FSK441 vs MSK144
for meteor scatter at 222 MHz

2022 CSVHF Conference
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BACKGROUND

2016: K9AN and K1JT introduce new meteor scatter digital mode MSK144

MSK144 almost immediately replaces FSK441 on 50 and 144 MHz

Most (?) 222 MHz operators decide to keep using FSK441 because:

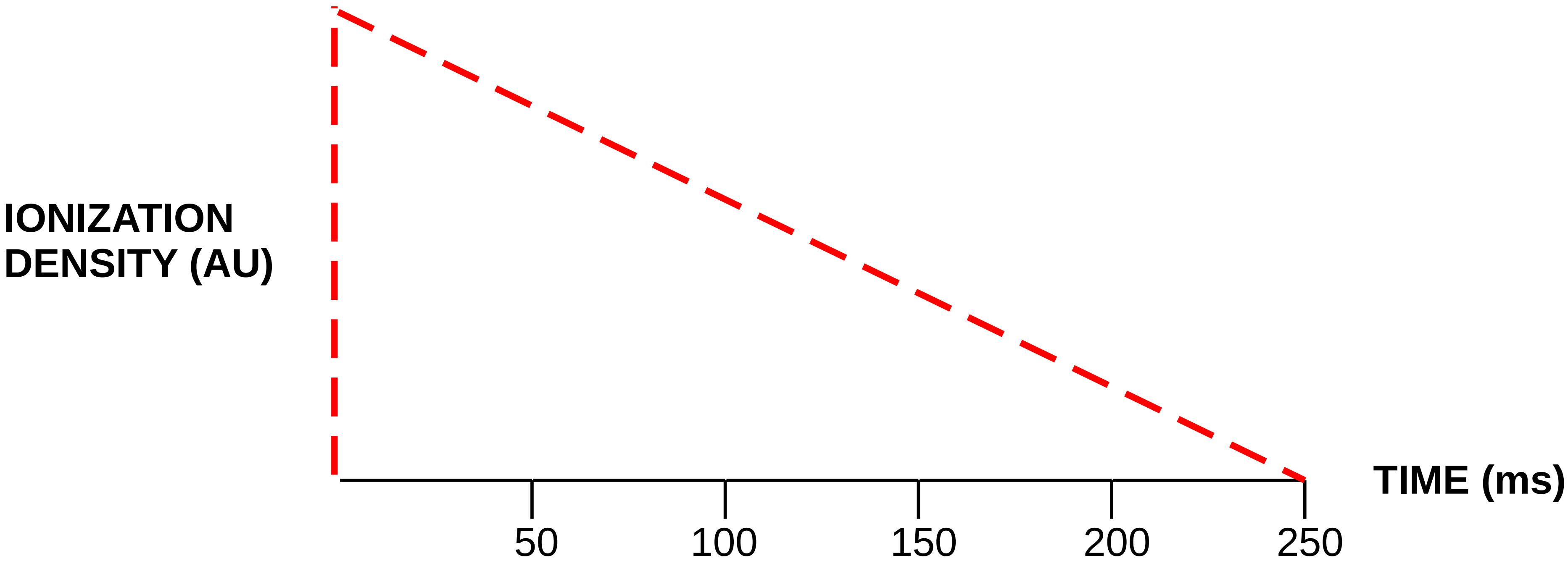
"Pings on 222 MHz on are ***too short*** for reliable decoding with MSK144"

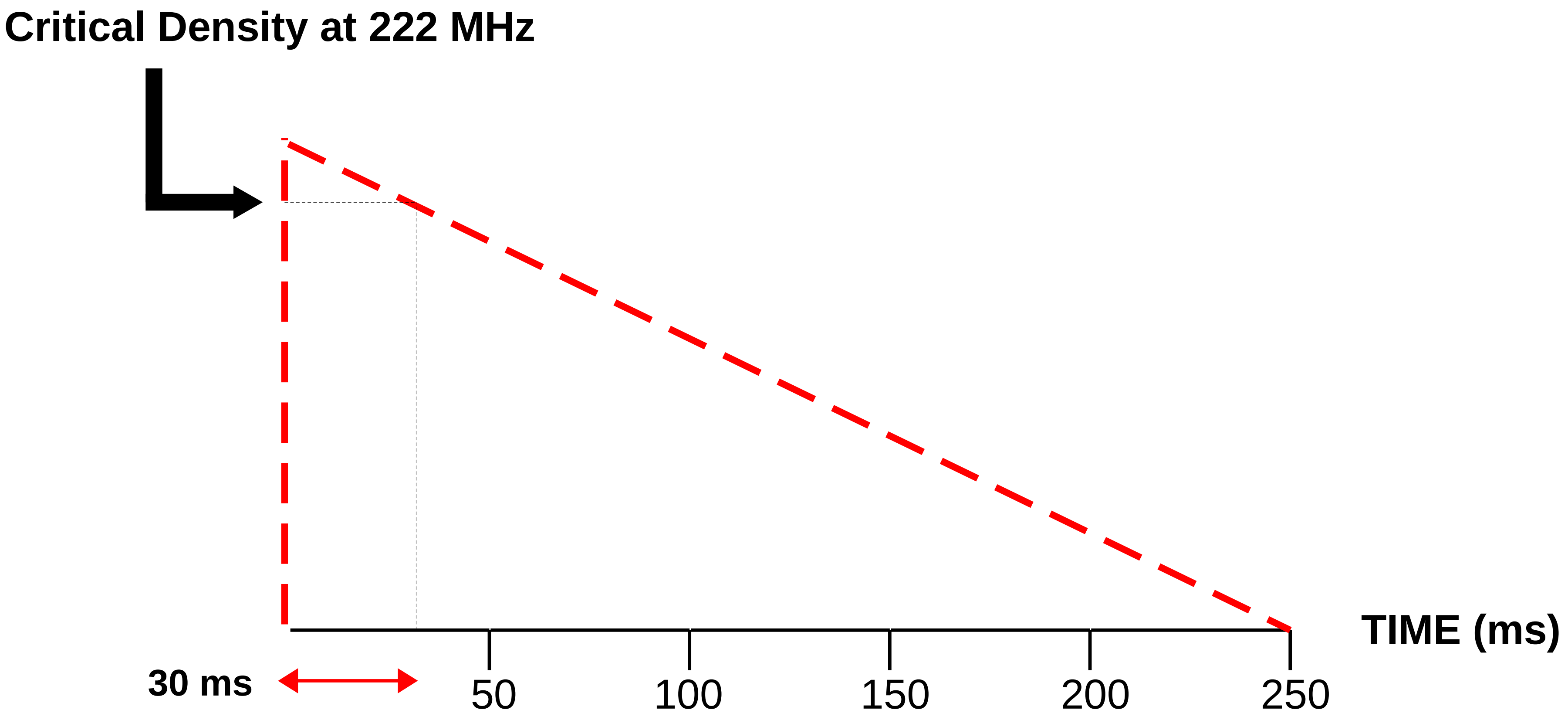
Ping duration explained by elementary plasma physics

CRITICAL FREQUENCY: $f_c \propto \sqrt{\text{Ionization Density}}$

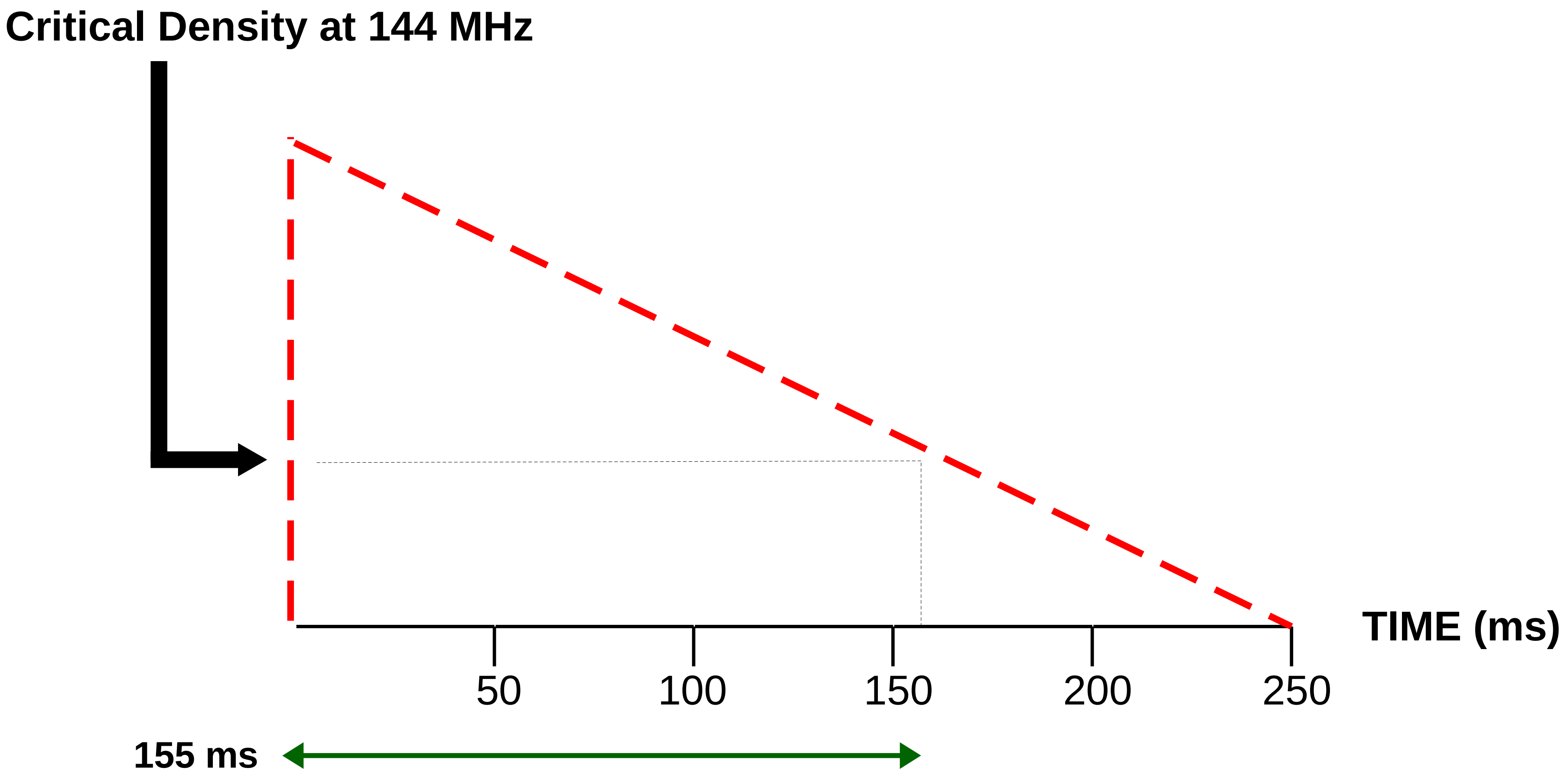
REFLECTION: $f < f_c$

Assume meteor instantly ionizes *E*-layer followed by a linear decay

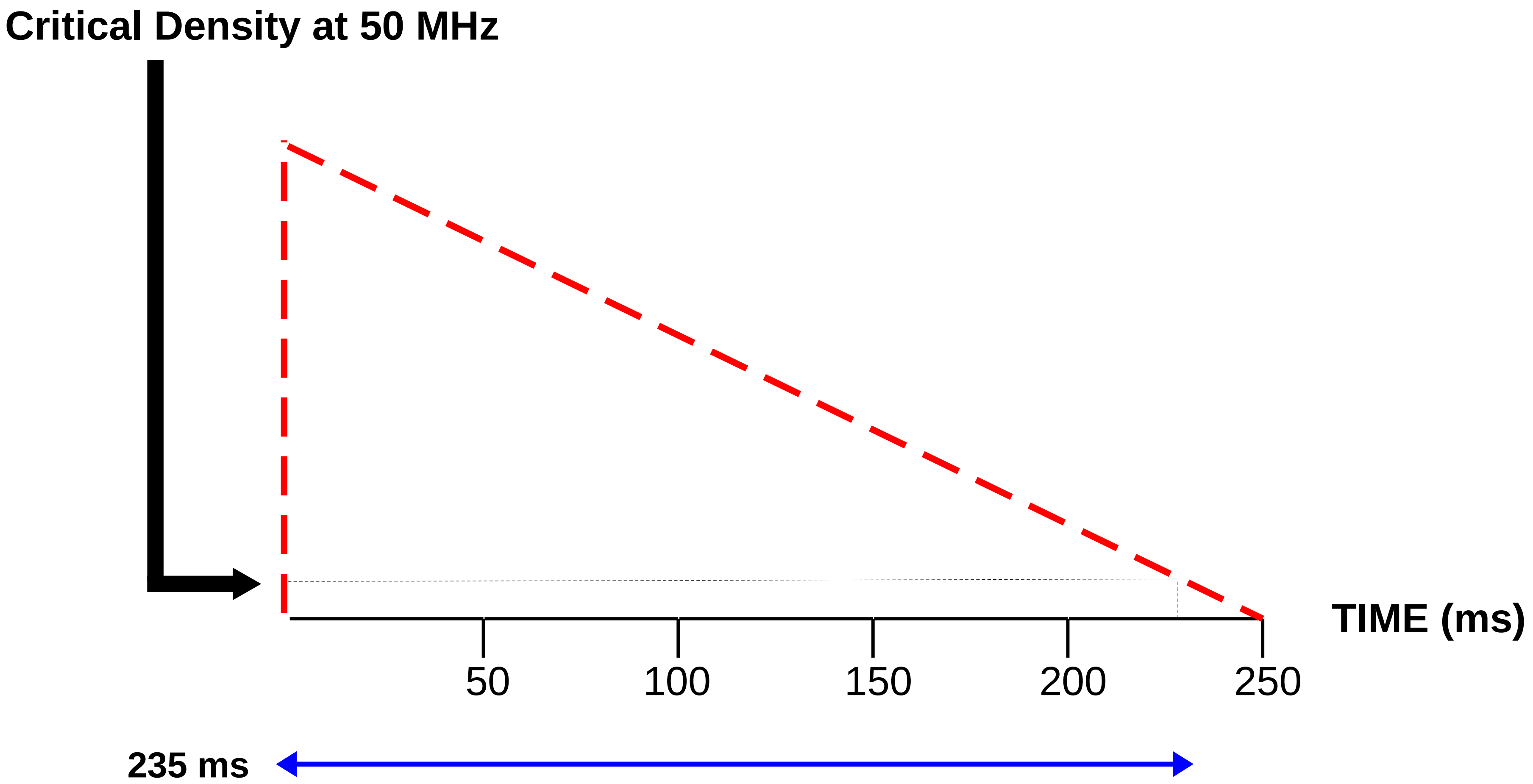




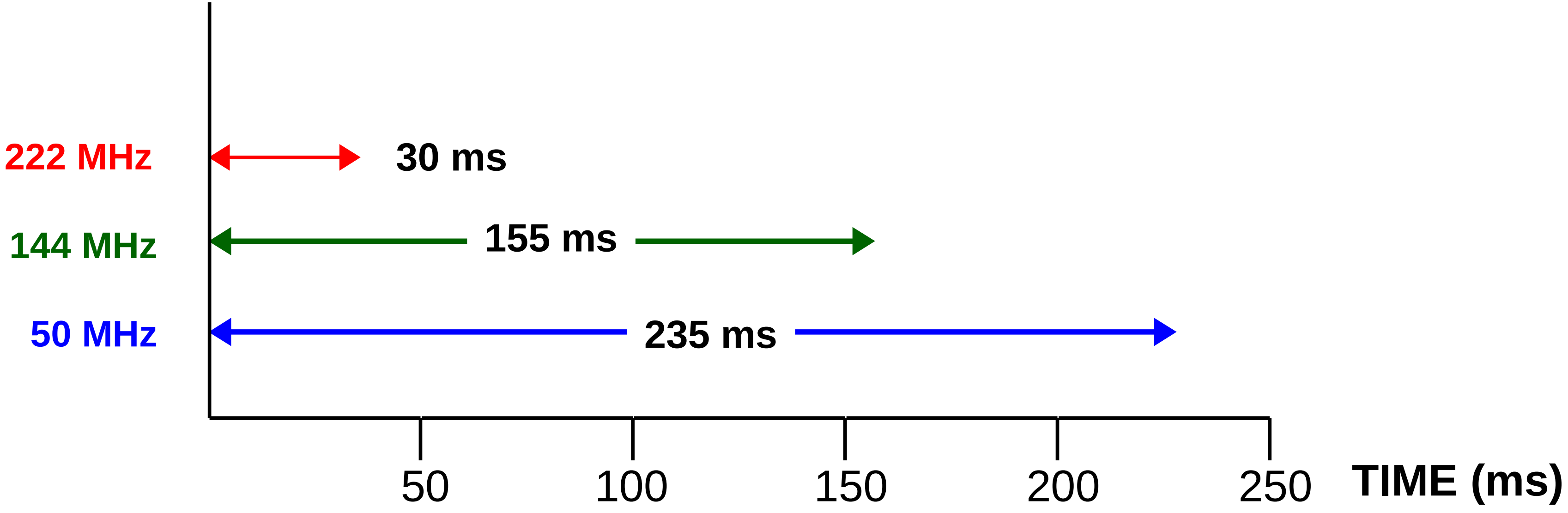
Critical Density at 222 MHz
TIME (ms)
30 ms
50
100
150
200
250



Critical Density at 144 MHz
TIME (ms)
50
100
150
200
250
155 ms


Critical Density at 50 MHz
TIME (ms)
50
100
150
200
250
235 ms

Pings get shorter as radio frequency increases



COMPARING THE TWO MODES

FSK441 (2001)	**MSK144 (2017)**
147 char/s	250 char/s
441 baud	2000 baud
No FEC	FEC + CRC
Partial decodes to **20 ms**	Complete **70 ms** frame required: All-or-nothing decodes

The FSK441 Protocol (K1JT, QST, 2001)

Characters formed by combination of 3 tones

Tone 0: 882 Hz
Tone 1: 1323 Hz
Tone 2: 1764 Hz
Tone 3: 2205 Hz

K5QE W9RM

123011201230033213021202131033

← **68 ms** →

MESSAGE LENGTH DEPENDS ON CHARACTER COUNT:

WA2VOI WA5VJB EM12

213101002212133121033213101011212122102033230131001002033

129 ms

Partial Decodes are possible but ping
MUST contain **SYNCHRONIZATION CHARACTERS**:

Synch 1: Single characters

Character **O** or the **space symbol***

Synch 2: Multiple characters

One of these characters: **L, M, N, E, Z**

AND

One of these characters: **0, 3, 7, C, G, K, S, W**

* Every message has at least two spaces

Statistical Simulation

Assume ***only*** 30 ms pings

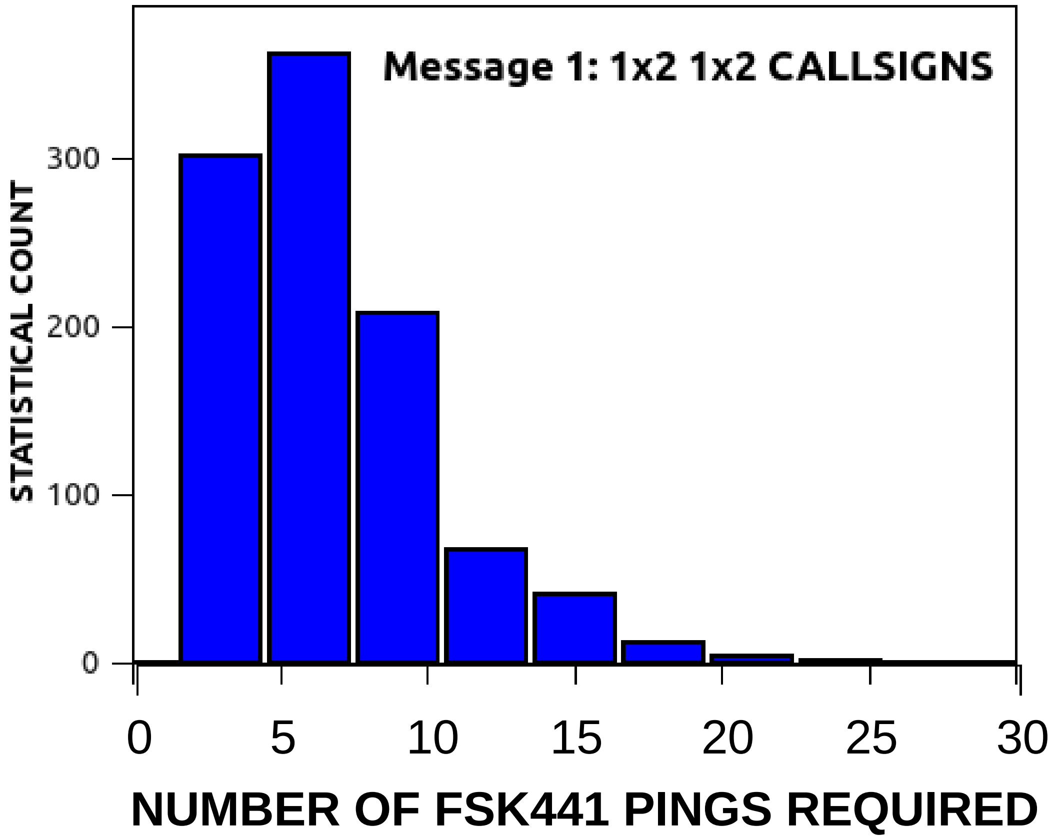
Decodes not possible with MSK144

Long enough for only four FSK441 characters: Partial decodes

May or may not have synch character (space)

How many pings needed to send a complete message?

W9RM K5QE using FSK441



Only 30 ms pings (4 characters)

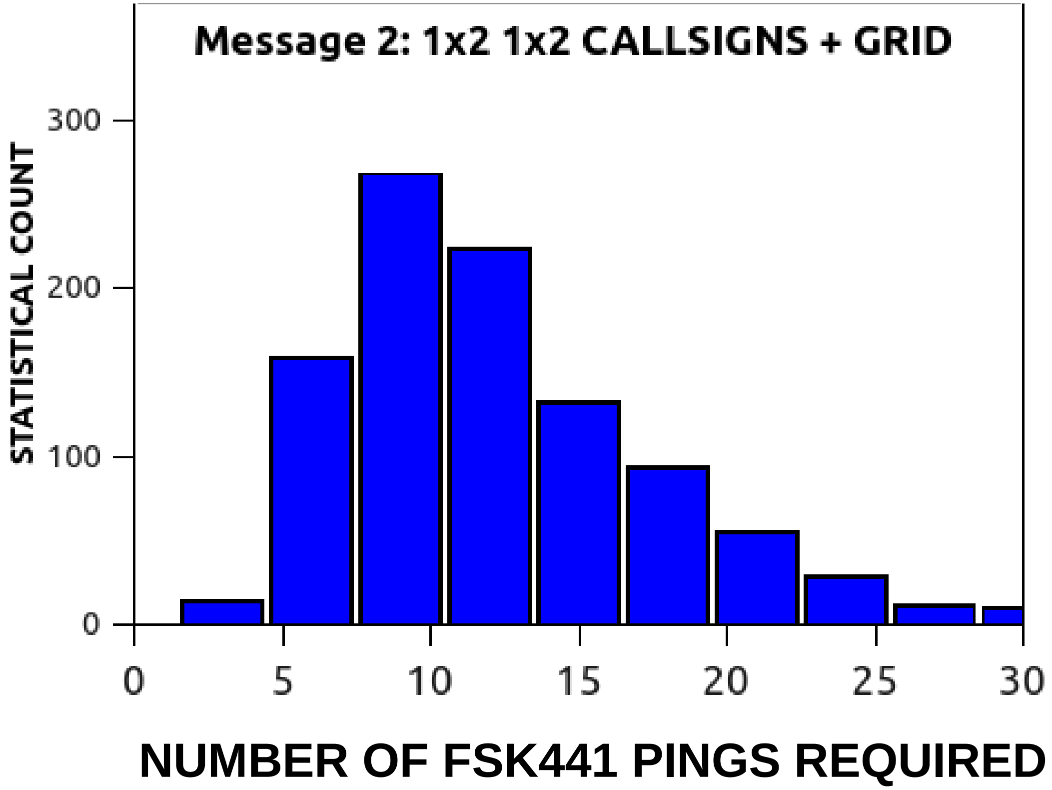
1x2 calling 1x2

10 character message: **68 ms**

1000 simulated attempts

Avg number of pings required: **7.7**

W9RM K5QE EM31 using FSK441



1x2 calling 1x2 with grid report

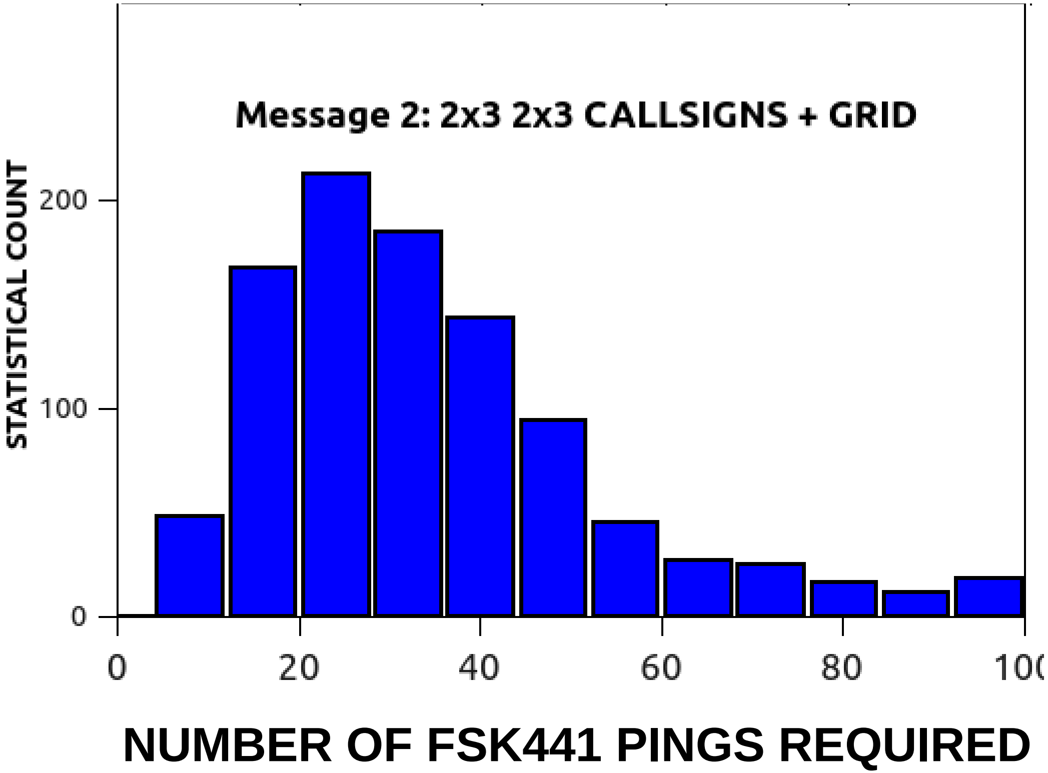
15 character message: **102 ms**

Only 30 ms pings (4 characters)

1000 simulated attempts

Avg number of pings required: **13.4**

WA2VOI WA5VJB EM12 using FSK441



2x3 calling 2x3 with grid report

19 character message: **129 ms**

Only 30 ms pings (4 characters)

1000 simulated attempts

Avg number of pings required: **38**

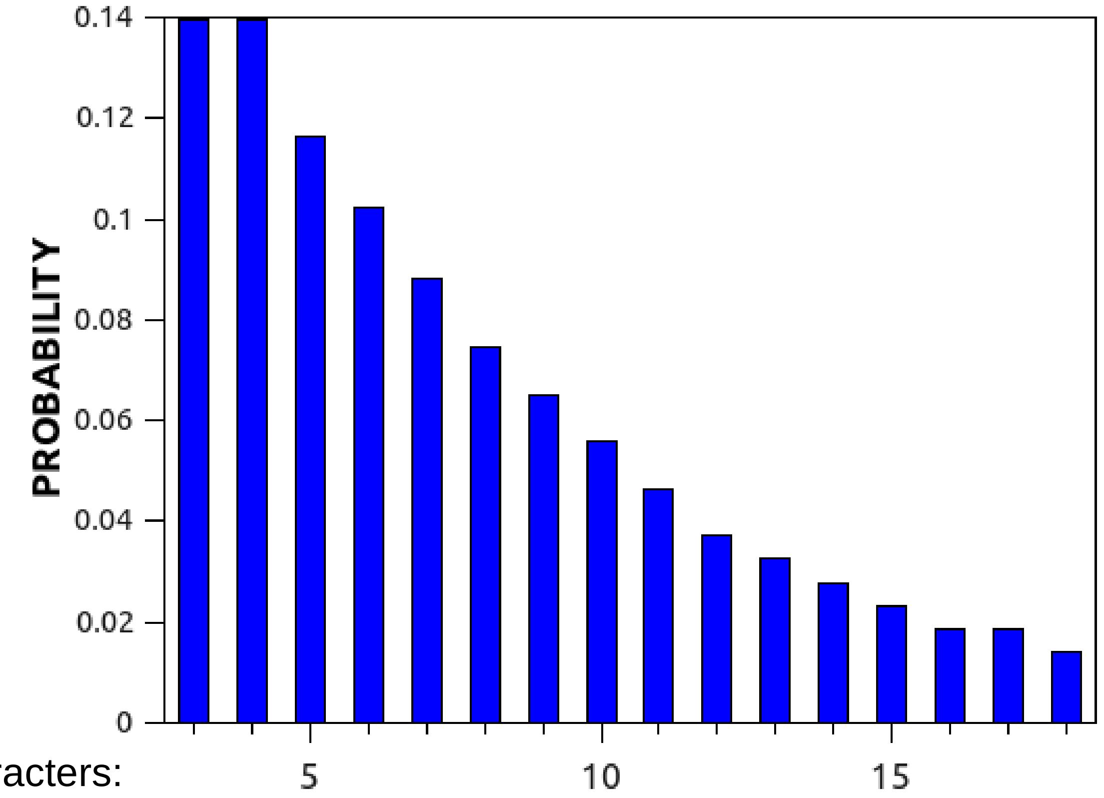
WHAT ABOUT 70 ms PINGS?*

1000 simulations for each message

Message	Pings needed FSK441	Pings needed MSK144
W9RM K5QE	1	1
W9RM K5QE EM31	3.1	1
WA2VOI WA5VJB	2.7	1
WA2VOI WA5VJB EM12	4.2	1

*Assume sensitivity of both modes identical

Heuristic Simulation: Statistical Distribution of Ping Duration

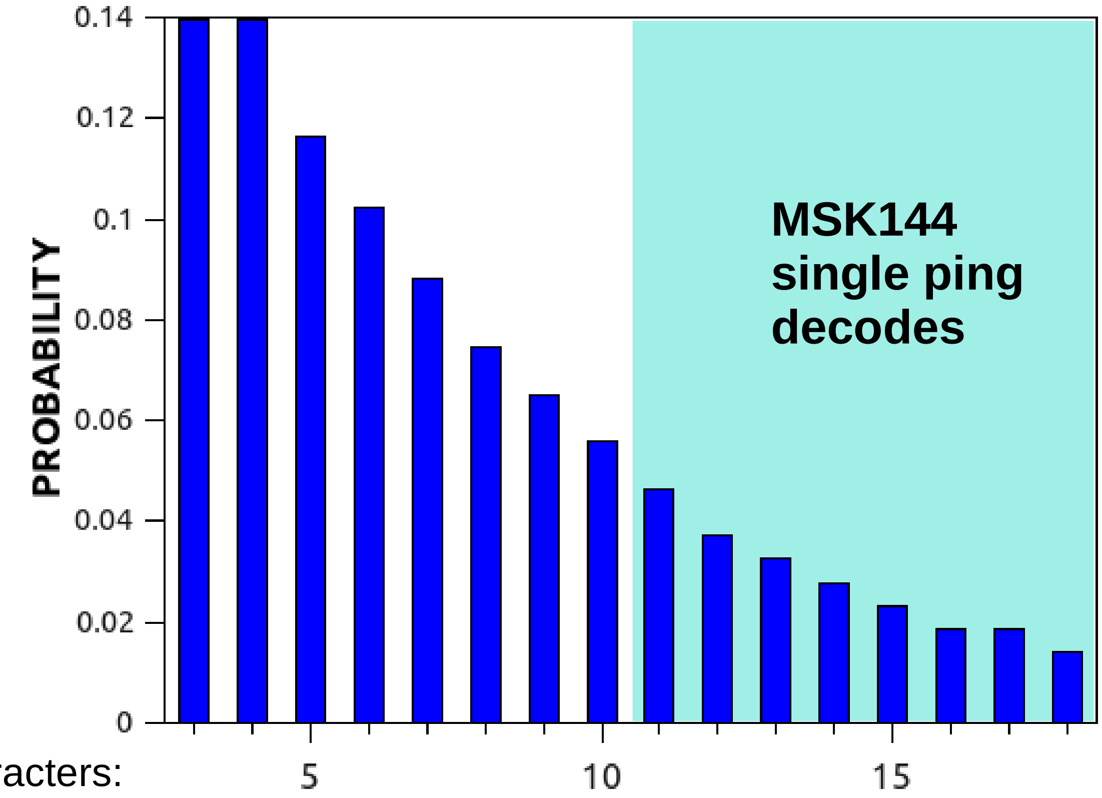


Number of FSK441 Characters:

Ping Duration: 20 ms 60 ms 100 ms

Heuristic Simulation: Statistical Distribution of Ping Duration

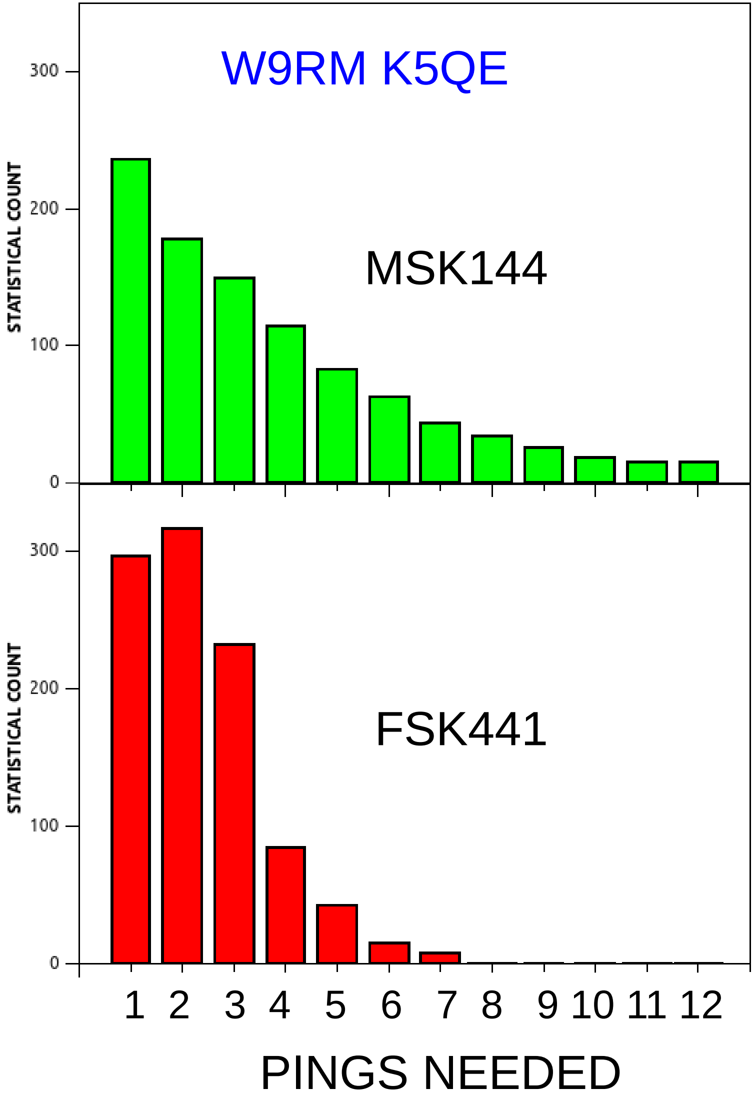
23% of the pings decode the 70 ms MSK144 frame



Number of FSK441 Characters:

Ping Duration: 20 ms 60 ms 100 ms

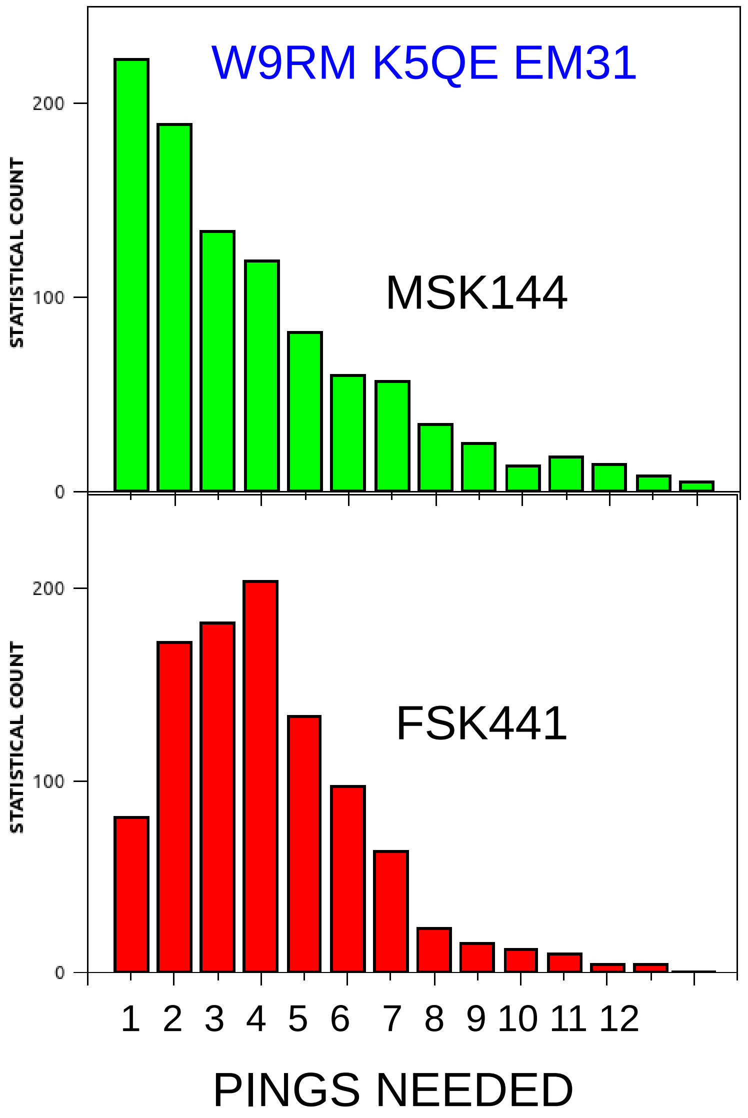
Pings needed to send complete 1x2 1x2 callsigns



Average: 4.0 ± 2.0

Average: 2.4 ± 1.6

Pings needed to send complete 1x2 1x2 callsigns + grid



Average: 4.0 ± 2.0

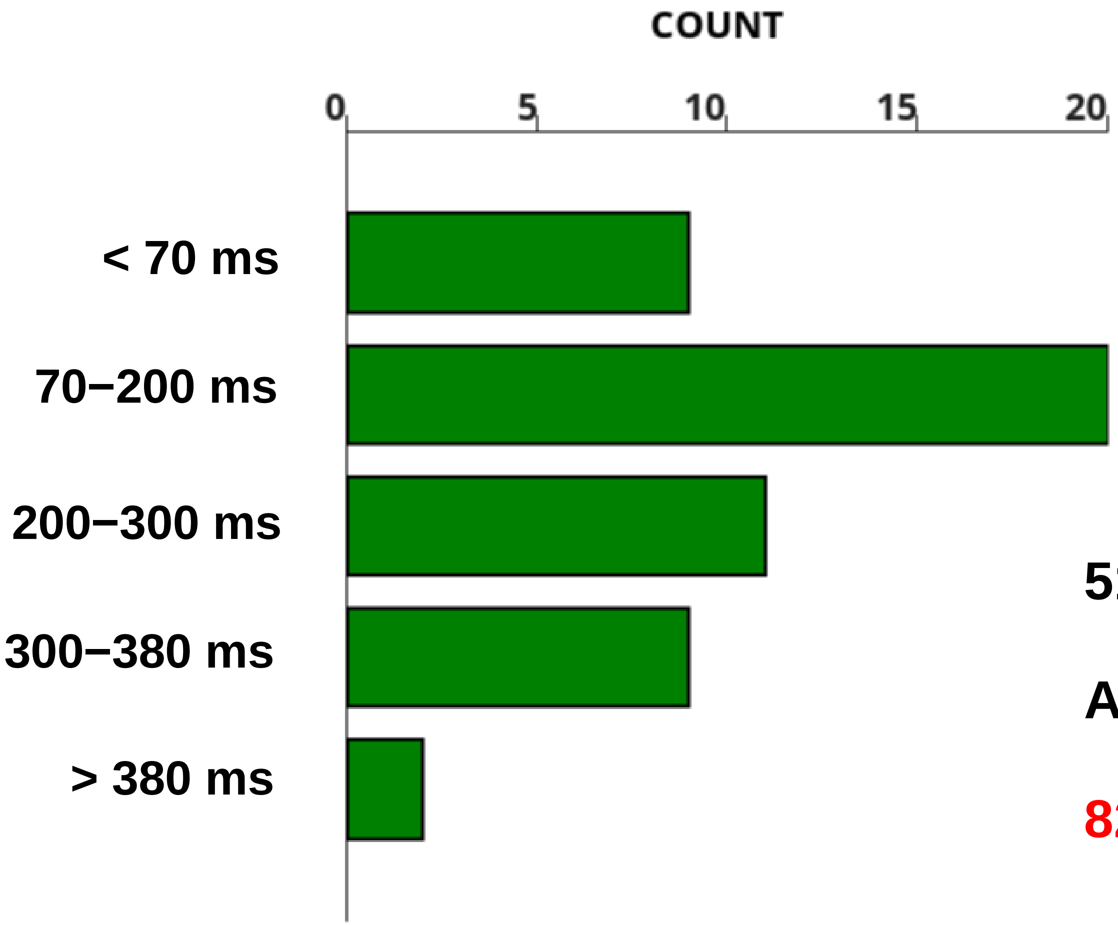
Average: 4.1 ± 2.0

1000 simulations for each message
Assume sensitivity of both modes identical

Message	Pings needed FSK441	Pings needed MSK144
W9RM K5QE	2.4 ± 1.6	4.0 ± 2.0
W9RM K5QE EM31	4.1 ± 2.0	4.3 ± 2.1
WA2VOI WA5VJB	3.7 ± 1.9	4.1 ± 2.0
WA2VOI WA5VJB EM12	6.0 ± 2.4	4.0 ± 2.0


REAL OPERATING DATA FROM K7ULS

K7ULS ping duration data from FSK441



51 pings recorded

Average: 191 ± 122 ms

82% are long enough for MSK144

Pings should be plenty long enough for MSK144 on 222 MHz

Most pings allow multi-frame averaging with MSK144

FSK441 operators are losing sensitivity provided by FEC and frame averaging

“Pings are audible but MSK144 won’t decode them”

What about Doppler shift?

Occurs when path length between transmitter and receiver changes

Higher radio frequency will produce more Doppler shift

A given meteor ping will:

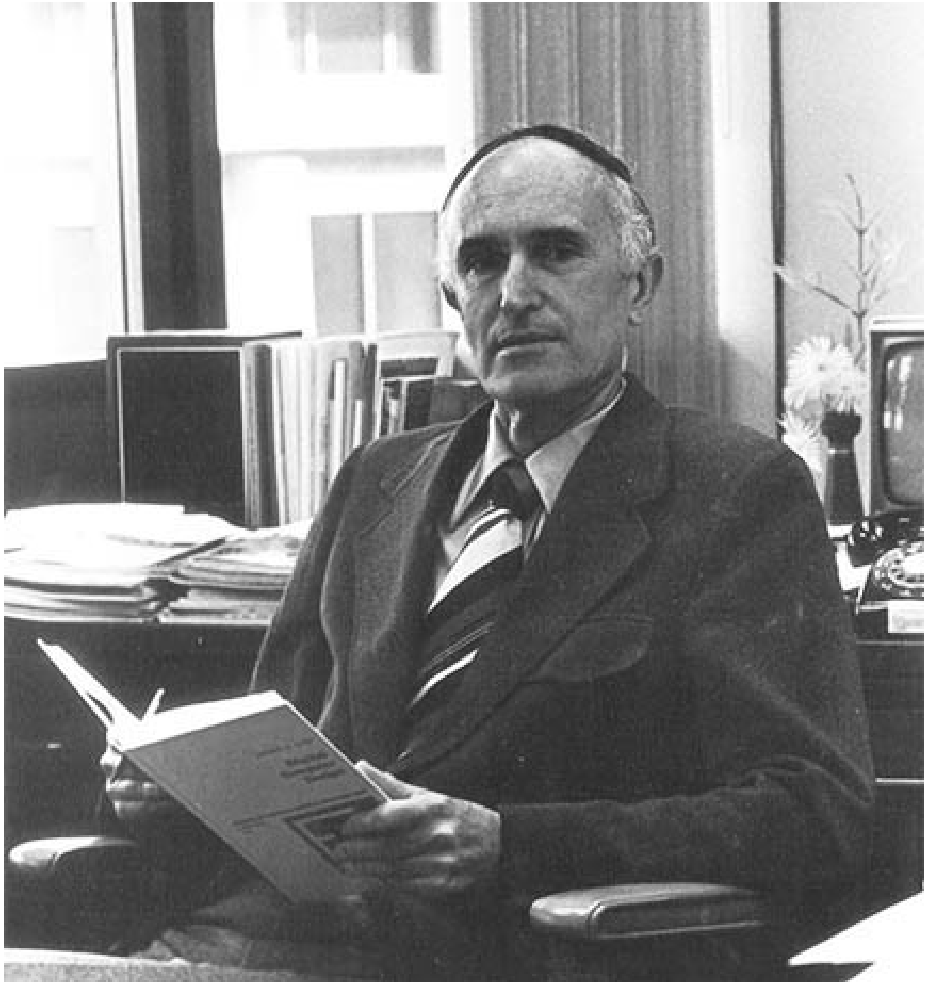
Induce 2.9x more Doppler shift on 144 MHz compared to 50 MHz

Induce 4.4x more Doppler shift on 222 MHz compared to 50 MHz

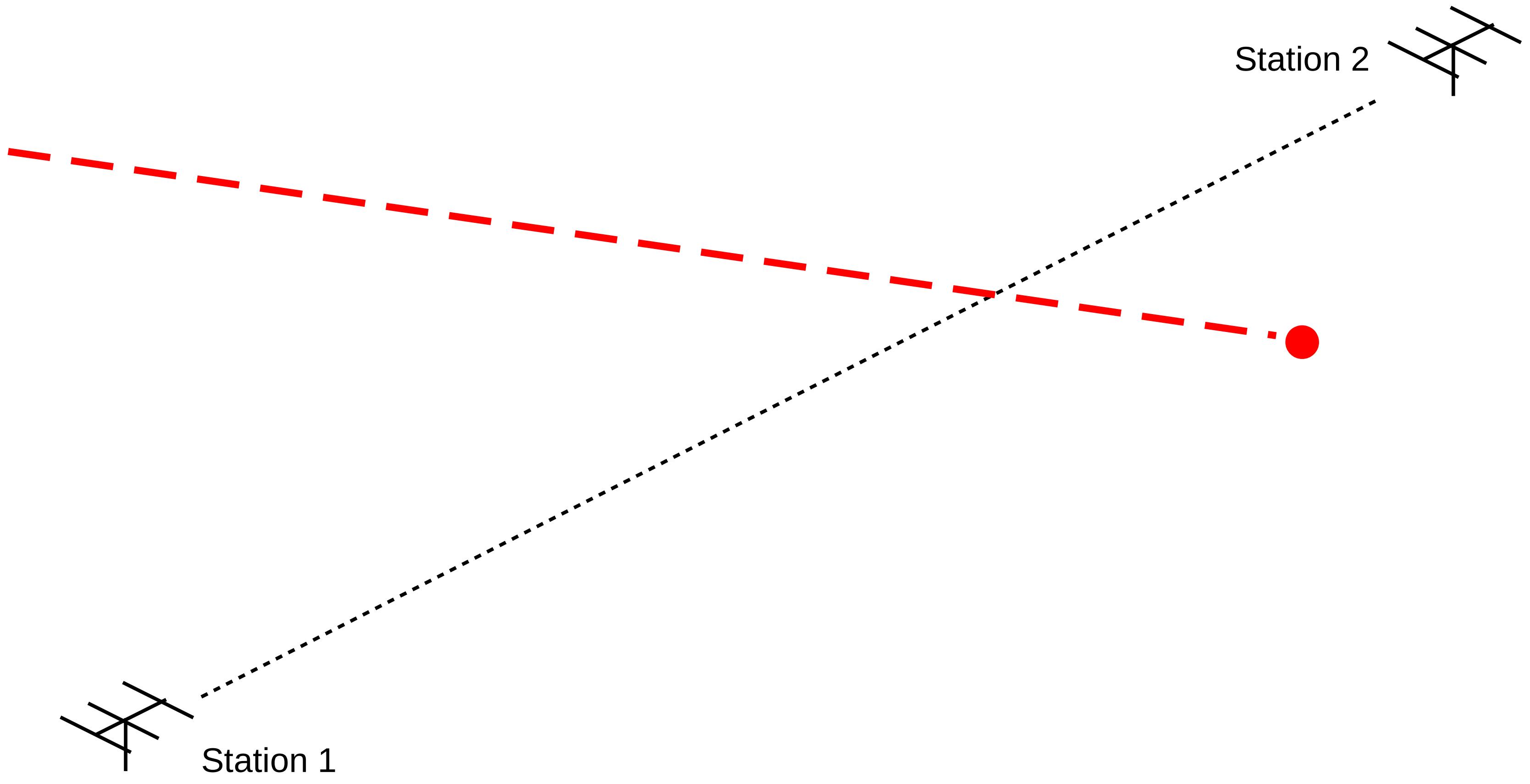
The Theory of Radio Detection of Meteors

Journal of Applied Physics (1948)

Laurence A Manning, Stanford University



Two components of meteor ionization in *E*-layer



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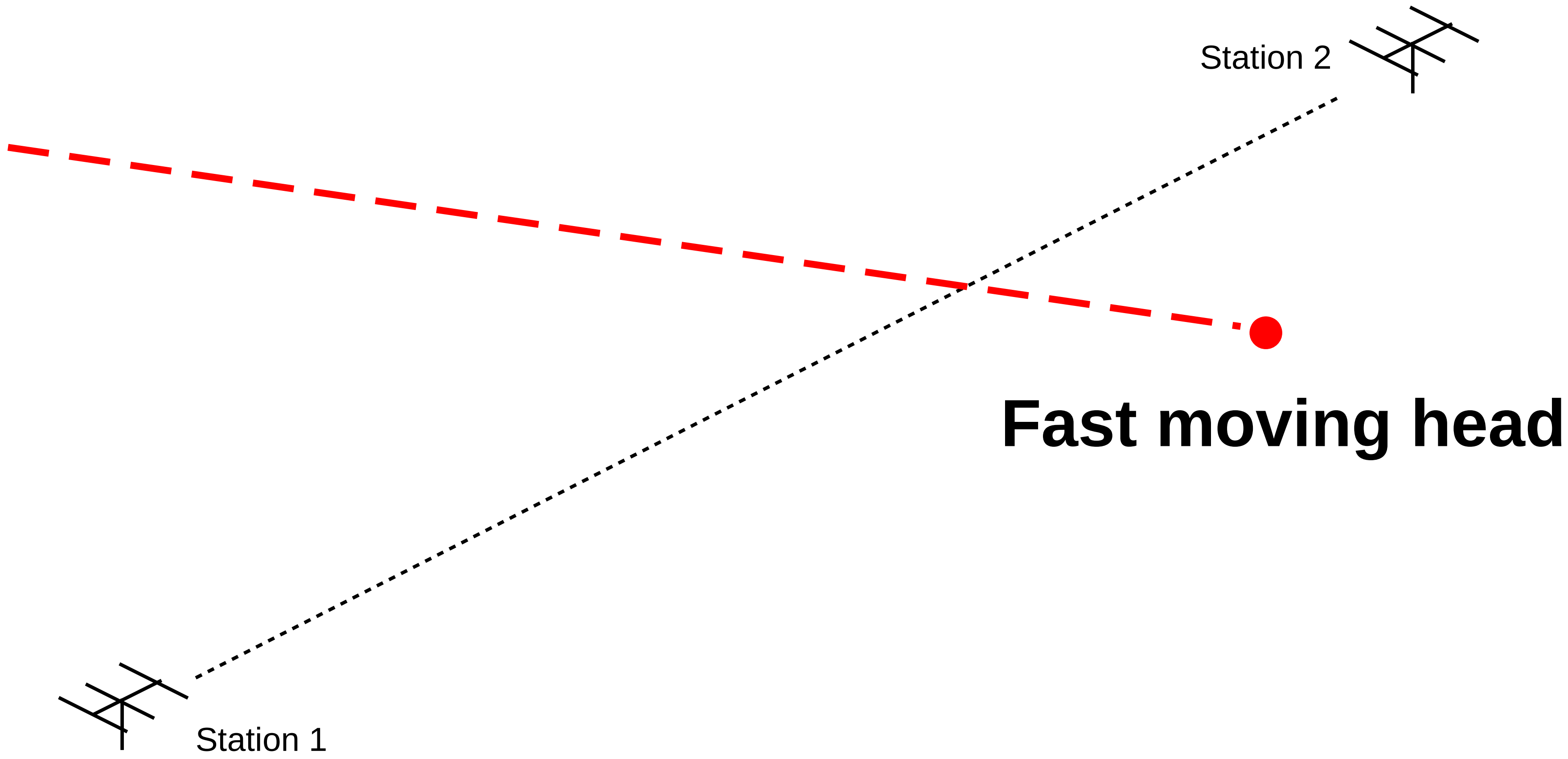
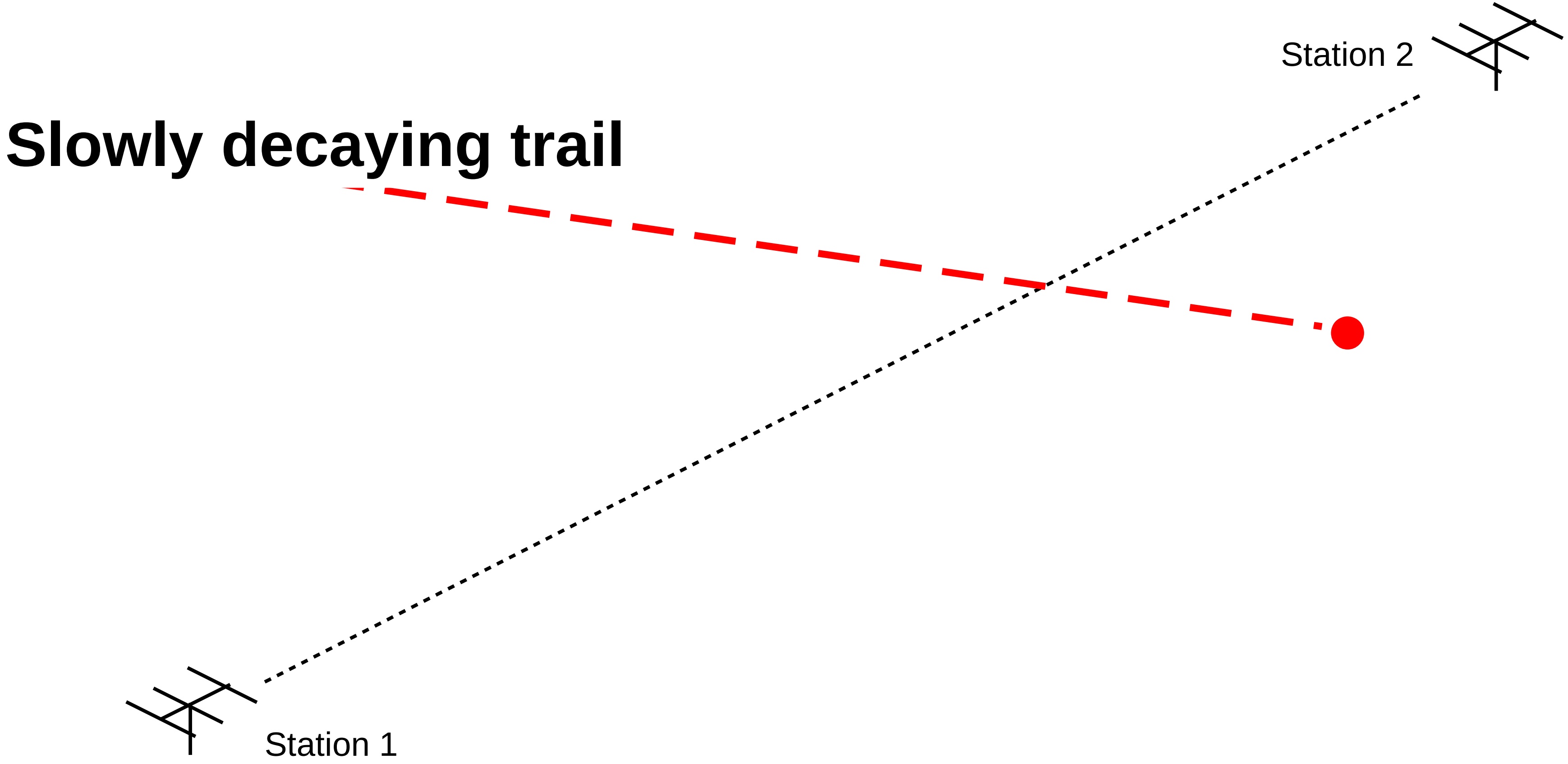


Two components of meteor ionization in *E*-layer



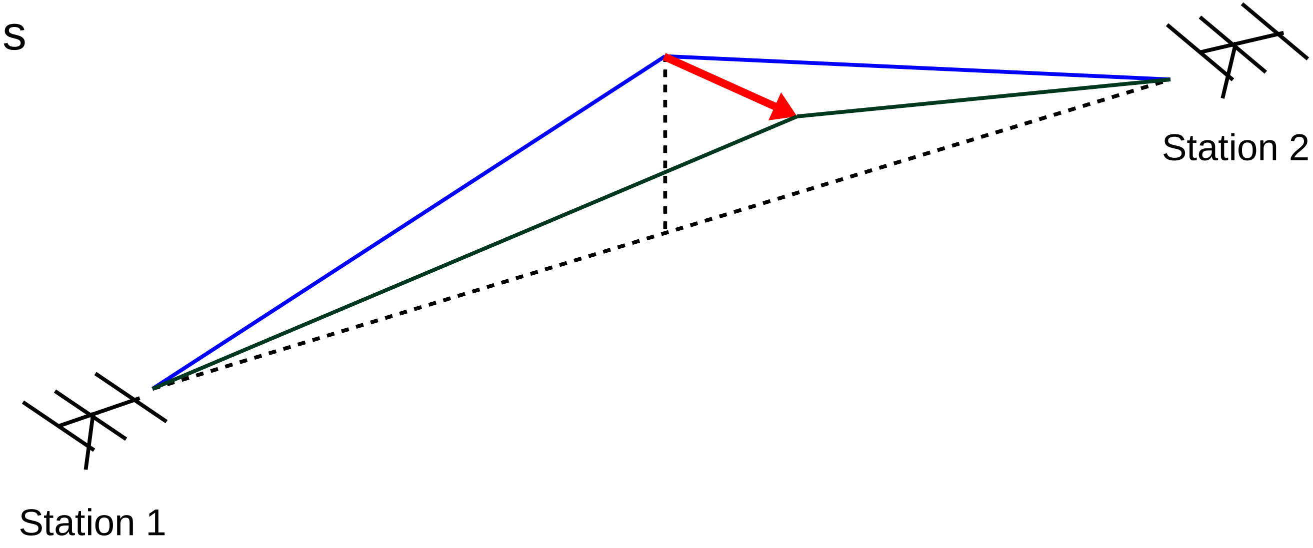
Calculate Doppler Shift induced by METEOR HEAD*

Vector analysis allows for any path or trajectory

Account for head velocity, altitude, station separation, ping duration, radio frequency

Models for forward-scatter and backward-scatter

*Details in Proceedings



Initial Doppler Shift: Start of the Burn

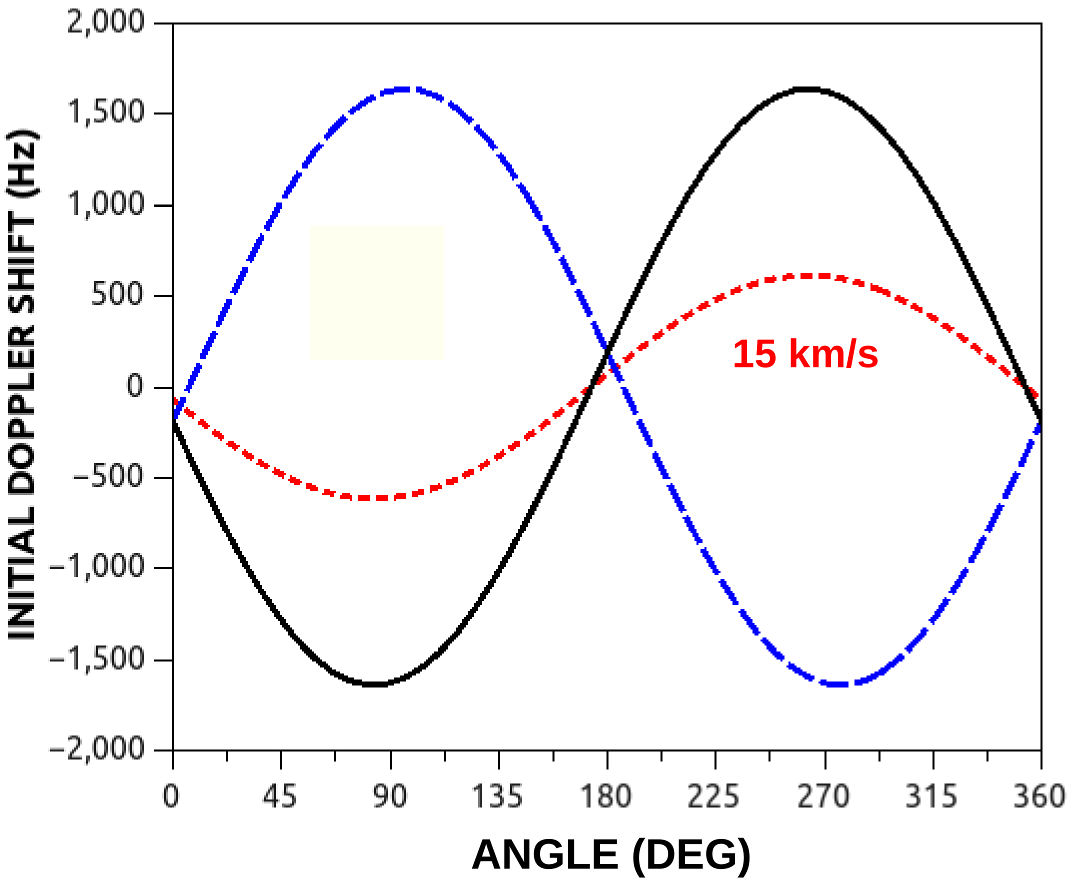
Frequency: 222 MHz

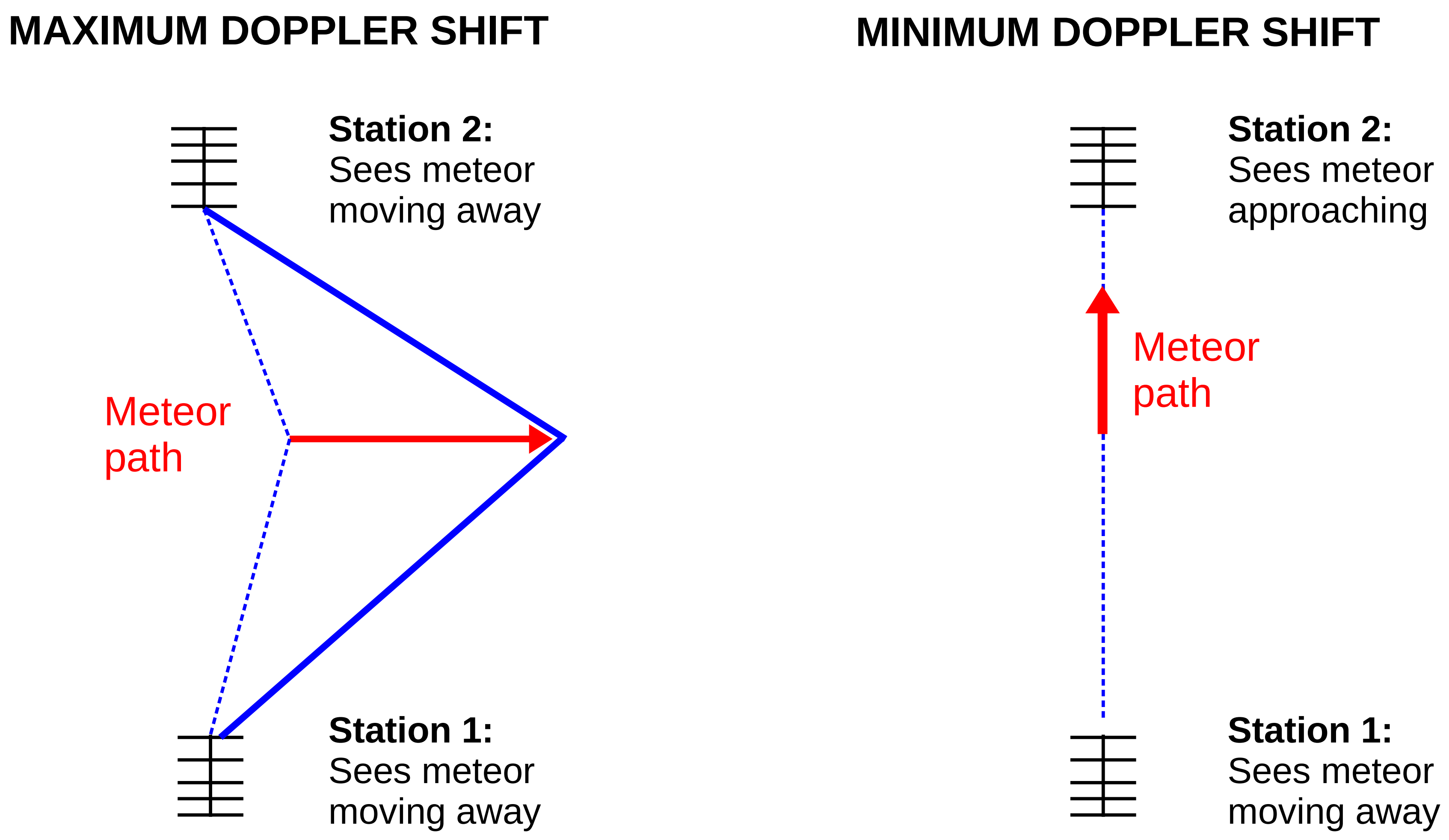
Separation: 1500 km (930 mi)

Midpoint offset: ± 150 km

Head velocity: 40 km/s

Height: 90 km





MAXIMUM DOPPLER SHIFT
Station 2:
Sees meteor
moving away
Meteor
path
Station 1:
Sees meteor
moving away
MINIMUM DOPPLER SHIFT
Station 2:
Sees meteor
approaching
Meteor
path
Station 1:
Sees meteor
moving away

The initial Doppler shift will add to or subtract from the VFO mismatch

There is also Doppler shift *during* the ping (chirp)

Frequency: 222 MHz

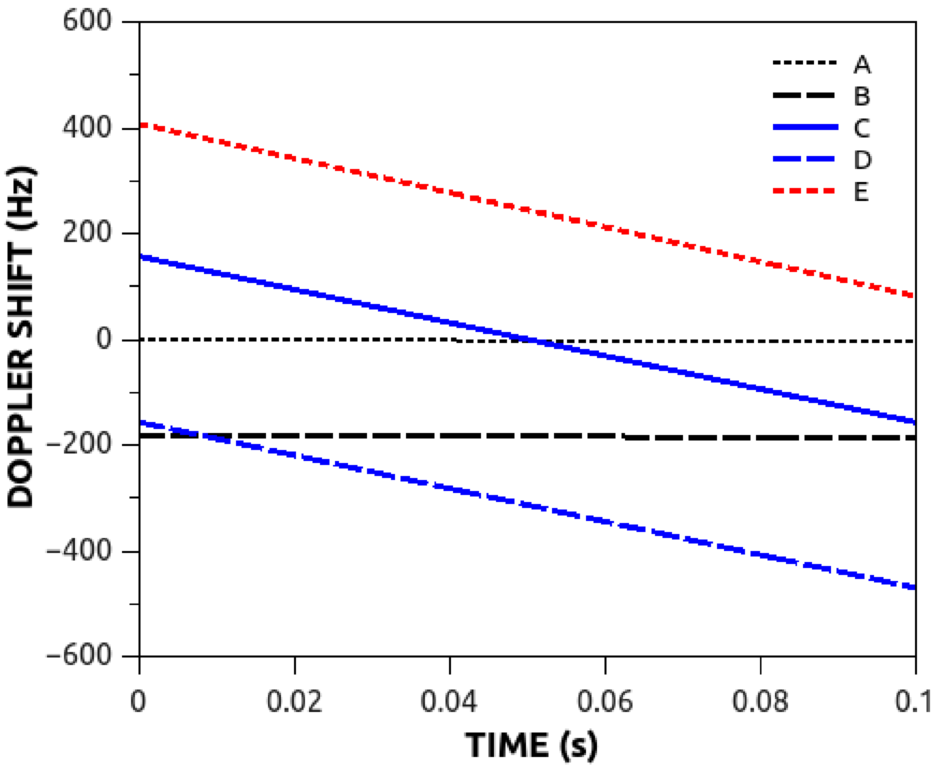
Separation: 1500 km (930 mi)

100 ms ping

Head velocity: 40 km/s

Height: 90 km

Chirp depends on path geometry



Digital Modes: Maximum Frequency Compensation

	FSK441	MSK144
Initial Doppler + VFO mismatch	± 600 Hz	± 200 Hz
Chirp on the ping	~ 100 Hz	~ 200 Hz

Digital Modes: Maximum Frequency Compensation

	FSK441	MSK144
Initial Doppler + VFO mismatch	± 600 Hz	± 200 Hz
Chirp on the ping	~ 100 Hz	~ 200 Hz

Calculated Doppler shifts generally exceed these limits

Estimate ~ 1% pings from **meteor heads** decode at 222 MHz

Pings likely originate from the relatively stationary ionization trail

SHORTHAND MESSAGES

	FSK441 [1]	**MSK144** [2]
Technique	4 messages; Single Tones	9 messages; LDPC FEC
Minimum ping duration	20 ms	20 ms
Sensitivity	< 0 dB	–1.5 dB
Reliability	Can be confused by birdies; QRM	Uses hash of both callsigns

[1] K1JT, QST (2001)
[2] K9AN and K1JT, QEX (2017)

SUMMARY

Most pings are long enough on 222 MHz to support 72 ms MSK144 frames

Partial FSK441 decodes should not be preferred over MSK144

Decoded pings are reflection from ionization trails – not the meteor head

Pro tip: Get more MSK144 sensitivity
by setting phase equalization on the IF transceiver

ACKNOWLEDGMENTS

Mike K7ULS **Duffey KK6MC**

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