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The Real FT8, JT65, and JT9 Signal - to - Noise Ratio Revealed

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Introduction

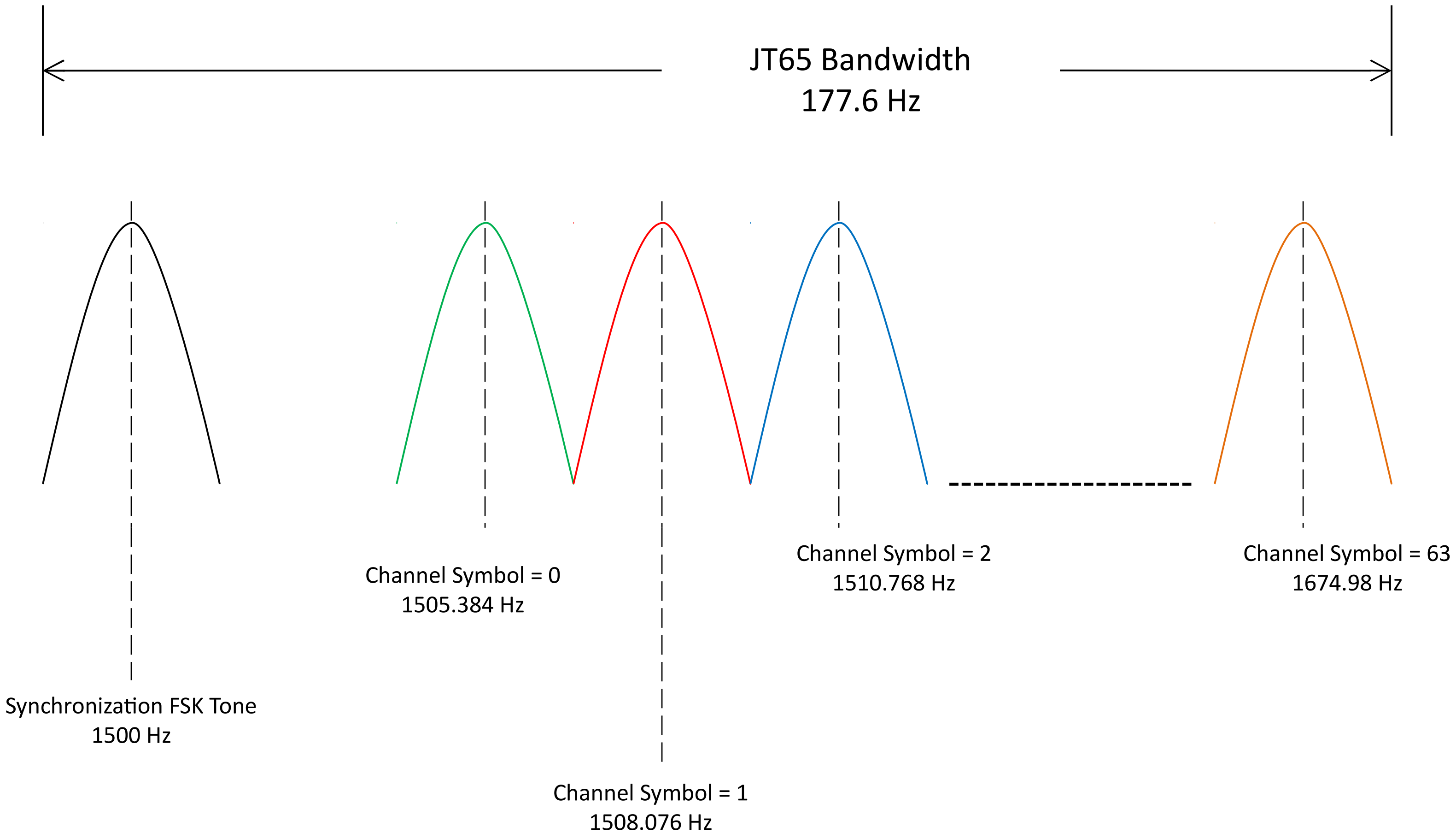
- You may receive a negative FT8, JT65, or JT9 digital HF communications mode Signal-to-Noise Ratio (SNR) report in the range of -27 dB to -1dB
  - Recall , a negative SNR report implies the signal is below the noise floor
- **In reality, this is not the case, the Frequency Shift Key (FSK) tones are well above the noise floor**
- Received FT8, JT65 and JT9 signal reports are actually referenced to a **much wider noise bandwidth** (2500 Hz) than the actual **detection bandwidth** required to successfully decode the digital data represented by the received FSK tone.
- The smaller detection bandwidth drives the actual SNR, which along with forward-error-correction, allows error-free message decoding
- **The purpose of this presentation**
  - **To demonstrate the SNR increases dramatically as we home-in on the detection bandwidth of a single FSK tone**

What is Signal-to-Noise Ratio (S/N)

- **SNR is typically measured and reported in decibels (dB)**
- **S = received signal power as it is received by the distant end**
  - **It is the only variable** in this SNR equation **you can actually control**
- **How do you influence the received signal power at the distant end?**
  - Increasing/decreasing the transmit power
  - Using a higher gain antenna, etc.
  - You are in control of the Effective Radiated Power (ERP)
- **N = noise power as it is received by the distant end**
  - **Solely owned** by the operator on the distant end, the transmitting station has **no influence, whatsoever,** on the received noise power at the distant end
- **Noise comes from various sources:**
  - Atmospheric Noise (culmination of man-made noise and noise produced by lightning around the world)
  - Cosmic Noise (noise generated outside the earth's atmosphere)
  - Self-generated receiver noise

What is the Detection Bandwidth, and the JT65 Waveform

description bullets on next slide



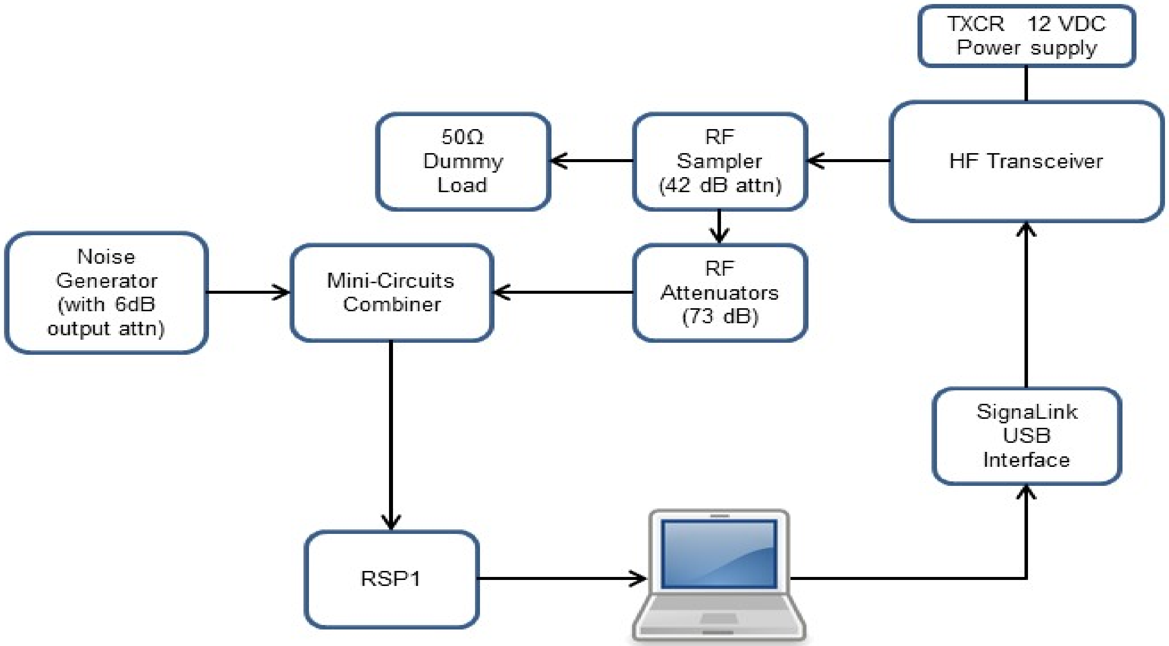
The JT65 Waveform Description

- The JT65 waveform gets its name from the inventor Joe Taylor and the 65 refers to fact that it utilizes a **64-ary FSK tones waveform with one extra FSK tone maintaining time and frequency synchronization**
- Hence, **64 FSK tones, which carry the message data**, plus **1 synchronization tone = 65**
- **The FSK sync tone is transmitted twice as frequently** as the FSK data tones during a message transmission
- Each of the 64 FSK tones represents a **6 bit encoded message symbol**
- The JT65 signaling waveform only occupies **a transmission bandwidth of approximately 178 Hz**
- **And even more significantly,** each FSK **signaling tone**, that is being transmitted only occupies **2.692 Hz** – **the detection bandwidth**
- **It is only the noise that exists in that super small bandwidth of 2.692 Hz** that drives the **real SNR** that determines the success of demodulating and decoding the text message
- The detection SNR is called the

FSK Symbol - to - Noise Power Density Ratio

The Test Configuration

*Used to demonstrate as we reduce the **Received Signal Report referenced 2500 Hz Noise Bandwidth** to that which approaches the **very small Detection Bandwidth** the **SNR increases dramatically** (description on next slide)*

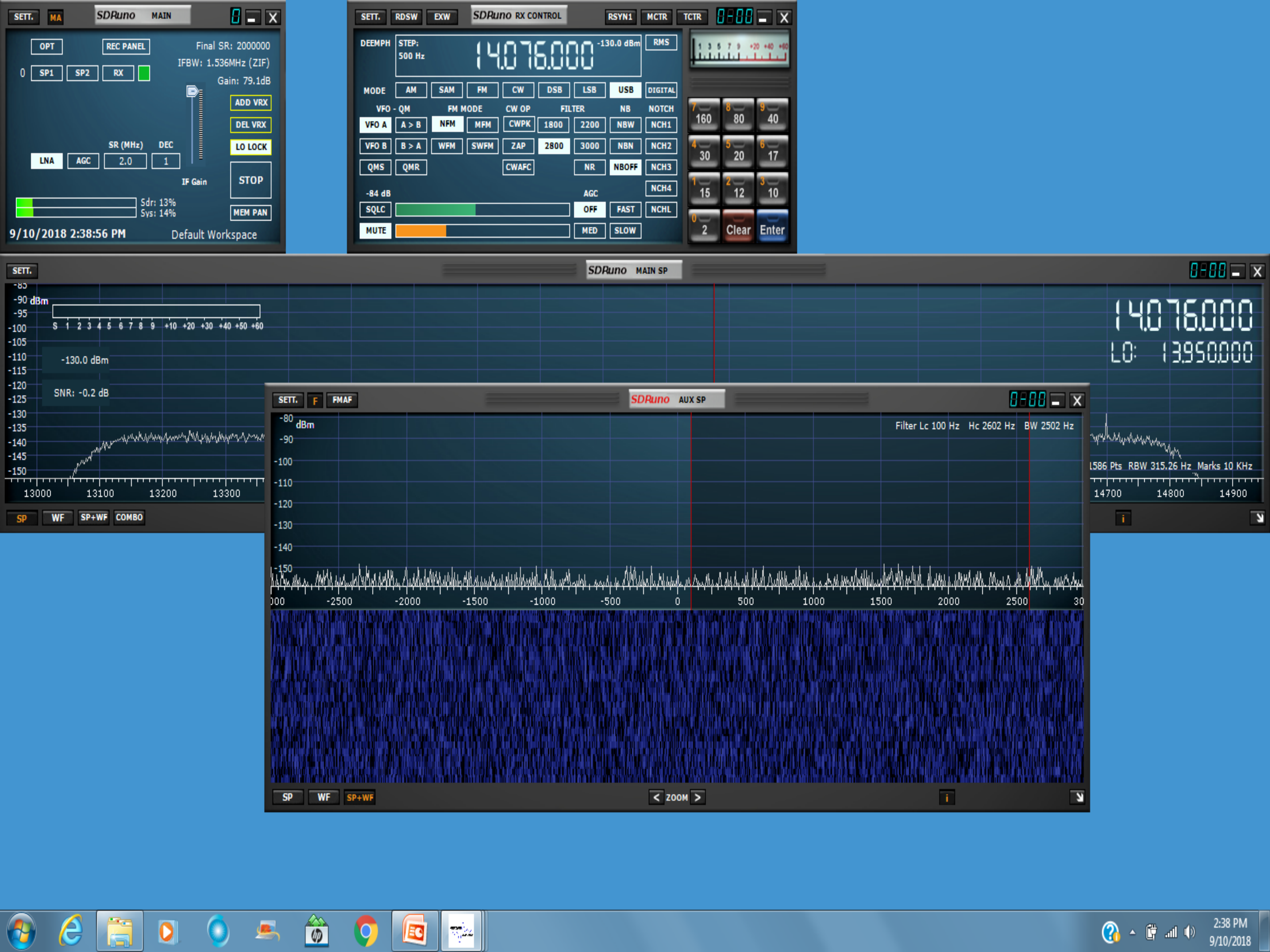


Test Configuration Description

- **To demonstrate this, I put together a JT65 transmission and receiver system**
- The PC is running WSJT-X software to generate a **CQ KC5RUO DM65** message
- The **encoded message symbols** are sent via the SignaLink USB interface to the transceiver (YAESU FT-891) as FSK tones
- The FSK tones modulate a 20 meter 14.076 MHz carrier which is transmitted out and received by this SDRPlay Radio Spectrum Processor (RSP1) receiver **at a realistic signal power level that you might receive at home via your antenna system.**
- To get the signal down to a S1 S-unit level of approximately -121 dBm **I use a series of attenuators you see here.** 115 dB of attenuation
- I am using the **SDRuno Software Defined Radio (SDR) signal processing software and receiver**, and in this *presentation* we are going to **focus on**:
  - The SP2, passband scope display
  - We'll be looking at the Signal Processing display and the waterfall
  - The RMS Power Level received power level measured in the SP2 defined bandwidth
    - Which is a measure of the signal and the noise within the SP2 defined bandwidth
  - The SNR, derived from the signal and noise power measured in the SP2 defined bandwidth
    - Note: The SDRuno measured SNR is actually (S+N)/N
- To simulate received noise and set the received noise power, I use a Rigol DG4162 waveform function generator to produce the Additive White Gaussian Noise (AWGN)
- The Mini-circuits combiner brings both the signal generated by the transceiver and noise to the RSP1 receiver

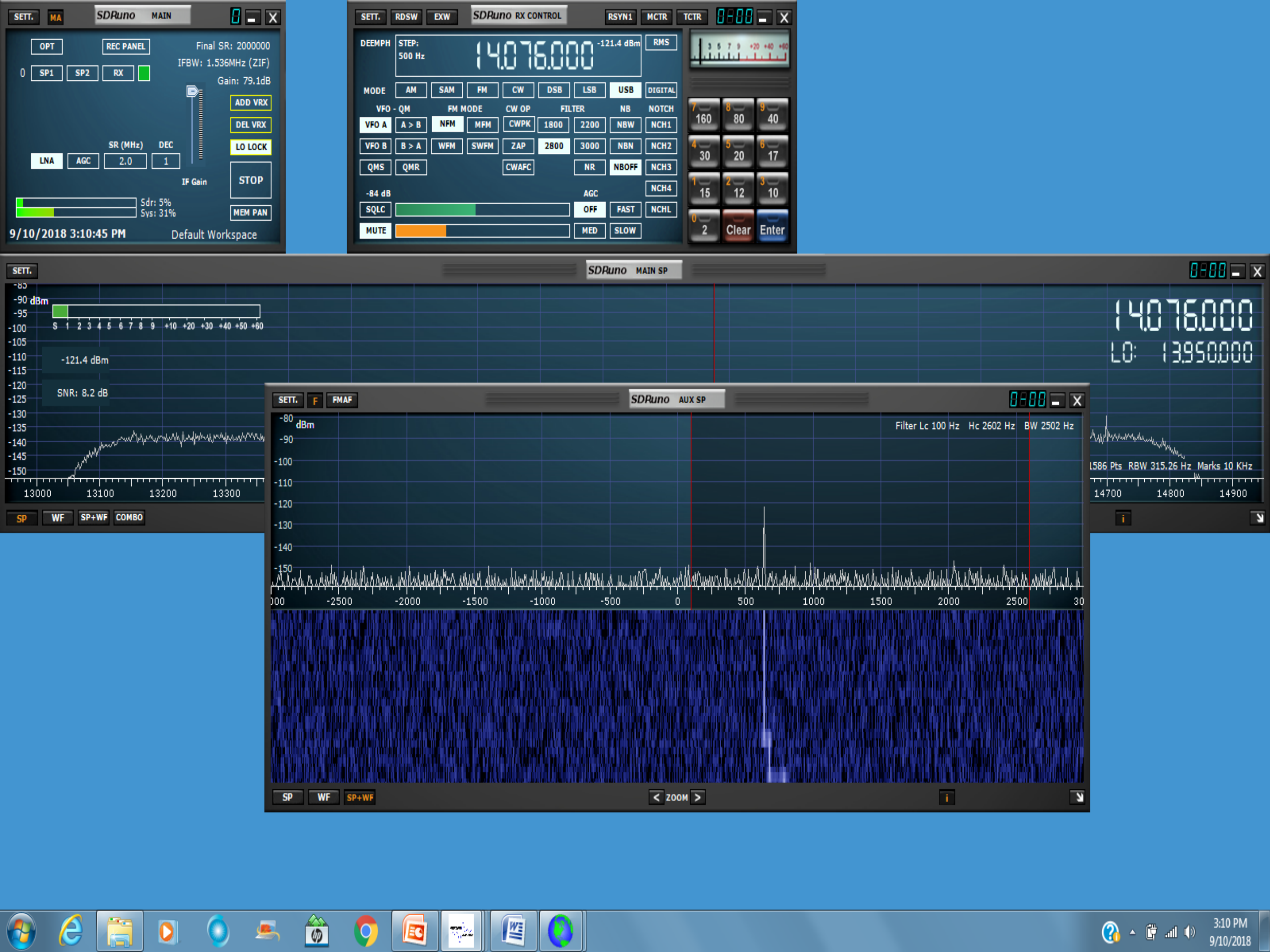
SDRuno Screen Shot
RSP1 Receiver Noise Floor
SP2 passband = 2500 Hz

- Receiver Noise Bandwidth = 2500 Hz
- RSP1 Receiver Noise Floor ≈ -130 dBm (9 dB below an S1 unit level)
- N_{PB} = Noise Power derived from the SP2 passband
- N_{PB} ≈ -130dBm as measured across a receiver noise bandwidth = 2500 Hz


SETT.
MA
SDRuno MAIN
OPT
REC PANEL
Final SR: 2000000
IFBW: 1.536MHz (ZIF)
Gain: 79.1dB
SP1
SP2
RX
ADD VRX
DEL VRX
LO LOCK
SR (MHz)
DEC
LNA
AGC
2.0
1
IF Gain
STOP
Sdr: 13%
Sys: 14%
MEM PAN
9/10/2018 2:38:56 PM
Default Workspace
RDSW
EXW
SDRuno RX CONTROL
RSYN1
MCTR
TCTR
DEEMPH
STEP:
500 Hz
14.076.000
-130.0 dBm
RMS
MODE
AM
SAM
FM
CW
DSB
LSB
USB
DIGITAL
VFO - QM
FM MODE
CW OP
FILTER
NB
NOTCH
VFO A
A > B
NFM
MFM
CWPK
1800
2200
NBW
NCH1
VFO B
B > A
WFM
SWFM
ZAP
2800
3000
NBN
NCH2
QMS
QMR
CWAFC
NR
NBOFF
NCH3
NCH4
-84 dB
AGC
SQLC
OFF
FAST
NCHL
MUTE
MED
SLOW
160
80
40
30
20
17
15
12
10
2
Clear
Enter
SDRuno MAIN SP
dBm
-130.0 dBm
SNR: -0.2 dB
14.076.000
LO: 13.950.000
1586 Pts RBW 315.26 Hz Marks 10 KHz
SP
WF
SP+WF
COMBO
F
FMAF
SDRuno AUX SP
Filter Lc 100 Hz Hc 2602 Hz BW 2502 Hz
ZOOM
2:38 PM
9/10/2018

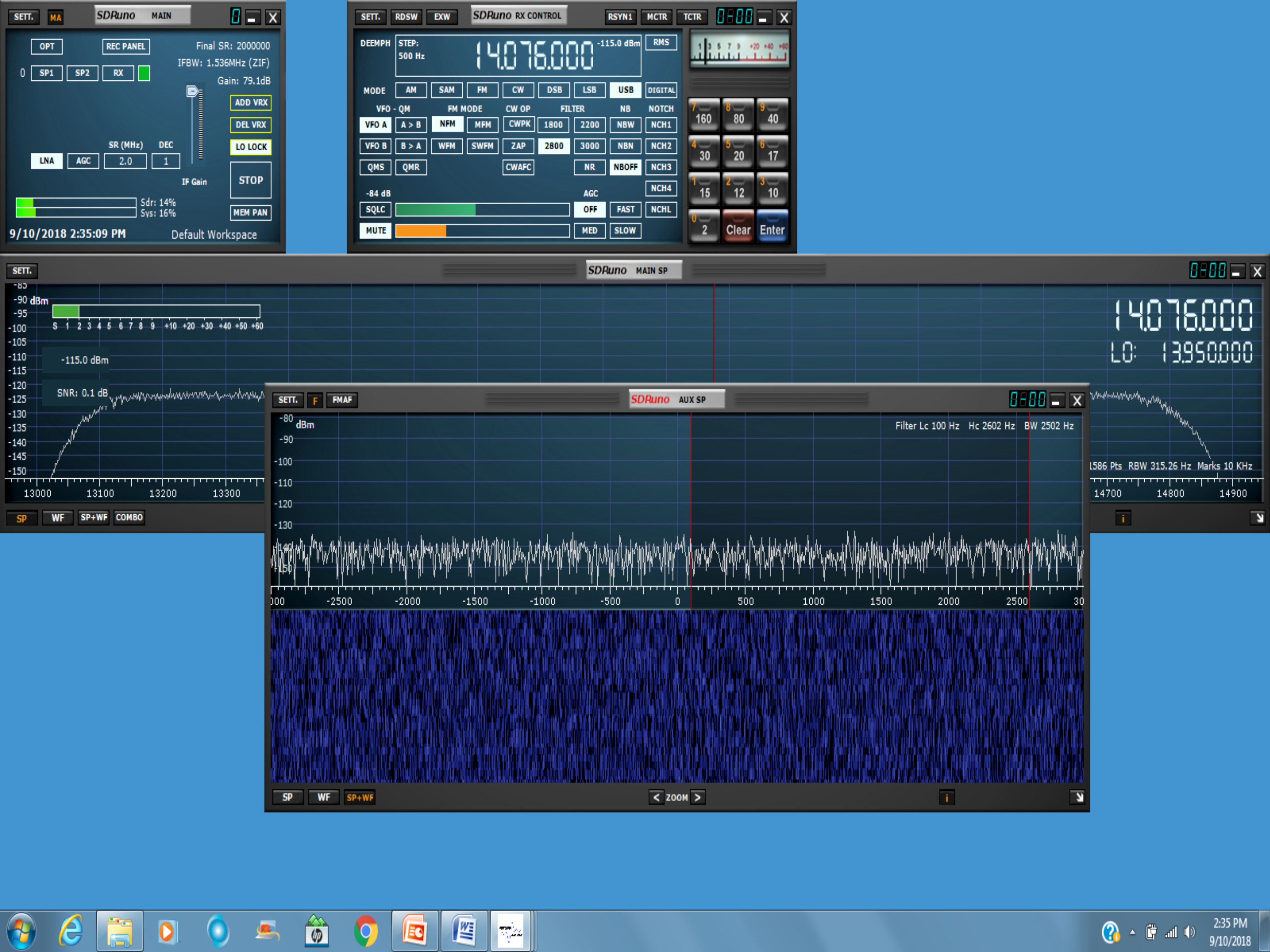
SDRuno Screen Shot
JT65 Signal & RSP1 Receiver Noise Floor
SP2 passband = 2500 Hz

- Receiver Noise Bandwidth = 2500 Hz
- S_{PB} = Signal Power derived from the SP2 passband
- $S_{PB} \approx$ - 121 dBm = S1 unit level
- RSP1 Receiver Noise Floor $N_{PB} \approx$ -130dBm as measured across a receiver noise bandwidth = 2500 Hz
- SNR ≈ 9 dB,
- Note:
  - SDRuno actual measured RMS power = $(S_{PB} + N_{PB})$
  - And, SDRuno actual measured SNR = $(S_{PB} + N_{PB})/ N_{PB}$
  - But, the JT65 signal level is so much larger than the Rx noise floor the measured RMS power and SNR are dominated by S_{PB}


SETT.
MA
SDRuno MAIN
OPT
REC PANEL
Final SR: 2000000
IFBW: 1.536MHz (ZIF)
Gain: 79.1dB
SP1
SP2
RX
ADD VRX
DEL VRX
LO LOCK
SR (MHz)
DEC
LNA
AGC
2.0
1
IF Gain
STOP
Sdr: 5%
Sys: 31%
MEM PAN
9/10/2018 3:10:45 PM
Default Workspace
RDSW
EXW
SDRuno RX CONTROL
RSYN1
MCTR
TCTR
DEEMPH
STEP:
500 Hz
14.076.000
-121.4 dBm
RMS
MODE
AM
SAM
FM
CW
DSB
LSB
USB
DIGITAL
VFO - QM
FM MODE
CW OP
FILTER
NB
NOTCH
VFO A
A > B
NFM
MFM
CWPK
1800
2200
NBW
NCH1
VFO B
B > A
WFM
SWFM
ZAP
2800
3000
NBN
NCH2
QMS
QMR
CWAFC
NR
NBOFF
NCH3
NCH4
-84 dB
AGC
SQLC
OFF
FAST
NCHL
MUTE
MED
SLOW
160
80
40
30
20
17
15
12
10
2
Clear
Enter
SDRuno MAIN SP
-90 dBm
-121.4 dBm
SNR: 8.2 dB
14.076.000
LO: 13.950.000
13000
13100
13200
13300
14700
14800
14900
1586 Pts RBW 315.26 Hz Marks 10 KHz
SP
WF
SP+WF
COMBO
SDRuno AUX SP
F
FMAF
dBm
Filter Lc 100 Hz Hc 2602 Hz BW 2502 Hz
-2500
-2000
-1500
-1000
-500
0
500
1000
1500
2000
2500
ZOOM
3:10 PM
9/10/2018

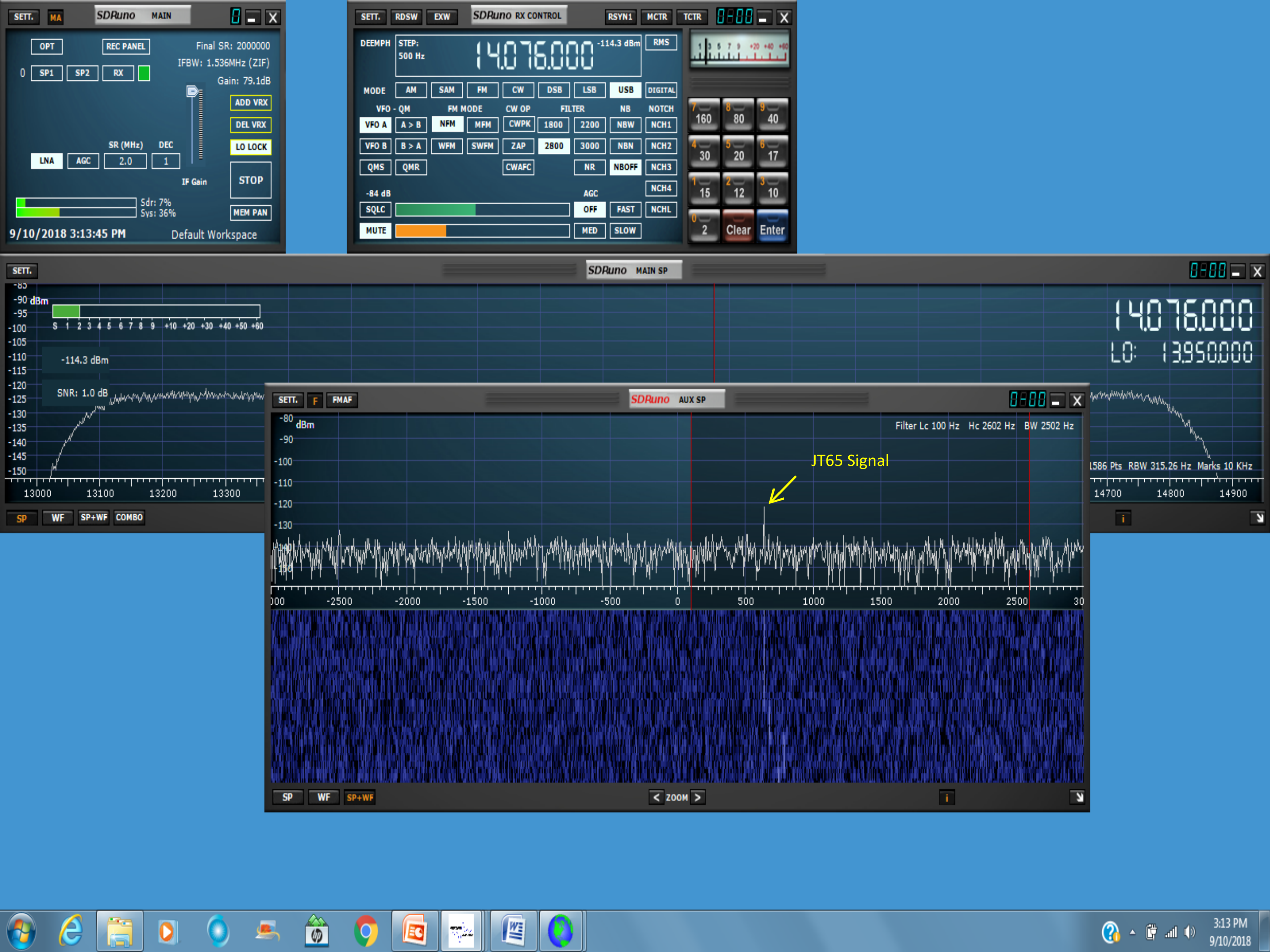
SDRuno Screen Shot
Received Additive White Gaussian Noise

- SP2 passband = 2500 Hz
- Receiver Noise Bandwidth = 2500 Hz
- AWGN power = N_{PB} ≈ -115 dBm = S2 unit level
- *As measured across a receiver noise bandwidth = 2500 Hz*


SDRuno MAIN
OPT
REC PANEL
Final SR: 2000000
IFBW: 1.536MHz (ZIF)
Gain: 79.1dB
SP1
SP2
RX
ADD VRX
DEL VRX
LO LOCK
SR (MHz)
DEC
LNA
AGC
2.0
1
IF Gain
STOP
Sdr: 14%
Sys: 16%
MEM PAN
9/10/2018 2:35:09 PM
Default Workspace
SDRuno RX CONTROL
RDSW
EXW
RSYN1
MCTR
TCTR
DEEMPH
STEP:
500 Hz
14.076.000
-115.0 dBm
RMS
MODE
AM
SAM
FM
CW
DSB
LSB
USB
DIGITAL
VFO - QM
FM MODE
CW OP
FILTER
NB
NOTCH
VFO A
A > B
NFM
MFM
CWPK
1800
2200
NBW
NCH1
VFO B
B > A
WFM
SWFM
ZAP
2800
3000
NBN
NCH2
QMS
QMR
CWAFC
NR
NBOFF
NCH3
NCH4
-84 dB
AGC
SQLC
OFF
FAST
NCHL
MUTE
MED
SLOW
160
80
40
30
20
17
15
12
10
2
Clear
Enter
SDRuno MAIN SP
-90 dBm
-115.0 dBm
SNR: 0.1 dB
14.076.000
LO: 13.950.000
1586 Pts RBW 315.26 Hz Marks 10 KHz
13000
13100
13200
13300
14700
14800
14900
SP
WF
SP+WF
COMBO
SDRuno AUX SP
FMAF
dBm
Filter Lc 100 Hz Hc 2602 Hz BW 2502 Hz
-2500
-2000
-1500
-1000
-500
0
500
1000
1500
2000
2500
ZOOM
2:35 PM
9/10/2018

SDRuno Screen Shot
JT65 Signal & AWGN
SP2 passband = 2500 Hz

- Receiver Noise Bandwidth = 2500 Hz
- $(S_{PB} + N_{PB})$ = -114 dBm
  - Where S_{PB} = -121 dBm and N_{PB} = *-115 dBm*
- N_{PB} ≈ 6 dB greater than S_{PB} *as measured across a receiver noise bandwidth = 2500 Hz*
- The signal and noise power measurement **within the 2500 Hz** Receiver Noise Bandwidth is no longer dominated by the received JT65 signal but now dominated by the noise
- SNR measured value ≈ 1.0 dB (*$S_{PB} + N_{PB}$ = -114 dBm, N_{PB} = -115 dBm*)
  - Where SNR = $(S_{PB} + N_{PB})/ N_{PB}$, and dominated by N_{PB} *as measured across a receiver noise bandwidth = 2500 Hz*


SDRuno MAIN
Final SR: 2000000
IFBW: 1.536MHz (ZIF)
Gain: 79.1dB
9/10/2018 3:13:45 PM
Default Workspace
SDRuno RX CONTROL
14.076.000
-114.3 dBm
SDRuno MAIN SP
14.076.000
LO: 13.950.000
-114.3 dBm
SNR: 1.0 dB
SDRuno AUX SP
Filter Lc 100 Hz Hc 2602 Hz BW 2502 Hz
JT65 Signal
3:13 PM
9/10/2018

SDRuno Screen Shot
JT65 Signal & AWGN
Receiver Noise Bandwidth = 2500 Hz

- **So why can we still see the FSK tones rise above the noise floor?**
- Because the FSK signal energy is concentrated over a very small bandwidth of 2.692 Hz. The FSK tone detection BW = 2.692 Hz
- The signal energy in that small concentrated BW is much greater than the noise power over that detection bandwidth.
- You see, **if the FSK tone bandwidth was actually 2500 Hz** we would never see the signal. The signal energy would be spread out over the 2500 Hz receiver noise bandwidth and "buried in the weeds".
- **It is the SNR within that FSK tone detection BW which determines the success or failure of demodulating and decoding an error-free JT65 message - not the reported SNR referenced across the much wider 2500 Hz noise bandwidth**

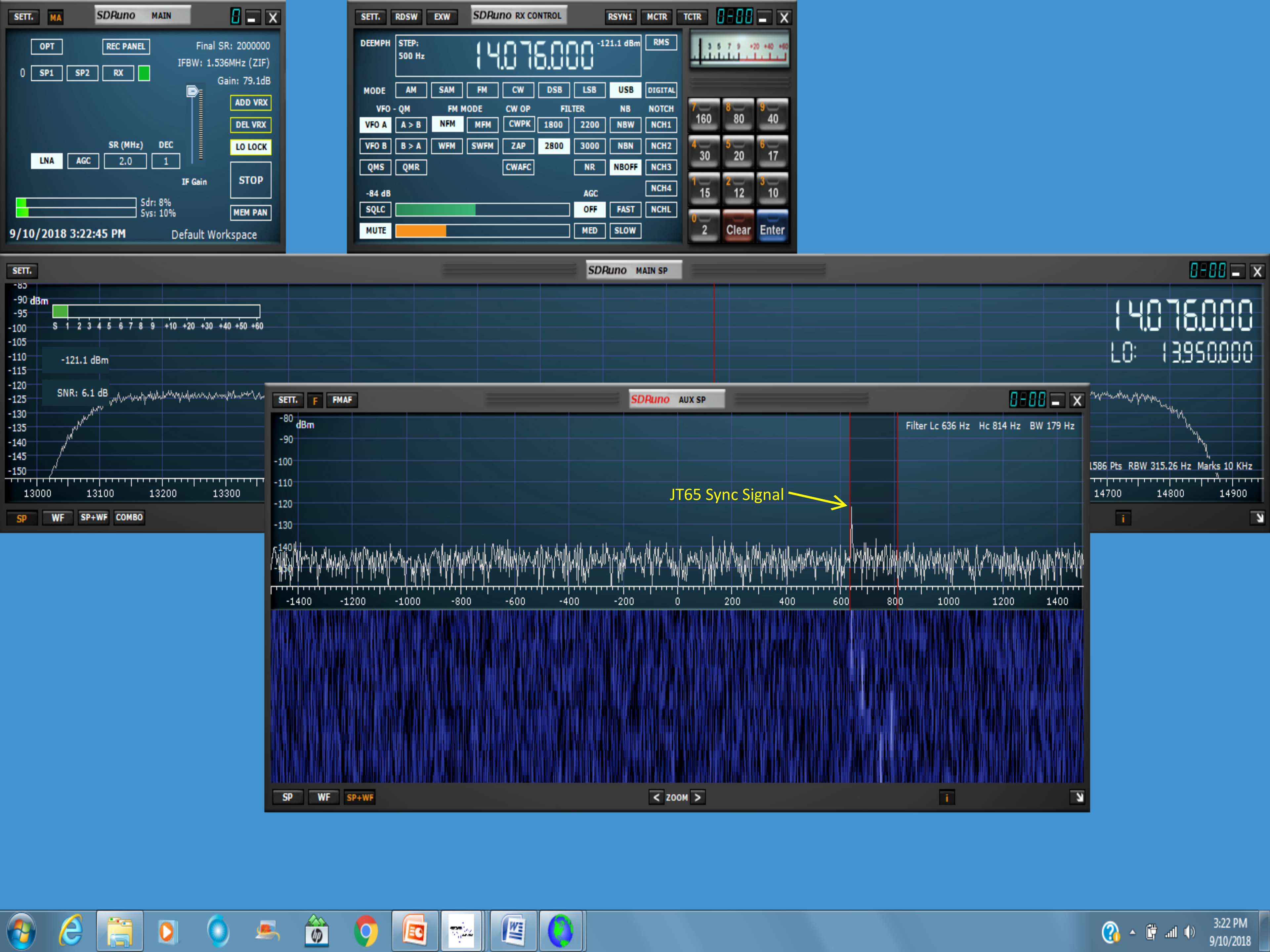
The Claim

As the receiver noise bandwidth decreases and approaches that of the actual detection bandwidth the SNR increases.

- I am going to change the SP2 receiver passband to 179 Hz the approximate transmission bandwidth of the JT65 signal
- Recall the JT65 transmission bandwidth encompasses the FSK sync tone and the 64 FSK message tones

SDRuno Screen Shot
JT65 Signal & AWGN
SP2 passband = 179 Hz

- Receiver Noise Bandwidth = 179 Hz
- N_{PB} is significantly reduced
- $(S_{PB} + N_{PB})$ = -121 dBm
  - Where S_{PB} = -121 dBm and *N_{PB} = -127 dBm*
- The signal and noise power measurement **within the 179 Hz** Receiver Noise Bandwidth is again dominated by the received JT65 signal
- SNR measured value ≈ 6 dB
  - SNR increased approx 5 dB, a factor of 3 times higher SNR

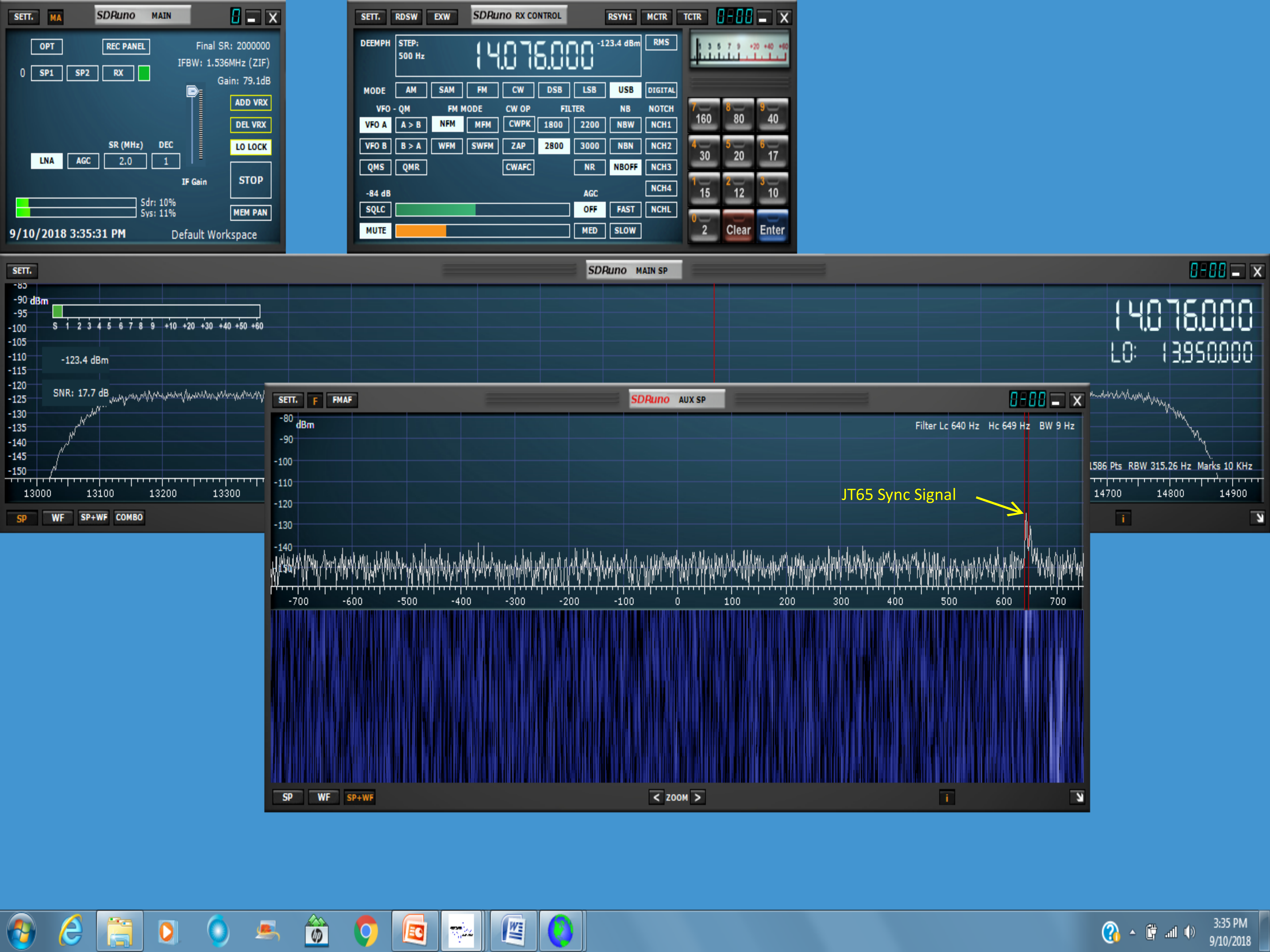

SDRuno MAIN
OPT
REC PANEL
Final SR: 2000000
IFBW: 1.536MHz (ZIF)
Gain: 79.1dB
ADD VRX
DEL VRX
LO LOCK
STOP
MEM PAN
Sdr: 8%
Sys: 10%
9/10/2018 3:22:45 PM
Default Workspace
SDRuno RX CONTROL
14.076.000
-121.1 dBm
STEP: 500 Hz
SDRuno MAIN SP
-121.1 dBm
SNR: 6.1 dB
14.076.000
LO: 13.950.000
1586 Pts RBW 315.26 Hz Marks 10 KHz
SDRuno AUX SP
Filter Lc 636 Hz Hc 814 Hz BW 179 Hz
JT65 Sync Signal

Close In on the Detection Bandwidth
Receiver Noise Bandwidth = 9 Hz

- Now I am going to close in on the JT65 FSK sync tone and try to get as close to the detection bandwidth as possible
  - By reducing the receiver passband to something as close to that which approaches the 2.692 Hz detection bandwidth

SDRuno Screen Shot JT65 Signal & AWGN SP2 passband = 9 Hz

- Receiver Noise Bandwidth = 9 Hz
- N_{PB} is further significantly reduced
- $(S_{PB} + N_{PB})$ = -121 dBm
  - Where S_{PB} = -121 dBm and *N_{PB} = -138 dBm*
- The signal and noise power measurement **within the 9 Hz** Receiver Noise Bandwidth is again dominated by the received JT65 signal
- SNR measured value ≈ 17 dB
  - SNR increased by a factor of 40


SDRuno MAIN
Final SR: 2000000
IFBW: 1.536MHz (ZIF)
Gain: 79.1dB
9/10/2018 3:35:31 PM
Default Workspace
SDRuno RX CONTROL
14.076.000
-123.4 dBm
SDRuno MAIN SP
14.076.000
LO: 13.950.000
-123.4 dBm
SNR: 17.7 dB
SDRuno AUX SP
Filter Lc 640 Hz Hc 649 Hz BW 9 Hz
JT65 Sync Signal
3:35 PM
9/10/2018

So, what is the Real SNR that determines JT65, JT9, FT8 Message Decoding Performance?

- **FSK Symbol – to – Noise Power Density Ratio (Es/No)**
- $\mathbf{(Es/No)_{dB}}$ can be derived mathematically from the **Reported SNR**

$$(Es/No)_{dB} = (SNRreported)_{dB} + (10 \times LOG\ (2500\ Hz/\ (FSK\ symbol\ detection\ BW))_{dB}$$

- JT65 FSK symbol detection BW = 2.692 Hz
- JT9 FSK symbol detection BW = 1.736 Hz
- FT8 FSK symbol detection BW = 6.25 Hz

HF Digital Communication Mode JT65

$$(Es/No)_{JT65\ (dB)} = (SNRreported)_{JT65\ (dB)} + (10 \times LOG\ (2500\ Hz/2.692\ Hz))_{(dB)}$$

where:

1) 2500 Hz is the Reported SNR Noise bandwidth

2) 2.692 Hz is the actual JT65 signaling noise bandwidth also known as the JT65 FSK symbol detection bandwidth

$$(Es/No)_{JT65\ (dB)} = (SNRreported)_{JT65\ (dB)} + 29.7\ dB$$

HF Digital Communication Mode JT9

$$(Es/No)_{JT9\ (dB)} = (SNRreported)_{JT9\ (dB)} + (10 \times LOG\ (2500\ Hz/1.736\ Hz))_{(dB)}$$

where:

1) 2500 Hz is the Reported SNR Noise bandwidth

2) 1.736 Hz is the actual JT9 signaling noise bandwidth also known as the JT9 FSK symbol detection bandwidth

$$(Es/No)_{JT9\ (dB)} = (SNRreported)_{JT9\ (dB)} + 31.6\ dB$$

HF Digital Communication Mode FT8

$$(Es/No)_{FT8\ (dB)} = (SNRreported)_{FT8\ (dB)} + (10 \times LOG\ (2500\ Hz/6.25\ Hz))_{(dB)}$$

where:

1) 2500 Hz is the Reported SNR Noise bandwidth

2) 6.25 Hz is the actual FT8 signaling noise bandwidth also known as the FT8 FSK symbol detection bandwidth

$$(Es/No)_{FT8\ (dB)} = (SNRreported)_{FT8\ (dB)} + 26\ dB$$

JT65, JT9, and FT8 FSK Symbol-to-Noise Density Ratio $(Es/No)_{dB}$ derived from Reported SNR			
Reported SNR (dB) over a 2500 Hz Noise Bandwidth	$(Es/No)_{JT65\ (dB)}$	$(Es/No)_{JT9\ (dB)}$	$(Es/No)_{FT8\ (dB)}$
-30	-0.3	1.6	-4
-29	0.7	2.6	-3
-28	1.7	3.6	-2
-27	2.7	4.6	-1
-26	3.7	5.6	0
-25	4.7	6.6	1
-24	5.7	7.6	2
-23	6.7	8.6	3
-22	7.7	9.6	4
-21	8.7	10.6	5
-20	9.7	11.6	6
-19	10.7	12.6	7
-18	11.7	13.6	8
-17	12.7	14.6	9

SNR threshold referenced to a 2500 Hz BW at a 50% probability for decoding a JT9 message in AWGN

SNR threshold referenced to a 2500 Hz BW at a 50% probability for decoding a JT65 message in AWGN

SNR threshold referenced to a 2500 Hz BW at a 50% probability for decoding a FT8 message in AWGN

Takeaways

- JT65, JT9 and FT8 SNR reports are referenced to a much wider noise bandwidth, 2500 Hz, than is required to successfully demodulate and decode the message
- The SNR associated with the FSK tone detection BW or signaling bandwidth is the real SNR and it is much larger than the reported SNR
- Our amateur radio receiver's ability to successfully demodulate/decode the signal of interest is all dependent upon the noise level that exists over the detection bandwidth – whether it is CW, Phone, BPSK31, etc.
-
- **So why are the received signal reports based upon a 2500 Hz bandwidth?**
  - SNR is reported for all amateur radio modes traditionally based on a receiver bandwidth of 2500 Hz
  - Because JT65, JT9 and FT8 digital HF communication modes are usually received with a normal SSB receiver, whose **IF filter is approximately 2500 Hz wide**

References

1. ***Work the World with WSJT-X, Part 2: Codes, Modes, and Cooperative Software Development***, Joe Taylor, K1JT; Steve Frankie, K9AN, and Bill Somerville, G4WJS, ARRL QST, November 2017, Volume 101, Number 11.
2. ***Open Source Soft-Decision Decoder for the JT65 (63,12) Reed-Solomon Code***, Steven J. Frankie, K9AN and Joseph H. Taylor, K1JT, QEX, May/June 2016.
3. ***Work the World with JT65 and JT9, Digital Communication via Amateur Radio***, Steve Ford, WB8IMY, ***JT65 and JT9 Protocol Specifics***, by Dr Joe Taylor, K1JT, pg 1-6, ARRL Inc, ISBN: 978-1-62595-043-7

Handout

- You are welcome to the handout which shows the real SNR for a given Reported SNR
- The real SNR is provided for JT65, JT9 , and FT8
- The other side of the handout shows the algorithm used to derive the real SNR