0: 882 Hz**      2 periods generated

**Tone 1: 1323 Hz**      3 periods generated

**Tone 2: 1764 Hz**      4 periods generated

**Tone 3: 2205 Hz**      5 periods generated

**3 “bits” per character**

**Each bit represented by 1 of 4 tones**

**EXAMPLE: C = TONE1 TONE0 TONE2**

**64 unique characters (only 43 used)**

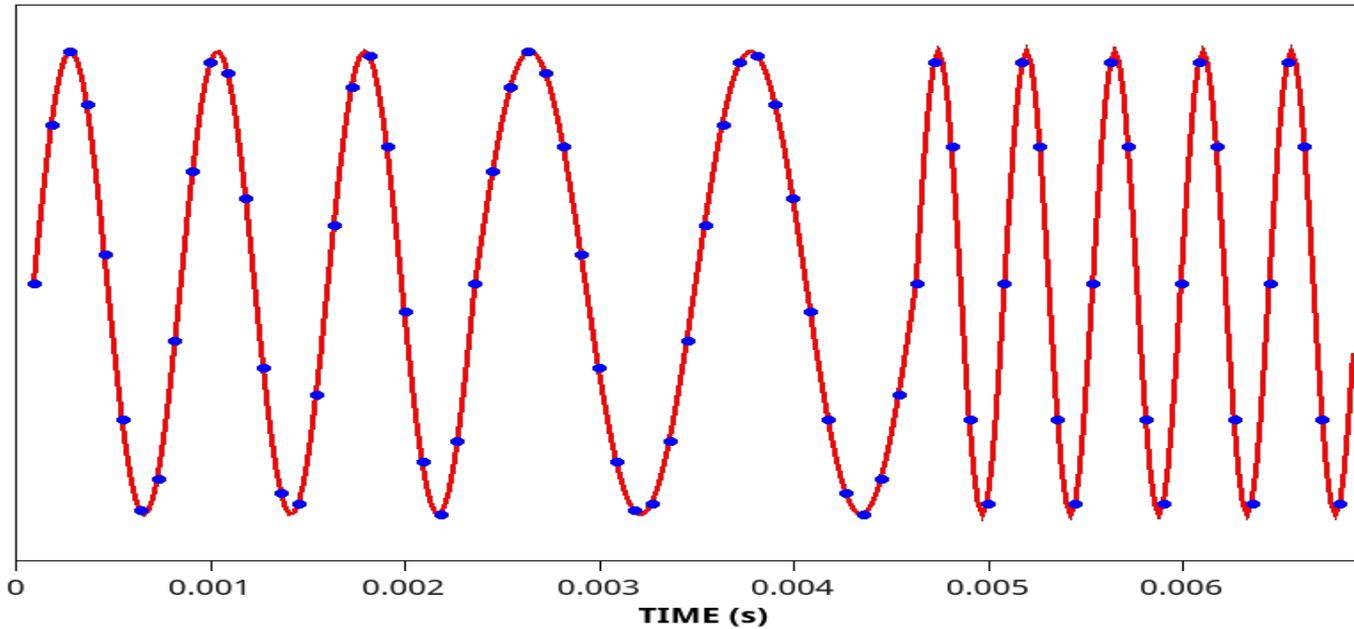
**Each character (3 tones) requires ~ 6.8 ms**

# The letter C in FSK441

TONE 1

TONE 0

TONE 3



← 6.8 ms →

# KG5FHU WB2FKO

03312311301112120211033213102002112123133033

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

Equivalent to 1765 wpm cw

# KG5FHU WB2FKO

033123113011112120211033213102002112123133033



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

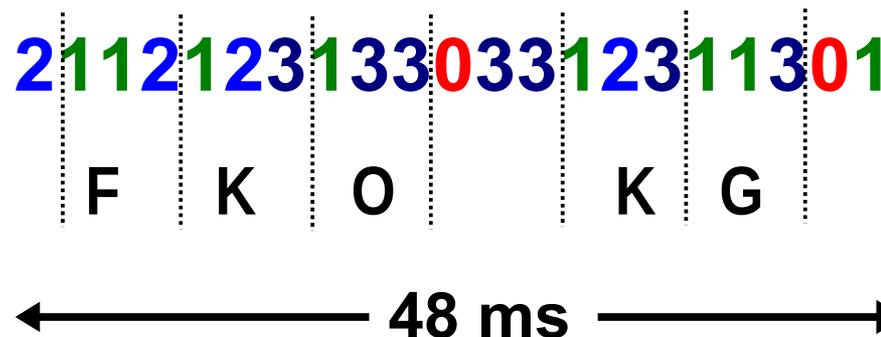
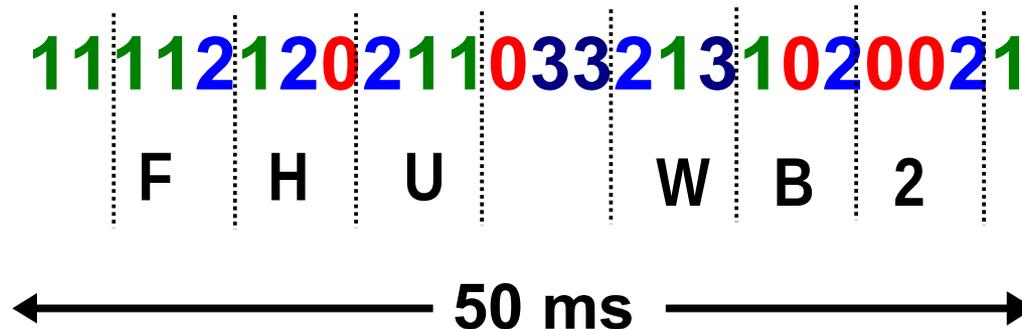
← 88.4 ms →

The **033** space character provides unambiguous synchronization

Must be in every message

No characters start with **3** to avoid confusion with **033**

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



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 S - + Decode Again ST - + Report: **DM65** QRN - + Reset Defaults Tol - +

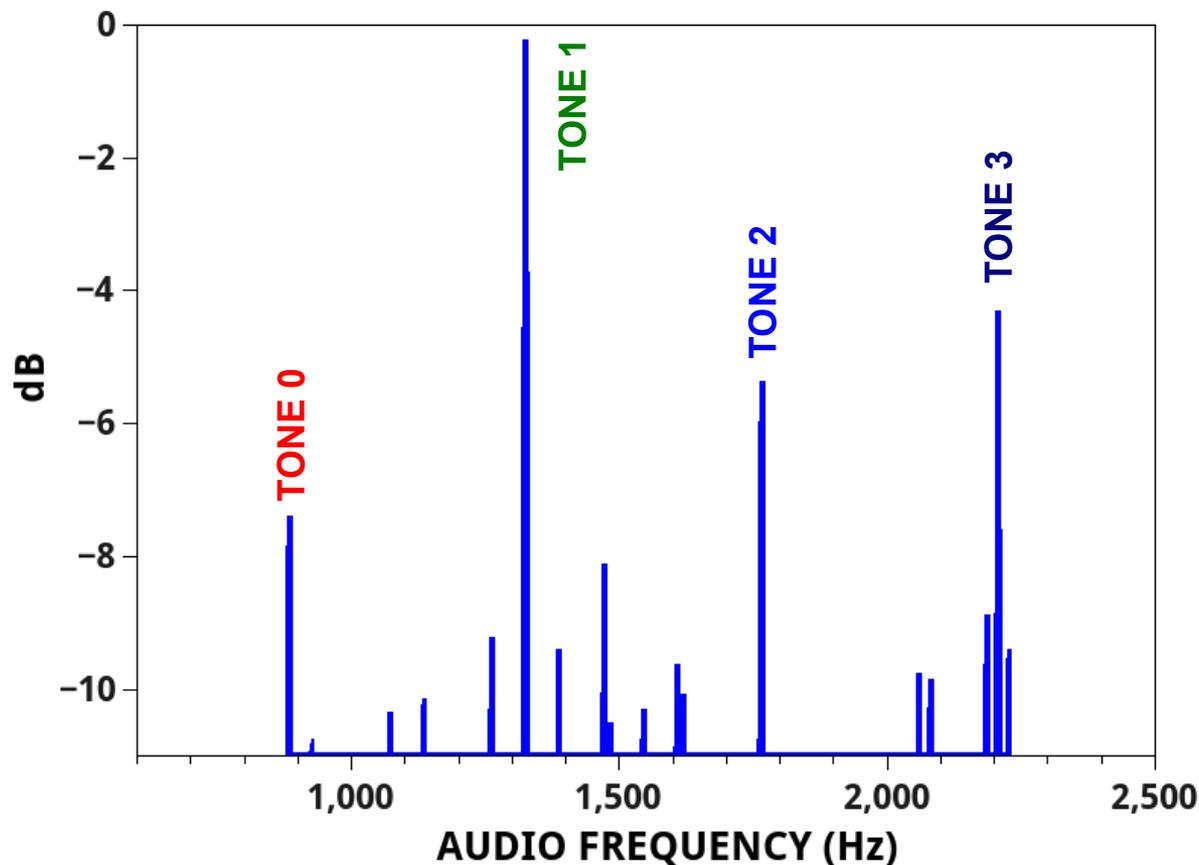
El: 6  723 mi 1163 km

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

**WA5UFH in  
Edna, Texas  
720 miles**

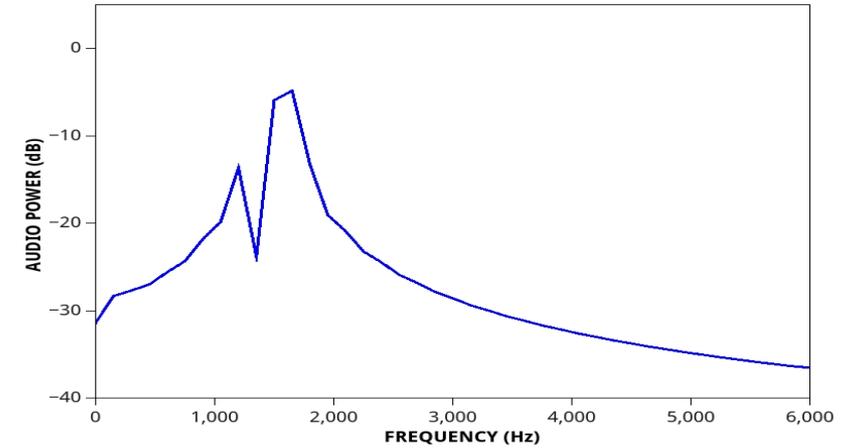
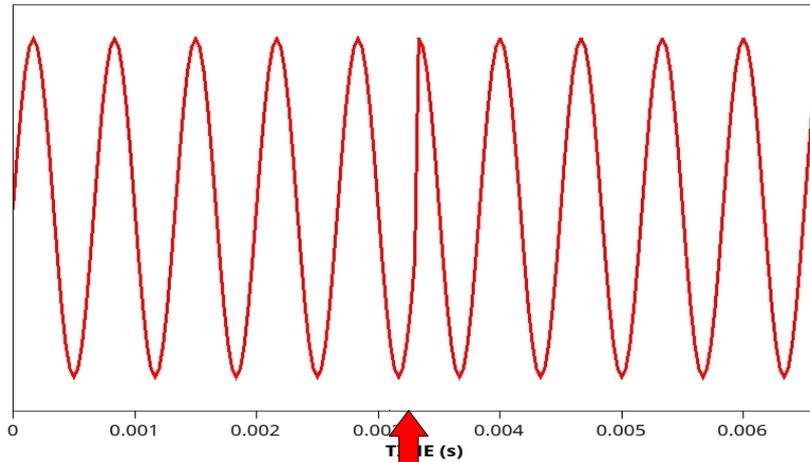
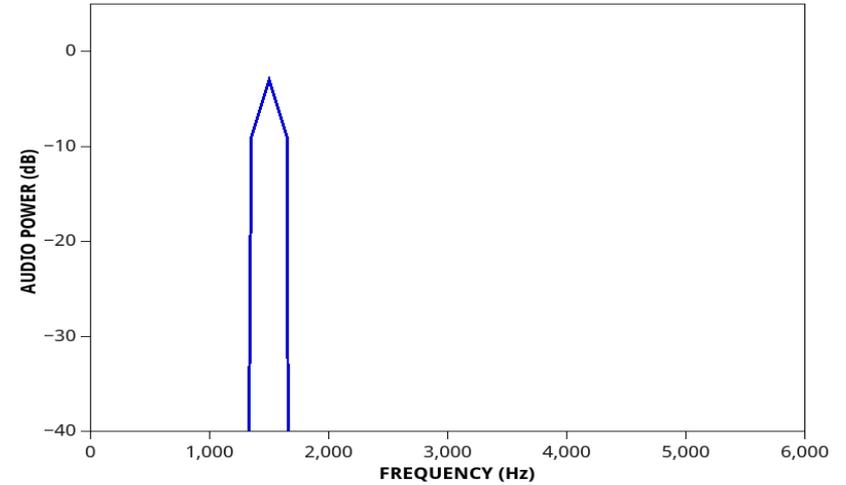
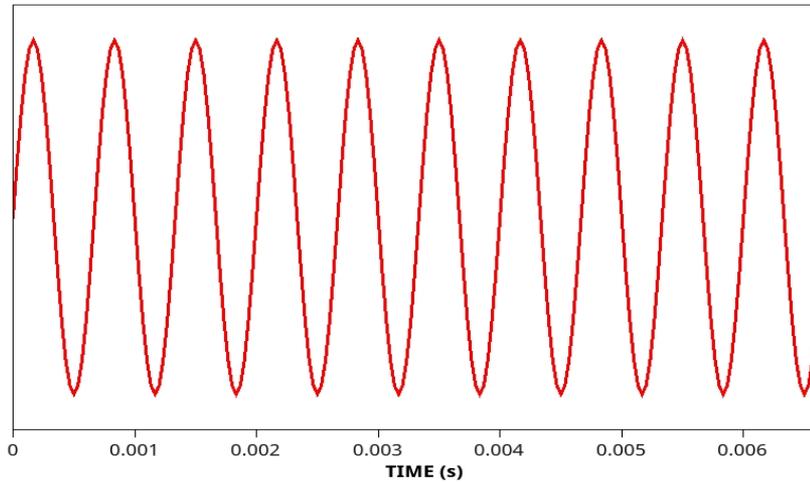
# TRANSMITTED AUDIO SPECTRUM: KG5FHU WB2FKO

033123113011112120211033213102002112123133



OCCURRENCE	
TONE 0:	7
TONE 1:	16
TONE 2:	9
TONE 3:	10

# HOW IMPORTANT IS CONTINUOUS PHASE?

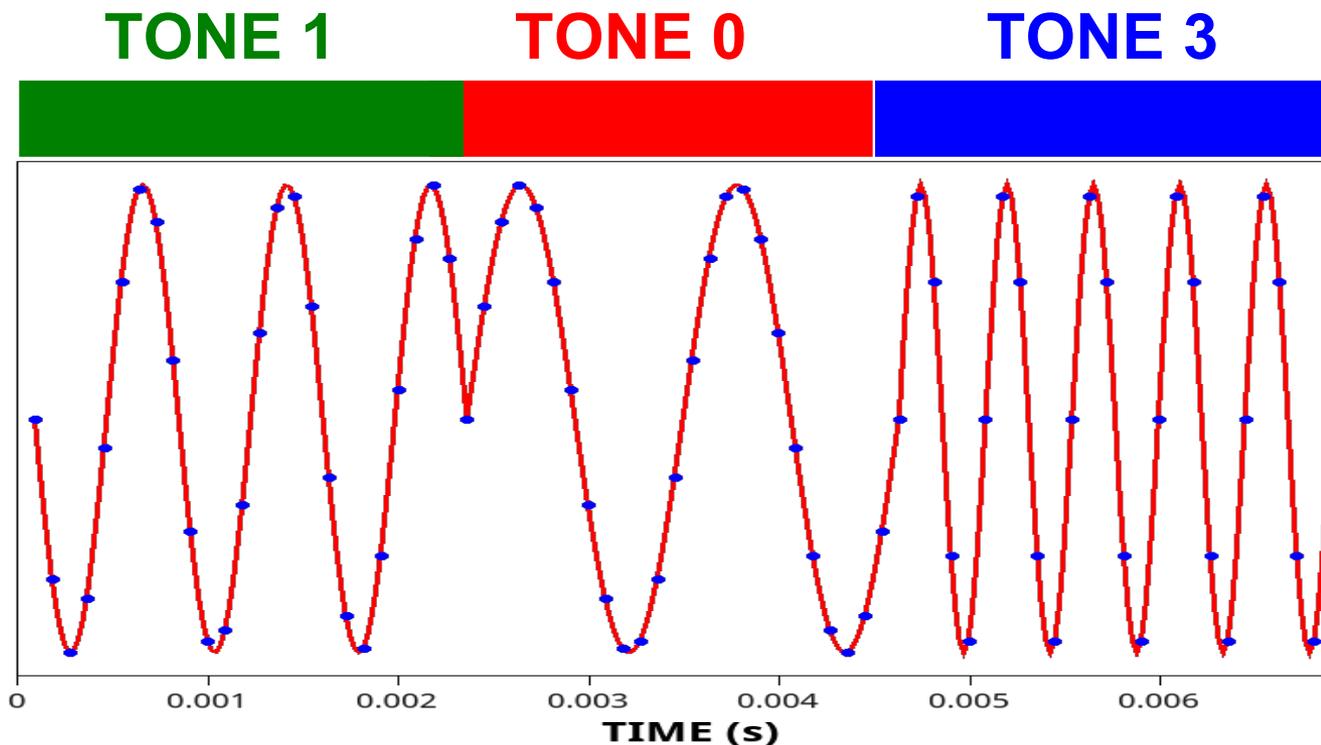


**90° phase-shift**

# HOW IMPORTANT IS CONTINUOUS PHASE?

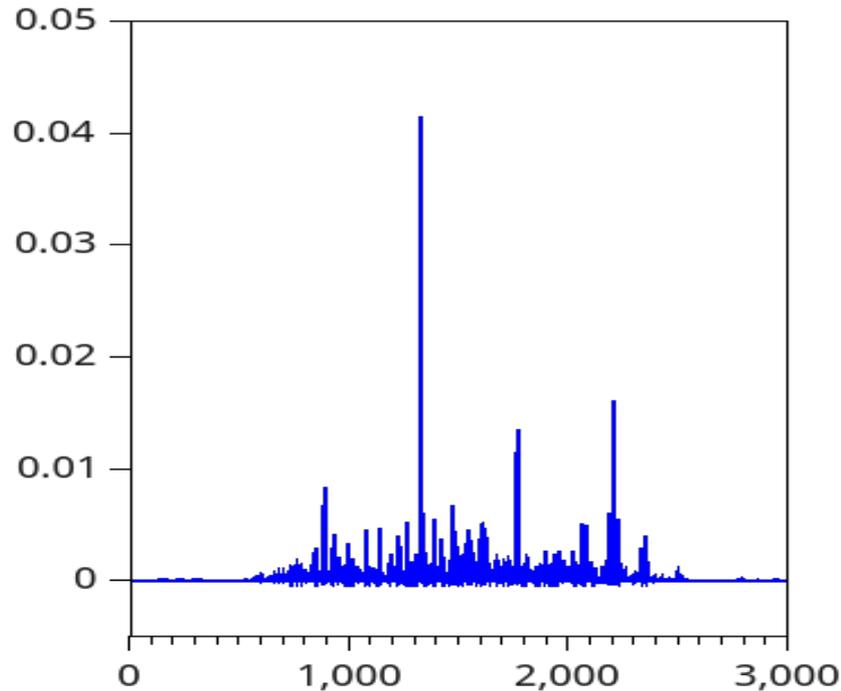
Deliberately introduce  $180^\circ$  phase discontinuity on **TONE 1**

FSK441 time trace of letter **C**:



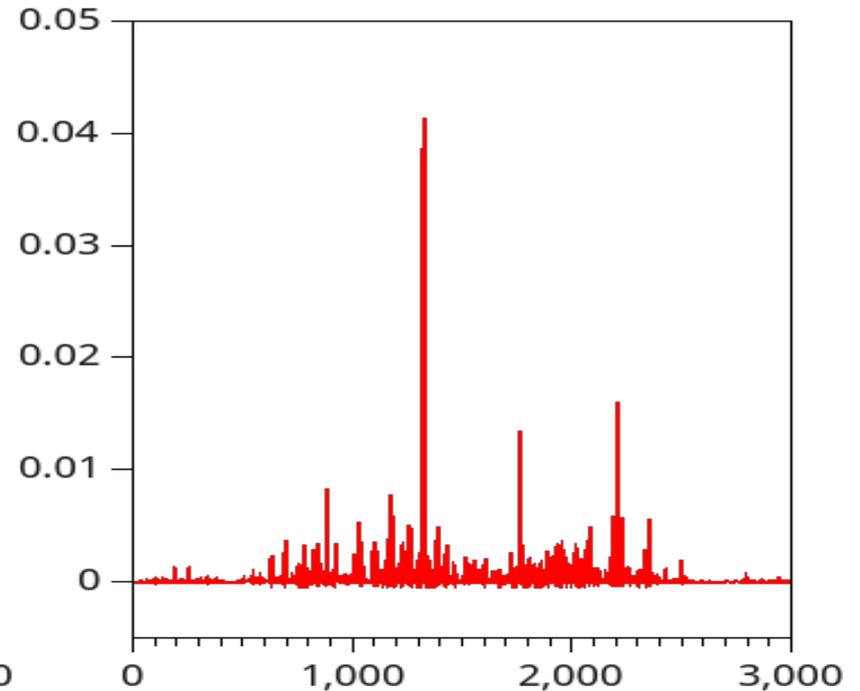
# TRANSMITTED AUDIO SPECTRUM: KG5FHU WB2FKO

CONTINUOUS PHASE



**AUDIO FREQUENCY (Hz)**

180° OFFSET ON TONE 1



**AUDIO FREQUENCY (Hz)**

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

Tolerant of fast fading and Doppler shifts typical of meteor pings

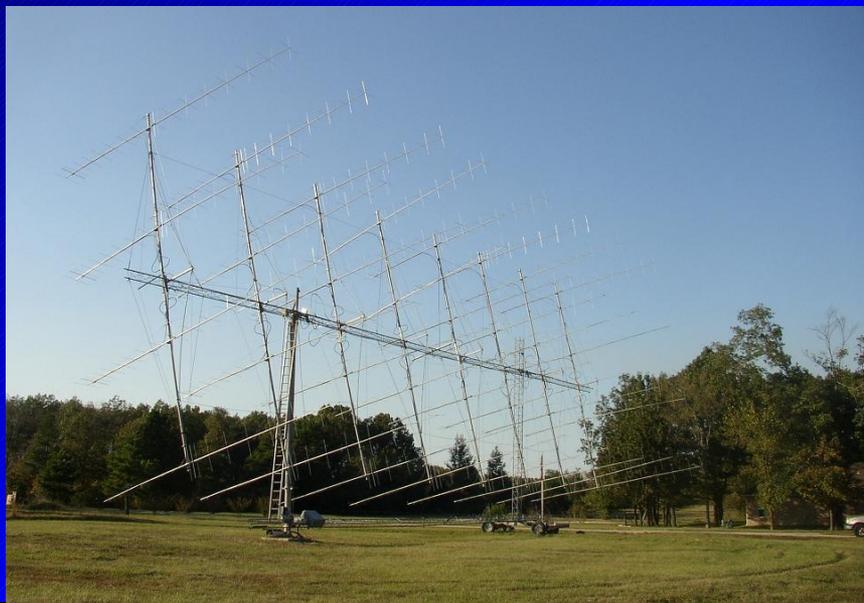
Phase-continuous frequency shifts consume minimal bandwidth:  
Signals fit nicely in audio passband of receiver (~ 2.4 kHz)

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**

**D-Star**

**Satellites**

**Deep-space probes**

# **FOWARD ERROR CORRECTION**

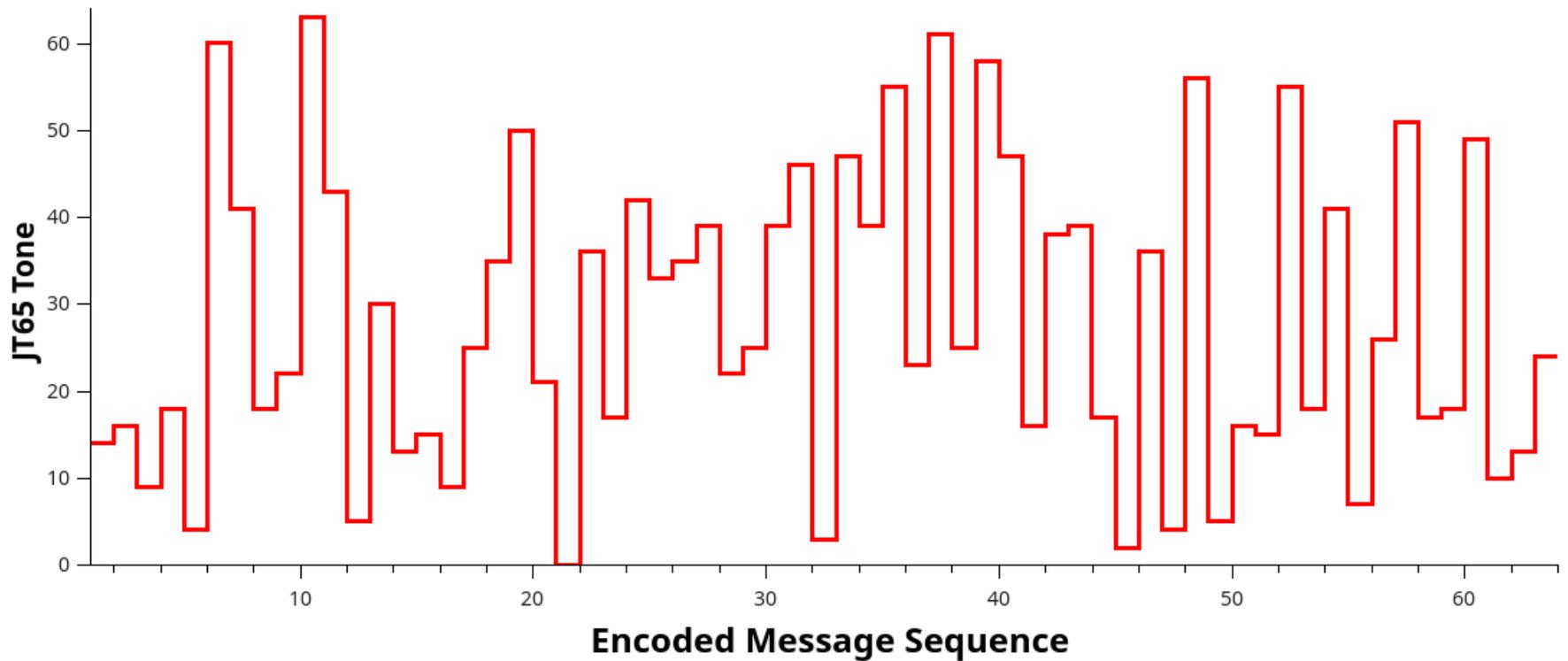
**Each 72 bit message is augmented with  
306 Forward Error Correction bits**

**81% of the message length is 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:

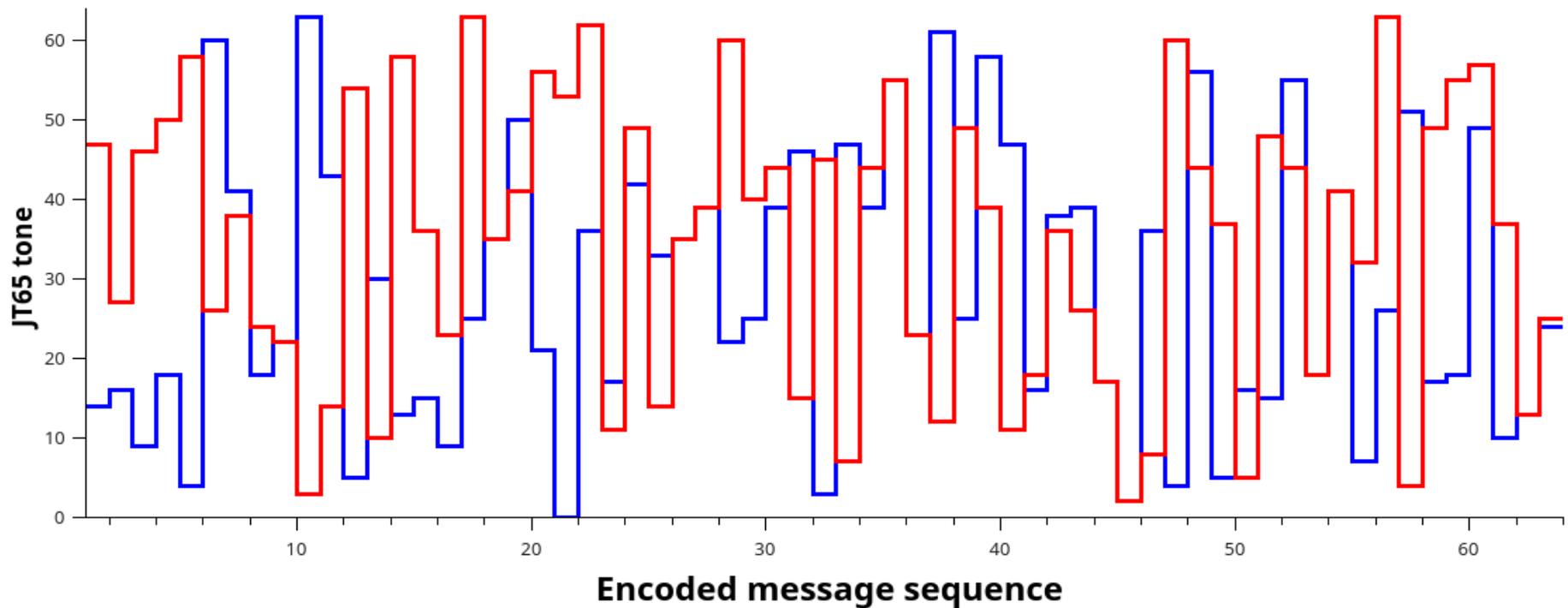
**G3LTF DL9KR JO40**



# 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

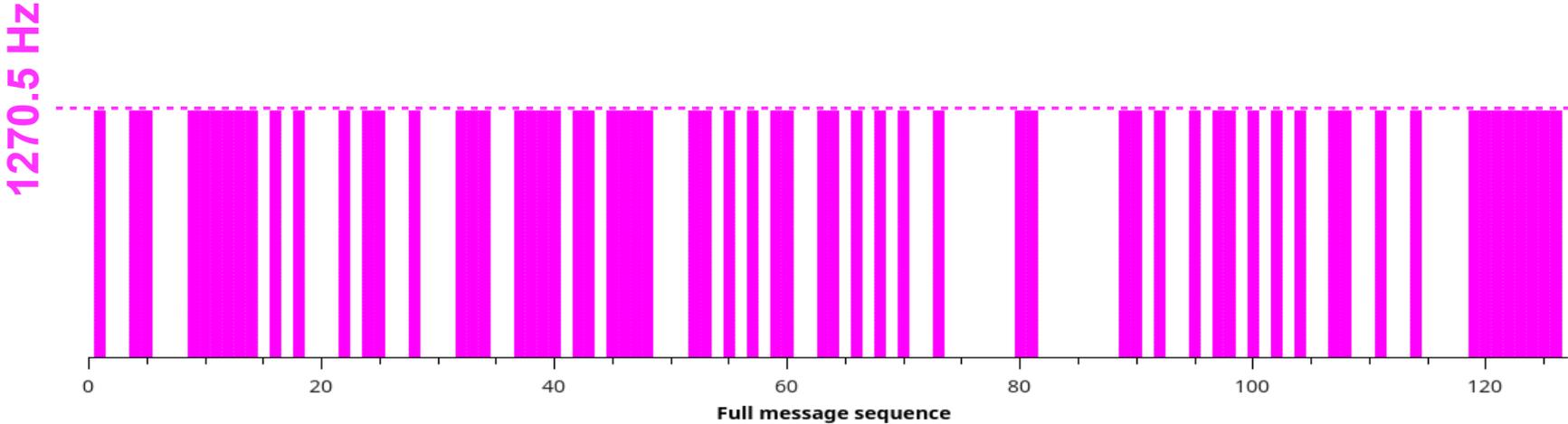
The decoder requires an accuracy  $\leq 0.03$  seconds

Can't accomplish this with amateur gear

The message must supply its own synch signal

**Synch tone at 1270.5 Hz**

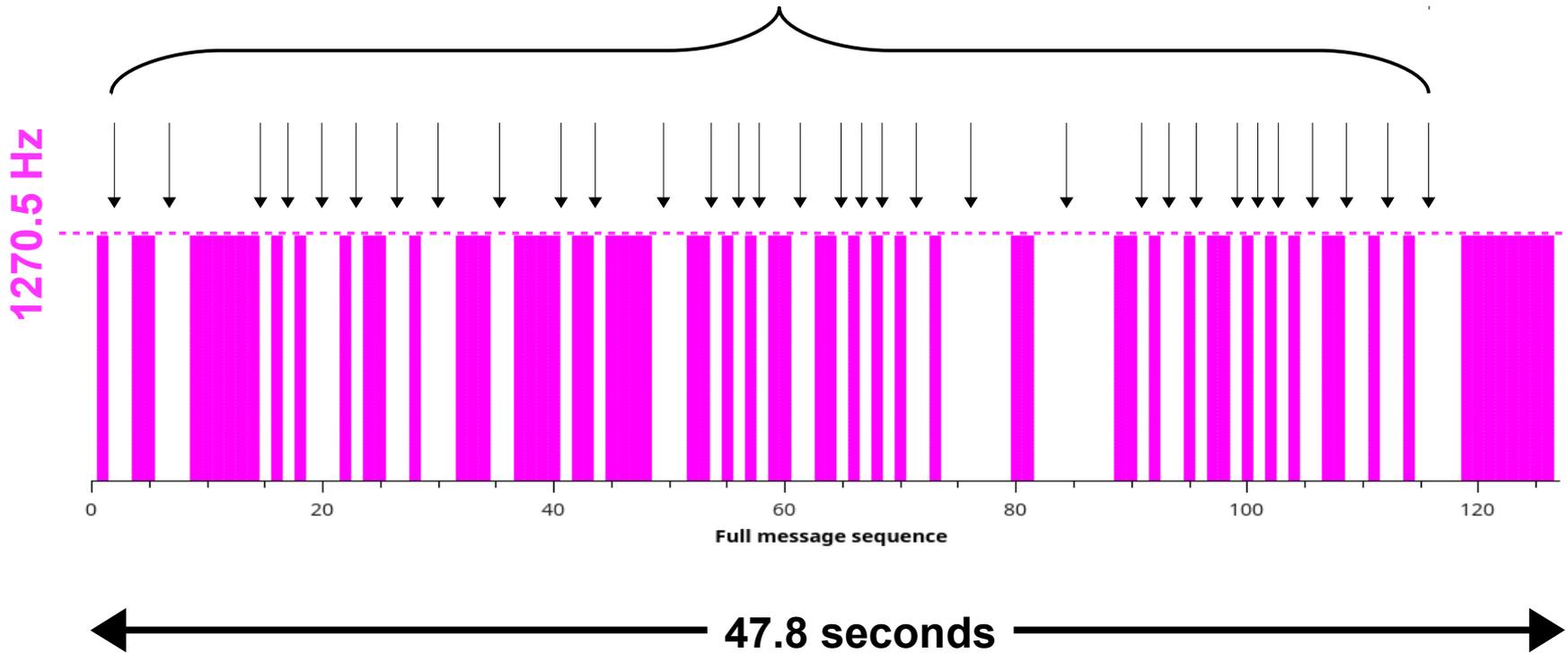
**Half of each message is used for synchronization**  
**Synch tone at 1270.5 Hz**



**← 47.8 seconds →**

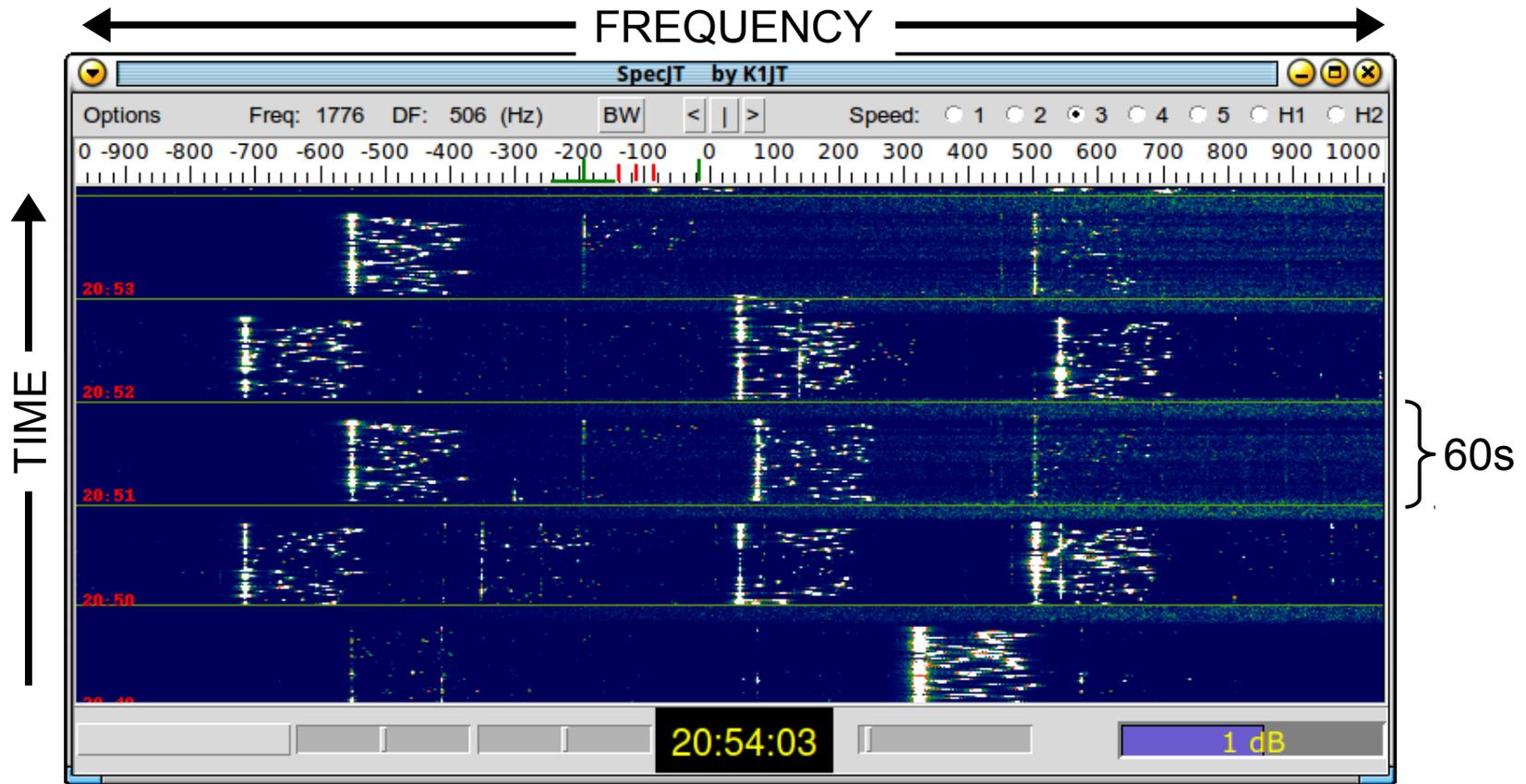
**Half of each message is used for synchronization  
Synch tone at 1270.5 Hz**

**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**

**Increasing Doppler shift on EME signals at UHF+**

**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



## **WSJT-X:**

**Meteor scatter with *Forward Error Correction***

**MSK144 has replaced FSK441 in North America**

**No partial decodes: All or nothing**

**More reliable**

**Real-time decodes: < 1 minute QSOs possible**

# **MSK144: How it works**

**72 information bits (same as JT65)**

**+ 8 bits: cyclical redundancy check**

**80 bits mapped into 128-bit codeword**



**Professor Steve Franke**  
**K9AN**

# **MSK144: How it works**

**72 information bits (same as JT65)**

**+ 8 bits: cyclical redundancy check**

**80 bits mapped into 128-bit codeword**

**+ 16 bits added for time synch**

**= 144 bits per message**

# **MSK144: How it works**

**Audio sampling rate: 44100 samples/sec**

**Message baud rate: 2000 (500  $\mu$ s/bit)**

**144 bit message requires only 72 ms**

**70% faster data rate than FSK441  
*including* time-synch and FEC**

# MSK144: How it works

3 bits per character

Bits generated with PSK

Phase-shifts on 1500 Hz carrier

0: Phase-shift  $0^\circ$

1: Phase-shift  $+90^\circ$

2: Phase-shift  $-90^\circ$  ( $270^\circ$ )

3: Phase-shift  $180^\circ$

Quadrature Phase-Shift Keying

# **MSK: Minimum Shift Keying**

**Derived from QPSK**

**0: Phase-shift  $0^\circ$**

**1: Phase-shift  $+90^\circ$**

**2: Phase-shift  $-90^\circ$**

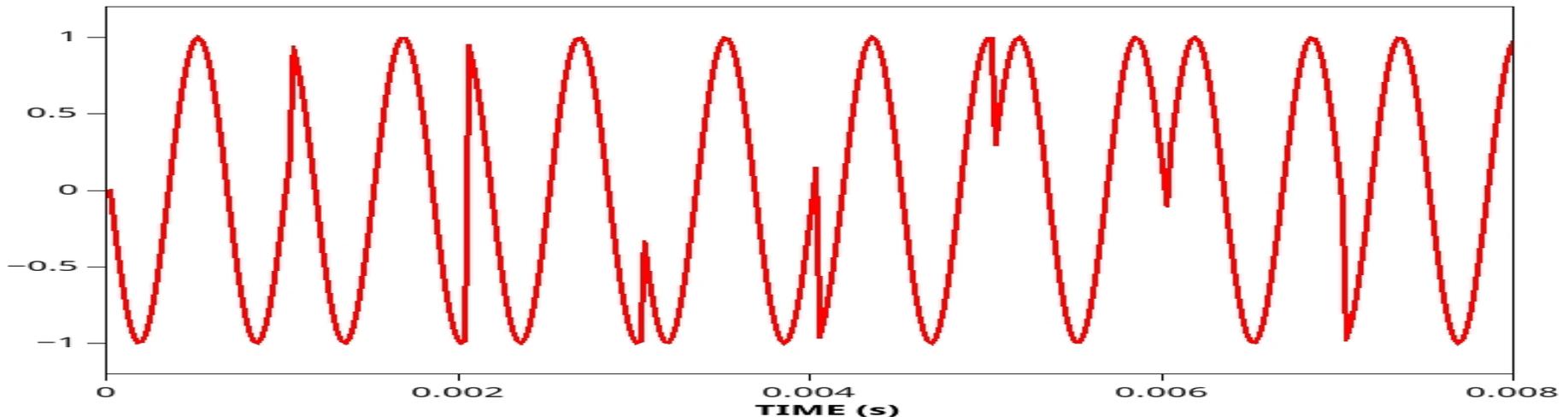
**3: Phase-shift  $180^\circ$**

**Protocols invented almost 50 years ago!**

**Differ only in how phase-shift implemented**

**MESSAGE: 1 3 0 2 3 1 2 0**

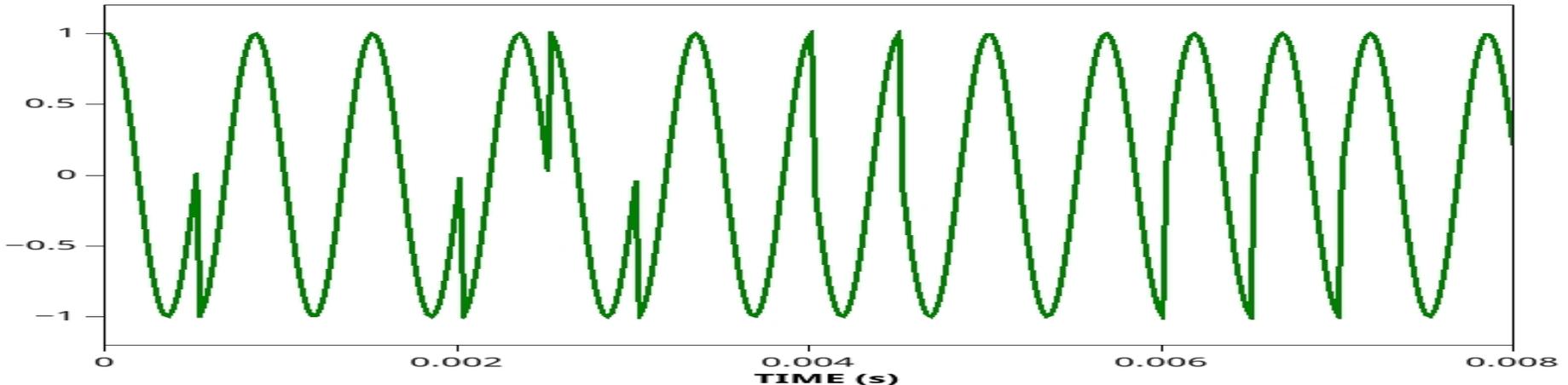
**Rendered using QPSK**



**AUDIO CARRIER FREQUENCY: 1500 Hz**  
**BAUD RATE: 2000 sec<sup>-1</sup>**

**MESSAGE: 1 3 0 2 3 1 2 0**

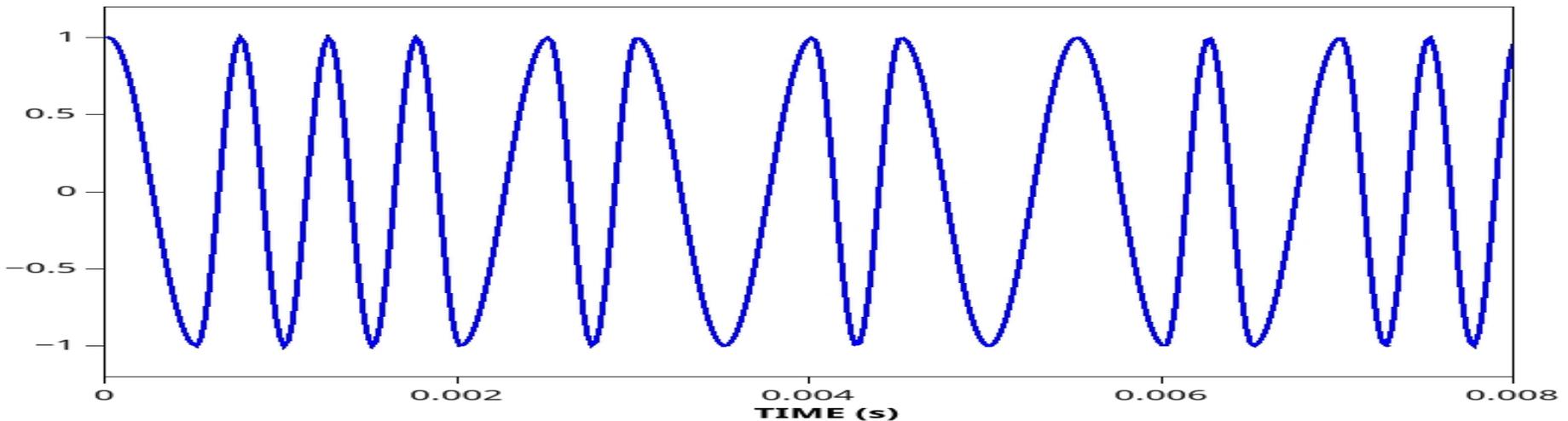
**Orthogonal-QPSK:**  
**Reduces severity of phase jumps**



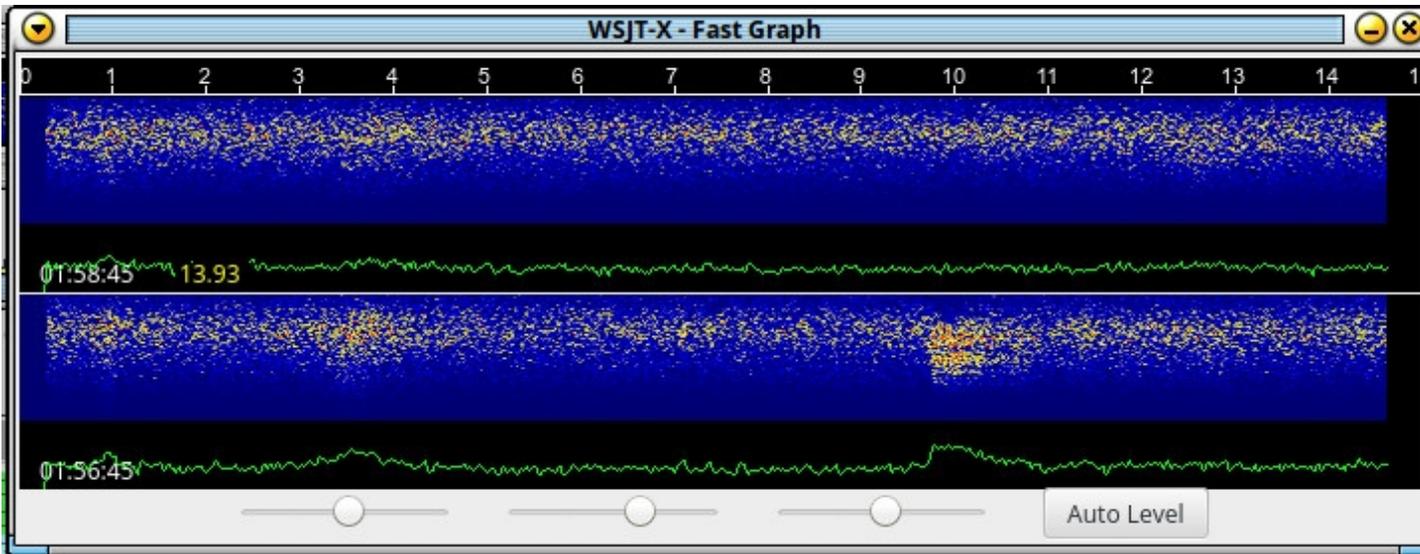
**AUDIO CARRIER FREQUENCY: 1500 Hz**  
**BAUD RATE: 2000 sec<sup>-1</sup>**

**MESSAGE: 1 3 0 2 3 1 2 0**

**MSK:** phase transitions are continuous



**AUDIO CARRIER FREQUENCY: 1500 Hz**  
**BAUD RATE: 2000 sec<sup>-1</sup>**



**WSJT-X v1.7.0 by K1JT**

File Configurations View Mode Decode Save Help

UTC	dB	T	Freq	Message	
015645	2	9.8	1536	& CQ K5DOG EM00	1
015645	3	9.8	1537	& CQ K5DOG EM00	1
015845	-5	12.7	1538	& WB2FKO K5DOG R EM00	4

UTC	dB	T	Freq	Message
015845	-5	12.7	1538	& WB2FKO K5DOG R EM00

Log QSO
Stop
Monitor
Erase
Decode
Enable Tx
Halt Tx
Tune

6m ●

**50.000 000**

60+  
50  
40  
30  
20  
10  
0  
0.0 dB

Tx even/1st

Rx 1500 Hz

F Tol 200

Report -5

T/R 15 s

Tx CQ 280

Sh  Auto Seq

Generate Std Msgs

Next	Now
K5DOG WB2FKO DM65	<input type="radio"/> Tx 1
K5DOG WB2FKO DM65	<input type="radio"/> Tx 2
K5DOG WB2FKO R DM65	<input type="radio"/> Tx 3
K5DOG WB2FKO RRR	<input checked="" type="radio"/> Tx 4
K5DOG WB2FKO 73	<input type="radio"/> Tx 5
CQ WB2FKO DM65	<input type="radio"/> Tx 6

Pwr

MSK144
0/15
WD:14m

# Online Resources

WSJT Yahoo Users Group

WSJT Developers Mailing List

Pingjockey.net