2018 ARRL/TAPR DCC

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

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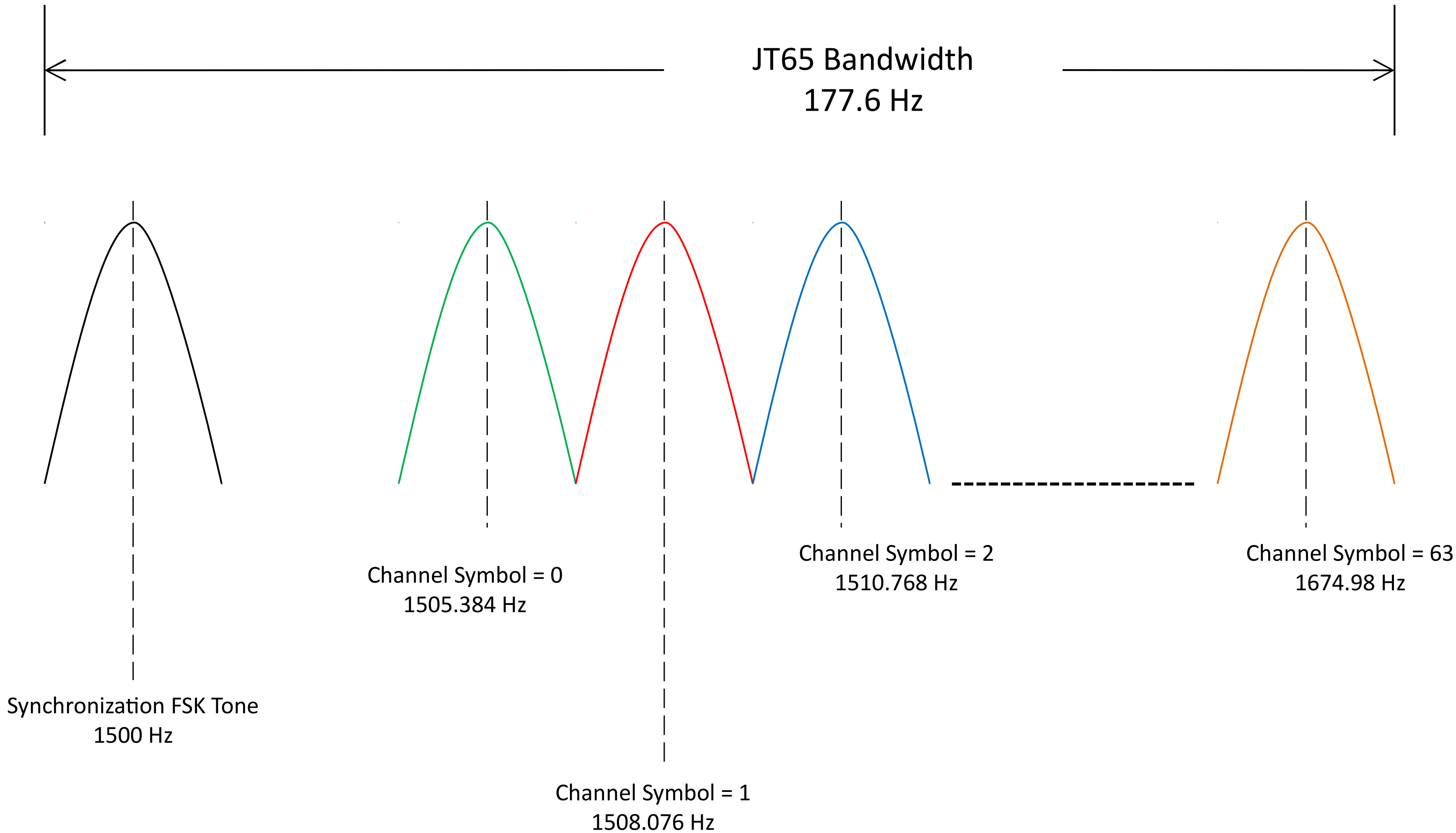

The JT65 Waveform Description

- 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***

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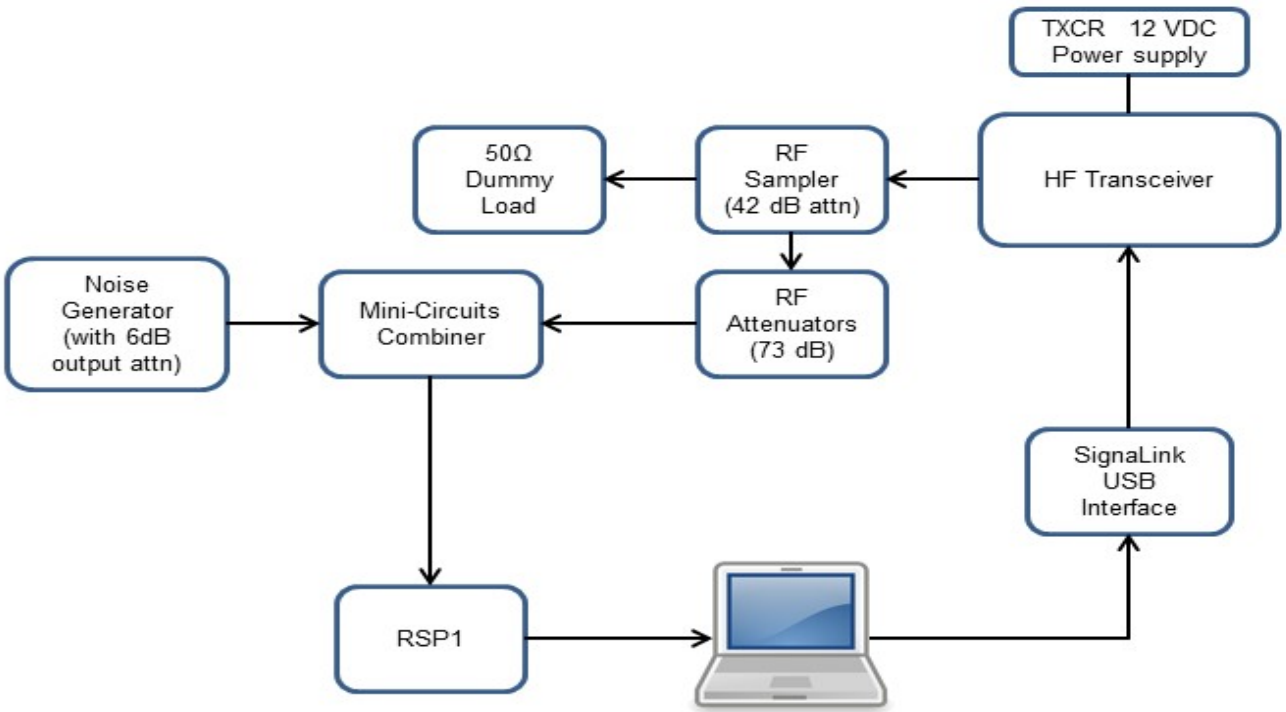
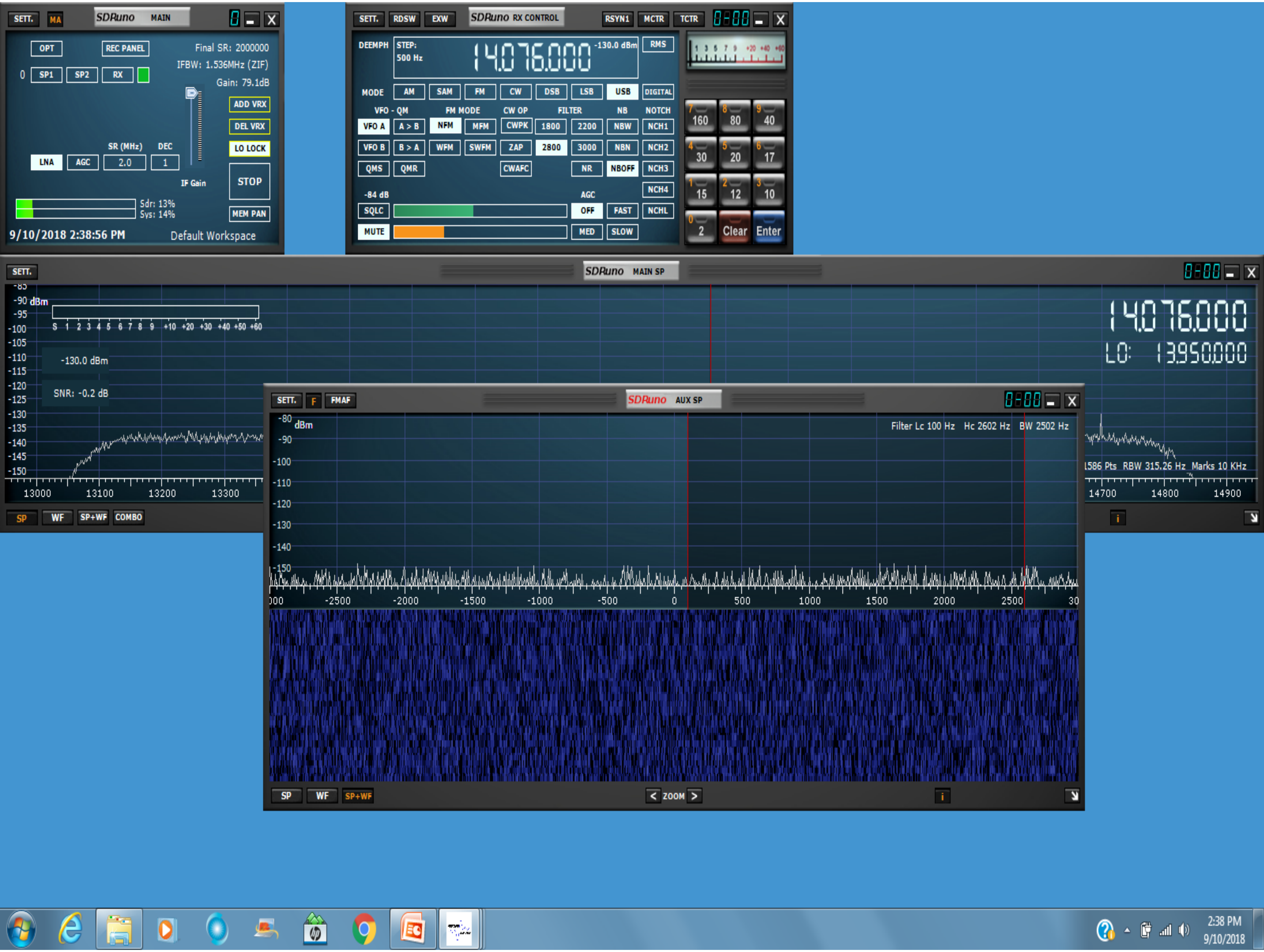


Test Configuration Description

- **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

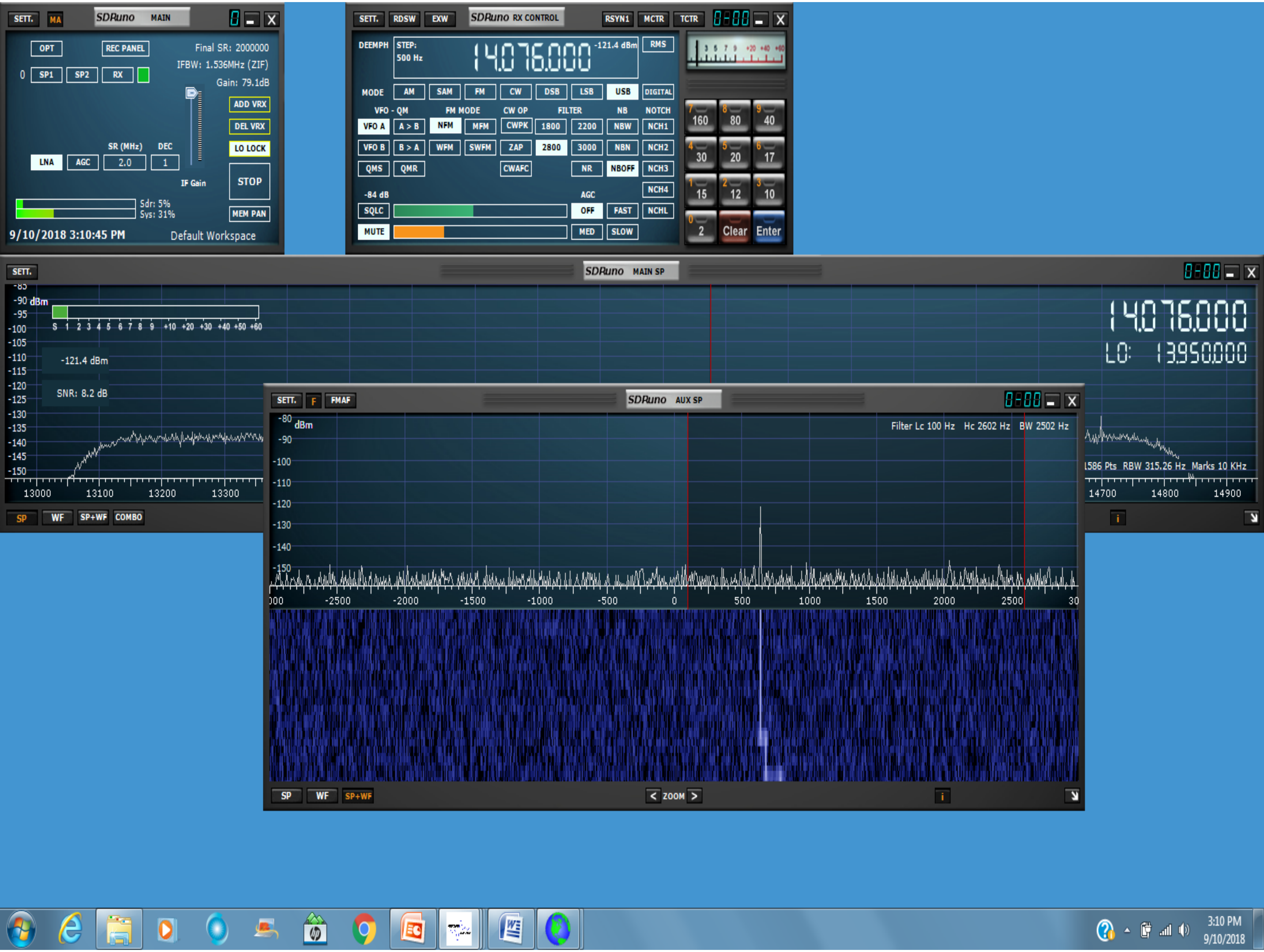
SDRuno Screen Shot
RSP1 Receiver Noise Floor
SP2 passband = 2500 Hz

- 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


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
SDRuno RX CONTROL
SETT.
RDSW
EXW
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
13000
13100
13200
13300
14700
14800
14900
SP
WF
SP+WF
COMBO
SDRuno AUX SP
FMAF
Filter Lc 100 Hz Hc 2602 Hz BW 2502 Hz
-2500
-2000
-1500
-1000
-500
0
500
1000
1500
2000
2500
ZOOM
2:38 PM
9/10/2018

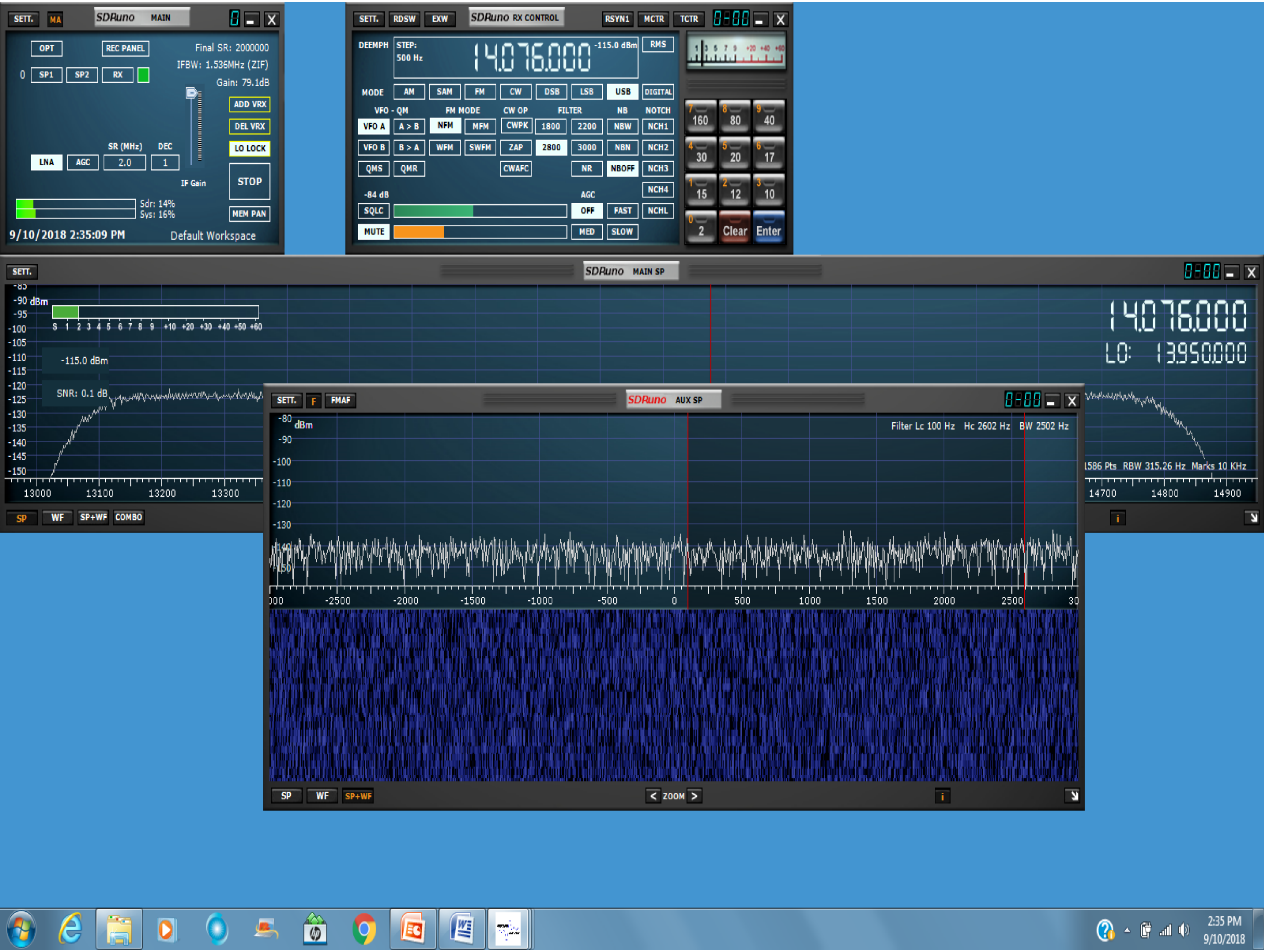
SDRuno Screen Shot
JT65 Signal & RSP1 Receiver Noise Floor
SP2 passband = 2500 Hz

- 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 $N_{PB} \approx -130$dBm 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}


SDRuno MAIN
Final SR: 2000000
IFBW: 1.536MHz (ZIF)
Gain: 79.1dB
OPT
REC PANEL
SP1
SP2
RX
ADD VRX
DEL VRX
LO LOCK
STOP
MEM PAN
LNA
AGC
SR (MHz)
2.0
DEC
1
IF Gain
Sdr: 5%
Sys: 31%
9/10/2018 3:10:45 PM
Default Workspace
SDRuno RX CONTROL
RDSW
EXW
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
1586 Pts RBW 315.26 Hz Marks 10 KHz
SP
WF
SP+WF
COMBO
SDRuno AUX SP
FMAF
dBm
Filter Lc 100 Hz Hc 2602 Hz BW 2502 Hz
ZOOM
3:10 PM
9/10/2018

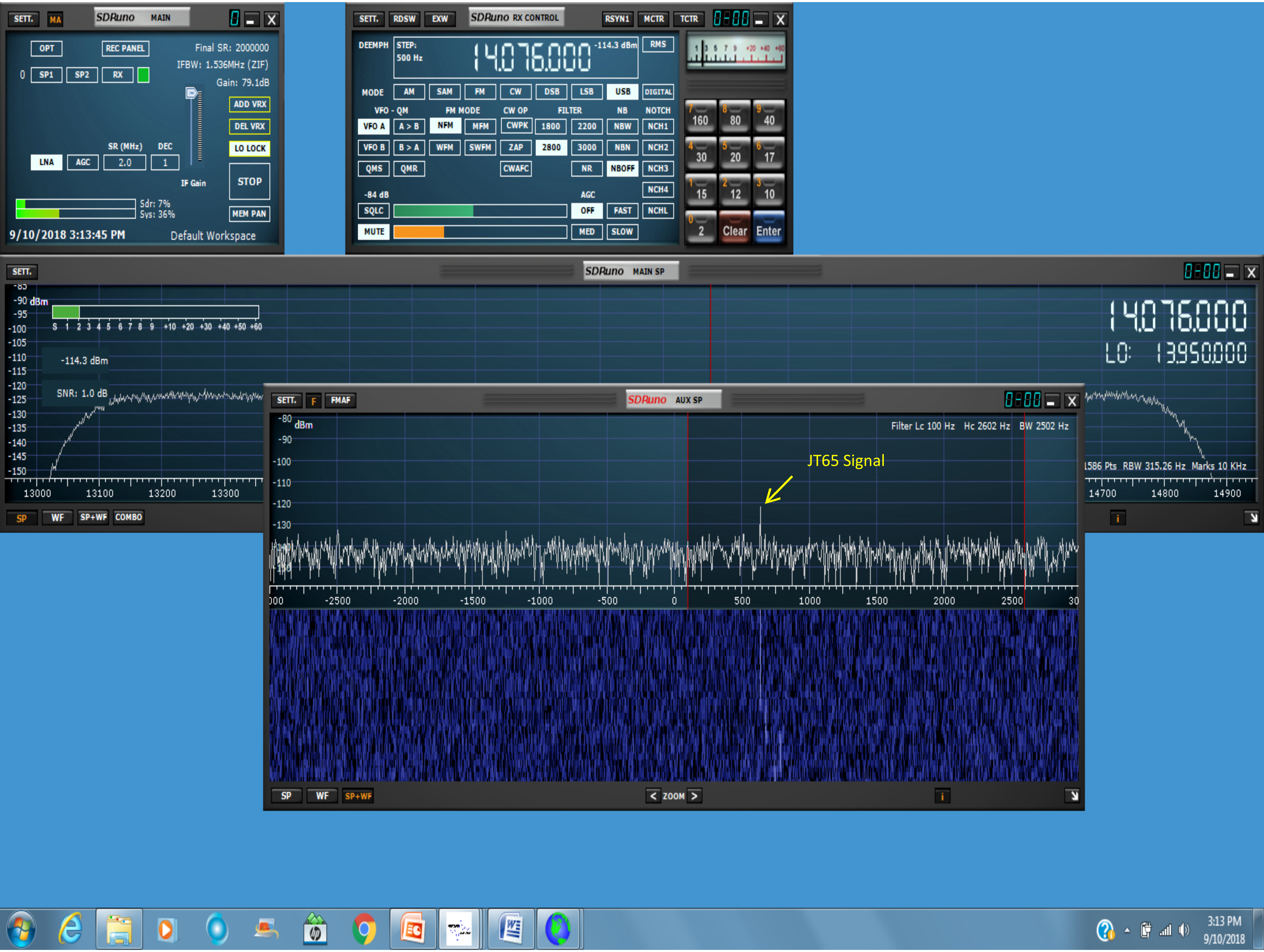
SDRuno Screen Shot
Received Additive White Gaussian Noise

- 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*


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: 14%
Sys: 16%
MEM PAN
9/10/2018 2:35:09 PM
Default Workspace
SETT.
RDSW
EXW
SDRuno RX CONTROL
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
SETT.
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
SETT.
F
FMAF
SDRuno AUX SP
dBm
Filter Lc 100 Hz Hc 2602 Hz BW 2502 Hz
-2500
-2000
-1500
-1000
-500
0
500
1000
1500
2000
2500
SP
WF
SP+WF
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
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: 7%
Sys: 36%
MEM PAN
9/10/2018 3:13:45 PM
Default Workspace
SDRuno RX CONTROL
RDSW
EXW
RSYN1
MCTR
TCTR
DEEMPH
STEP:
500 Hz
14.076.000
-114.3 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
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40
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20
17
15
12
10
2
Clear
Enter
SDRuno MAIN SP
-114.3 dBm
SNR: 1.0 dB
14.076.000
LO: 13.950.000
1586 Pts RBW 315.26 Hz Marks 10 KHz
SP
WF
SP+WF
COMBO
SDRuno AUX SP
FMAF
dBm
Filter Lc 100 Hz Hc 2602 Hz BW 2502 Hz
JT65 Signal
ZOOM
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**

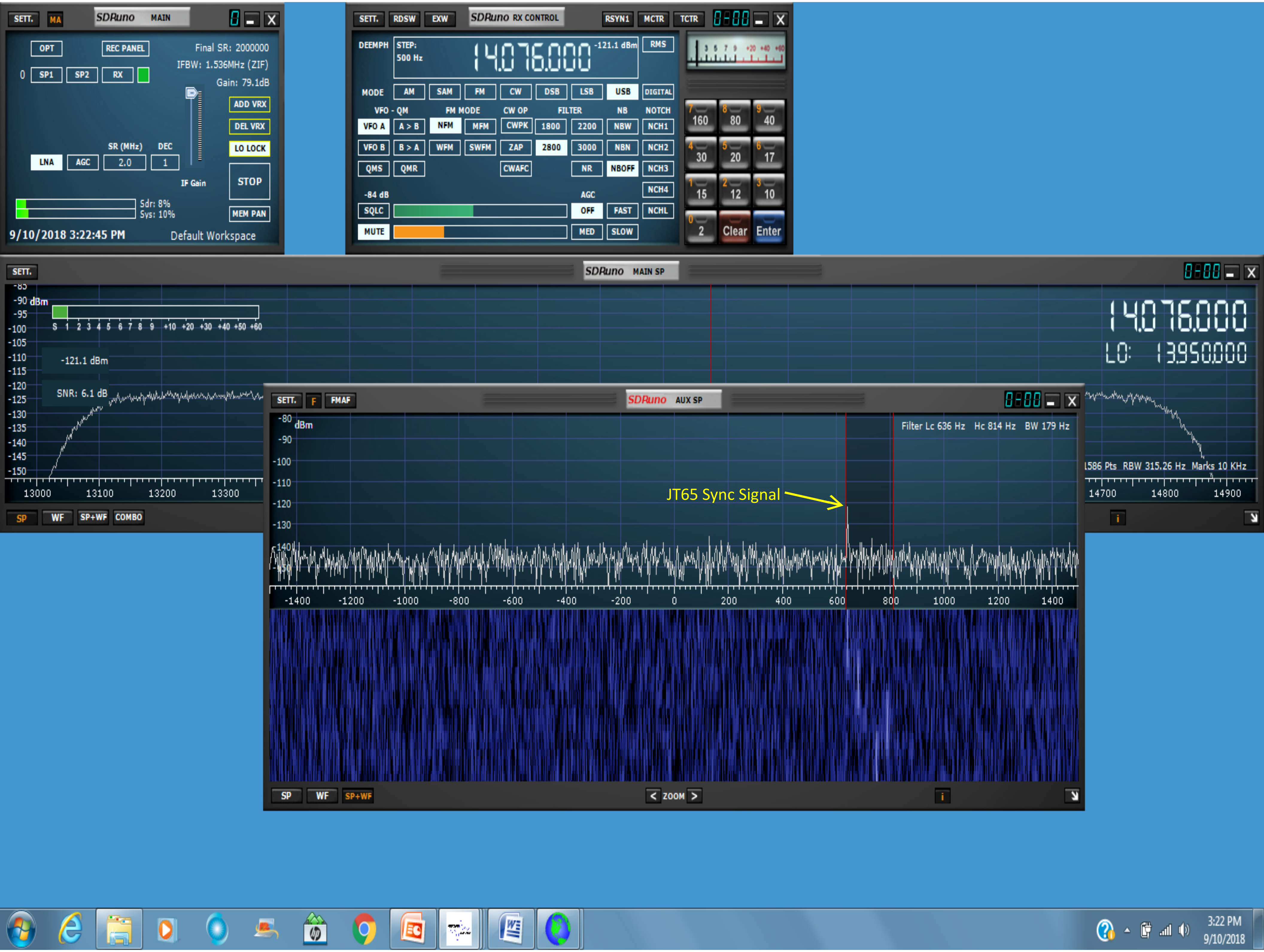
The Claim

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

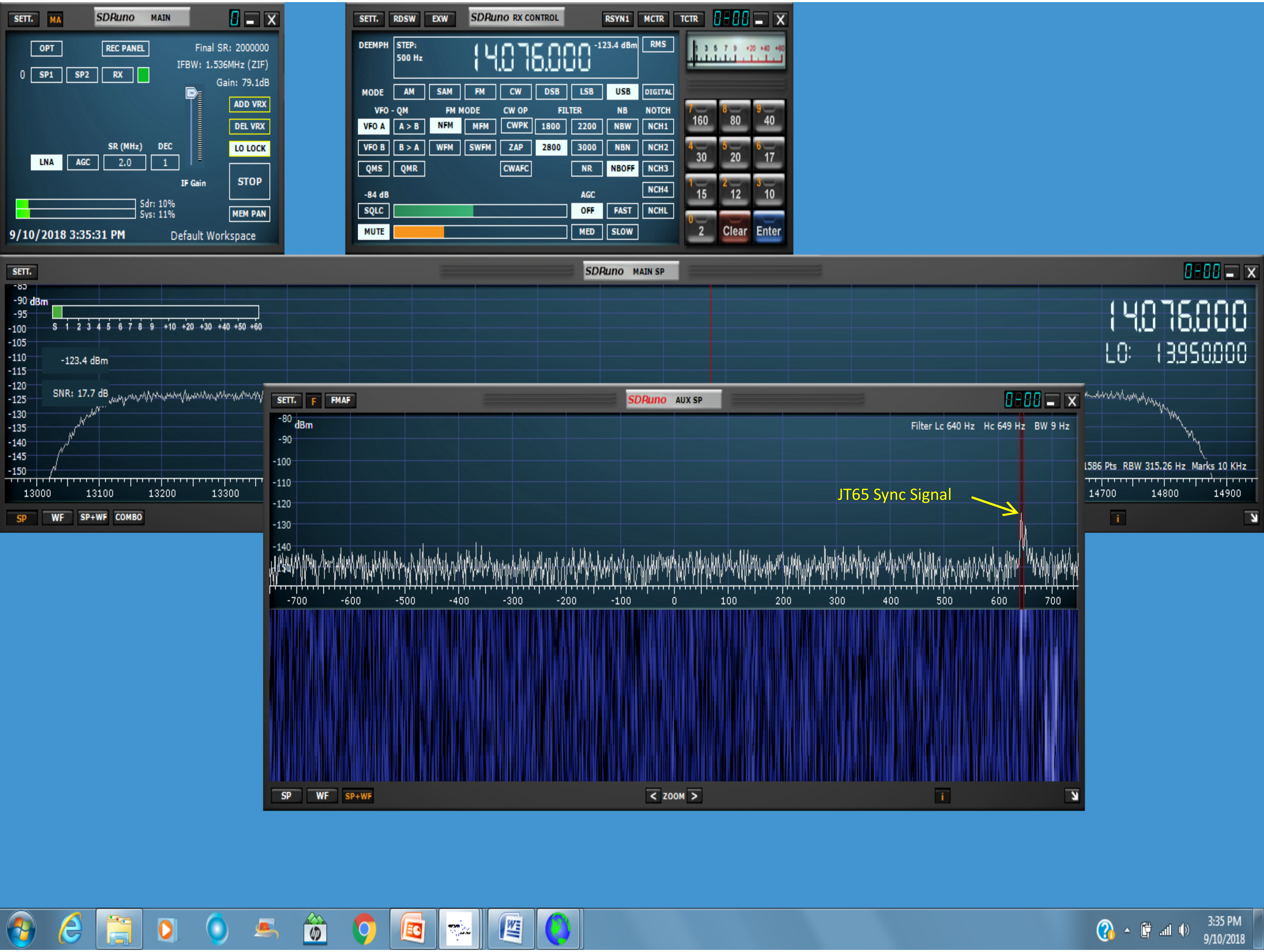

SDRuno MAIN
Final SR: 2000000
IFBW: 1.536MHz (ZIF)
Gain: 79.1dB
9/10/2018 3:22:45 PM
Default Workspace
SDRuno RX CONTROL
14.076.000
-121.1 dBm
STEP: 500 Hz
SDRuno MAIN SP
-121.1 dBm
SNR: 6.1 dB
LO: 13.950.000
SDRuno AUX SP
Filter Lc 636 Hz Hc 814 Hz BW 179 Hz
JT65 Sync Signal
3:22 PM
9/10/2018

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


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: 10%
Sys: 11%
MEM PAN
9/10/2018 3:35:31 PM
Default Workspace
RDSW
EXW
SDRuno RX CONTROL
RSYN1
MCTR
TCTR
DEEMPH
STEP:
500 Hz
14.076.000
-123.4 dBm
RMS
MODE
AM
SAM
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DSB
LSB
USB
DIGITAL
VFO - QM
FM MODE
CW OP
FILTER
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NOTCH
VFO A
A > B
NFM
MFM
CWPK
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VFO B
B > A
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SWFM
ZAP
2800
3000
NBN
NCH2
QMS
QMR
CWAFC
NR
NBOFF
NCH3
NCH4
-84 dB
AGC
SQLC
OFF
FAST
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MUTE
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SLOW
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12
10
2
Clear
Enter
SDRuno MAIN SP
-90 dBm
-123.4 dBm
SNR: 17.7 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
F
FMAF
dBm
Filter Lc 640 Hz Hc 649 Hz BW 9 Hz
JT65 Sync Signal
-700
-600
-500
-400
-300
-200
-100
0
100
200
300
400
500
600
700
ZOOM
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)**
- **$(Es/No)_{dB}$** can be derived mathematically from the **Reported SNR**

$(Es/No)_{dB}$ = $(SNRreported)_{dB}$ + (10 x 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