6dB Better than CW

Weak Signal Modes on the Microwave Bands

Andy Talbot G4JNT/G8IMR

Traditional CW

- Is the weak signal mode used when all else (especially SSB !) fails
- Limited by
  - Noise – Proportional the bandwidth
  - Operators ability to decode it
  - Often need to repeat messages
    - Talkback / handshaking
    - Alphabet prone to errors if message is broken

J (--- --- ---) = E E M (- - -- --)

A few Values

- Ear / Brain combination is surprisingly good at detecting tones buried in noise
  - SSB voice needs ~ 3kHz for full readability
  - We detect it as if the bandwidth were only a few tens of Hz
  - And especially tones at the right frequency, in something like 20 – 100Hz noise bandwidth
- This often gives a false impression how good a signal really is.

Some Audio

Generated by Maths!

Sampling Rate	8000	Hz	---	16 Bit sampling, noise RMS = -10dB
S/N Ref BW	2500	Hz	-5dB	= 32767 / SQRT(10) = 10361
Audio BW	100	Hz	-19dB	99% probability of no clipping

Source File	Amplitude dB wrt FSD	Dest File	Noise dB FSD	Signal/Noise 2.5kHz Norm.	Signal/Noise 100Hz Audio	
CWMSGM20	-20	..\dsp\weakcw01.wav	-10	**-5**	**9**	
CWMSGM25	-25	..\dsp\weakcw02.wav	-10	**-10**	**4**	
CWMSGM30	-30	..\dsp\weakcw03.wav	-10	**-15**	**-1**	
CWMSGM35	-35	..\dsp\weakcw04.wav	-10	**-20**	**-6**	CW Limit ?
CWMSGM40	-40	..\dsp\weakcw05.wav	-10	**-25**	**-11**	

The Limit for CW

- At best, around 10dB S/N in 30Hz for *easy copy* CW. No repeats
  - Several dB lower for detecting
- Assume 18WPM at this level.
- A Word has 5 chars, 4.5 bits / char (plain text) = 6 or 7 Bits /second equiv data rate
- Repeat the message, gives ~ 2 -3 Bits/s
  - This is manual *Forward Error Correction*

Compare simple data modes

- RTTY 30 Bits/s (for 50 baud)
  - Needs >15dB S/N in 100Hz (around the two tones)
  - Very inefficient
- PSK31 >10dB S/N in 31Hz
  - About the same as CW with a good operator
- Both of these are error prone, so repeats are needed
  - Reduces overall data rate

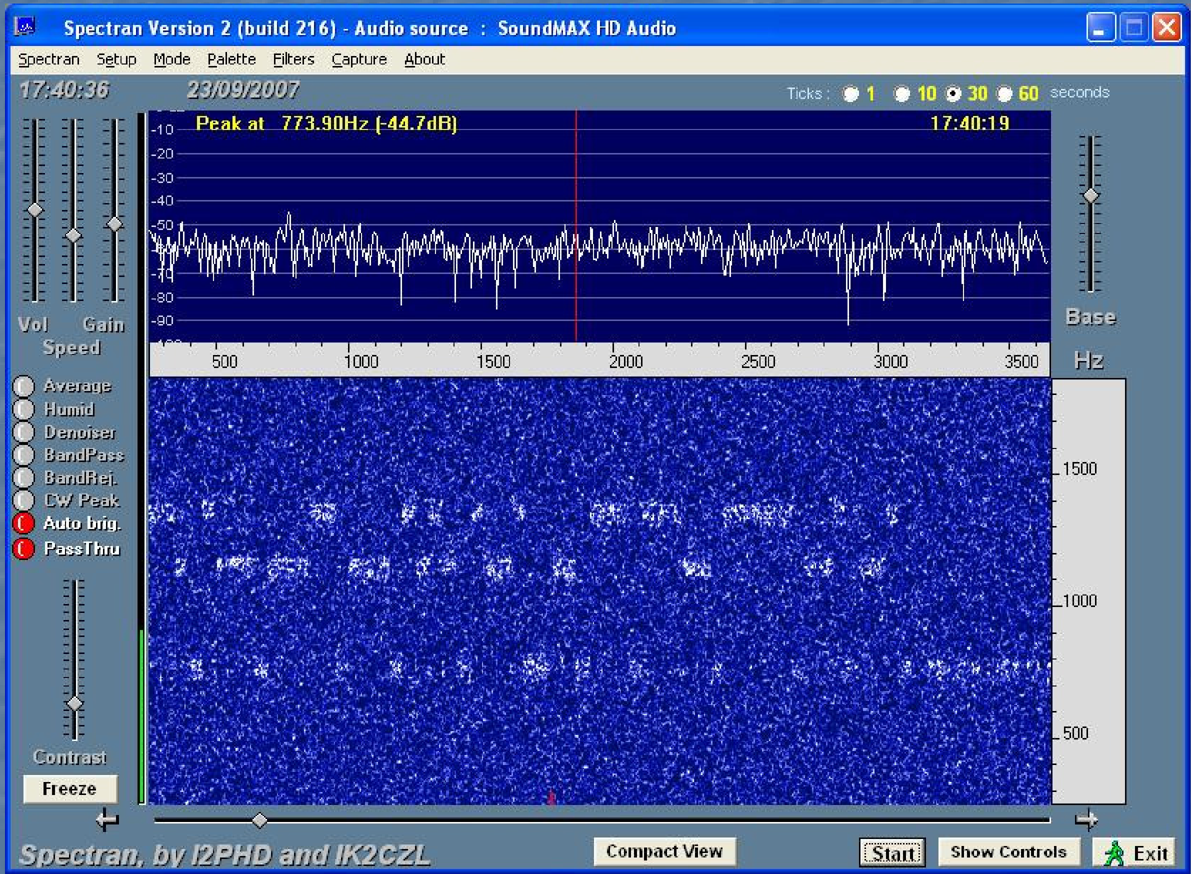
And what about Microwave Bands?

- Rain Scatter
  - Spreads the signal over 100 – 300Hz
  - CW survives this quite well, (and RS is often strong)
  - DFCW with spectral display works reasonably well
- Scattering / breakup / troposcatter / multipath
  - Kills CW
  - Kills most other data modes

Can we go Narrower

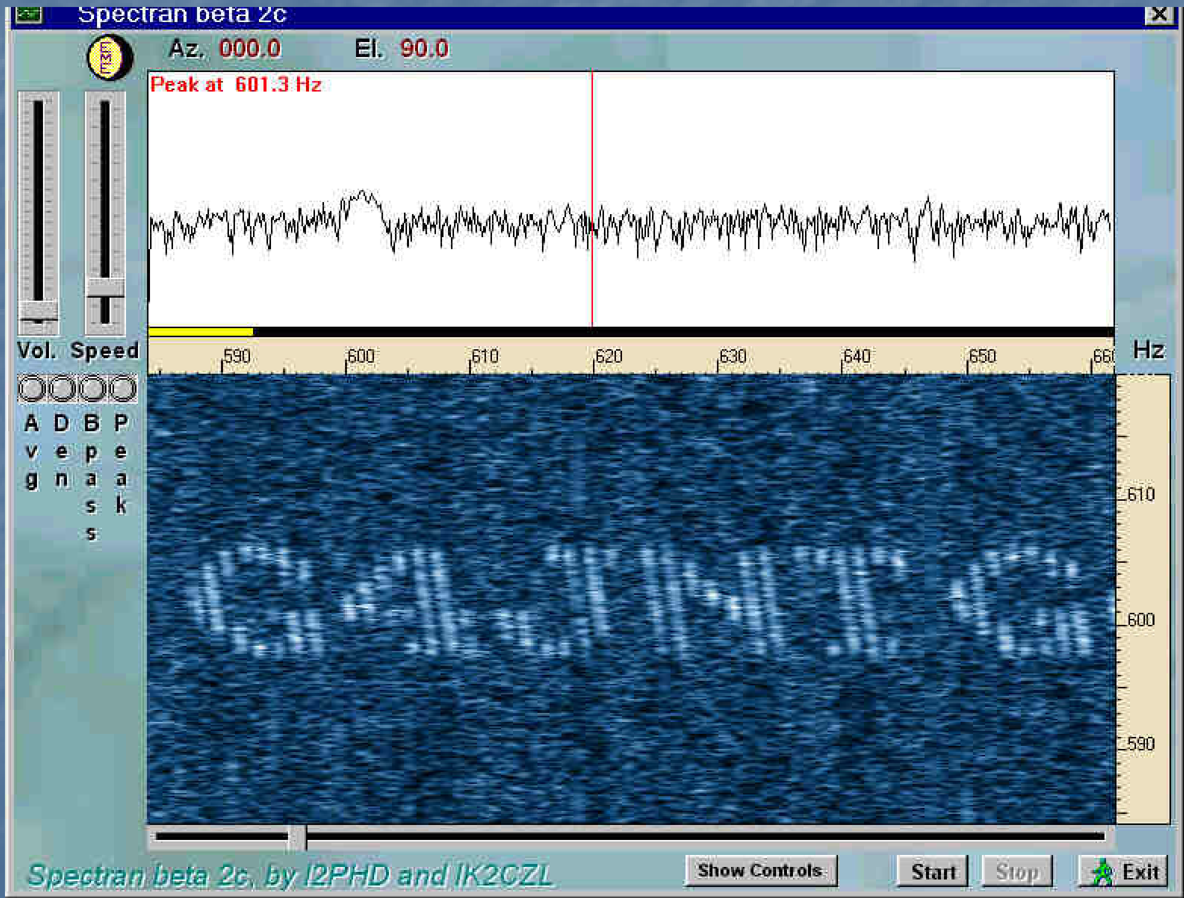
- Yes - Lower BW , less noise, increases S/N
- But the message takes proportionately longer to send
- Spreading could be a problem
- Need machine assistance
  - QRSS, Visual CW, DFCW, Hell
- 'About the same signalling efficiency as CW'

Visual CW / DFCW / DFCWi



Advantages for very slow data in narrow band
– about same as aural CW when scaled for speed/BWidth.

SMT Hell



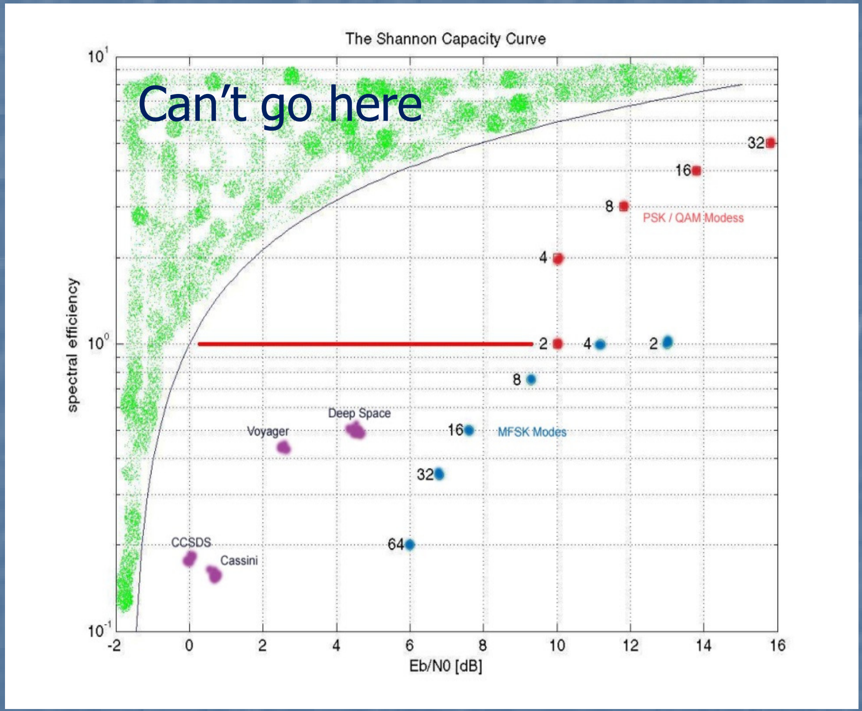
Spectran beta 2c
Az. 000.0
El. 90.0
Peak at 601.3 Hz
Vol.
Speed
590
600
610
620
630
640
650
Hz
A v g
D e n
B p a s s
P e a k
610
600
590
Spectran beta 2c, by I2PHD and IK2CZL
Show Controls
Start
Stop
Exit

Can We Do Better

- Yes – but there is a theoretical limit
- Shannon suggests two routes
  - Improve the signalling efficiency with better modulation (move left)
    - Not much scope with modern modulations
  - Increase the bandwidth (move up)
    - This appears counter-intuitive BUT----------
      - The maths sez so

The Shannon Curve

Was derived from basic Physics / Maths / Info theory and is NOT an experimental result. It is a TARGET.



- Horizontal – Normalised Signal/Noise, energy / bit
  - Move left, Lower Tx power, or increase noise
- Vertical – Spectral Efficiency, Bits/s/Hz.
  - Move up, increase bandwidth for same capacity
- Red – 2 … 32 PSK/QAM
- Blue – 2 … 64 MFSK
- Purple - Heavily coded deep space
- Red Line – "10dB from Shannon "

http://marconig.wordpress.com/2007/07/03/the-shannon-capacity-curve/

Bandwidth Expansion

- Commercially / military use spread spectrum
  - WLAN, Bluetooth, Wi-Fi.
  - All improve signalling efficiency by spreading the signal over a wide bandwidth to counter interference / multipath
- Not too easy on the Am. Bands as we nearly always want to keep within the 3kHz SSB bandwidth

Another Way

- Heavy Error Correction
  - Often not thought-of as a bandwidth spreading
    - We already see it in normal operation –
      - Repeat the information many times
    - Slowing the data rate and keeping the same modulation format *is equivalent to widening the bandwidth*
    - It’s the ratio of Data Rate / Bandwidth that matters

Source Coding

- First Get rid of redundant information (WSJT Style)
    - Compress callsigns using their known structure
    - Char-Char-Number-Letter-Letter-Letter
    - Letter = A-Z or [space]. Char = Letter or 0-9
      (but note the 2nd Char cannot be a [space])
    - Compresses to 37*36*10*27*27*27 = 262Meg
        - Which can be represented by 28 Bits
        - (RTTY needs at least 35 bits, could be more depending on letter/figure shift)
- Locator (4 digit) 18*18*10*10 = 32400 (15 Bits)
  6 Digit Loc 25 bits

Further Source Coding

- Assume 4 Million Radio Ams in the world *(we wish!)*
  - Use a codebook to store the callsign of everyone, then just transmit the reference number
  - Only needs 22 bits
  - This is contentious lets not go there !
- Reports and acknowledgements need only a few bits in reality
  - But this also sparks controversey
- With the natural redundancy removed, any random data message begins to look valid
  - Acknowledged ‘problem’ with source coding

An Aside....

- Morse is a classic example of source coding
  - Most common letters use less data bits than less popular ones
  - Same problem of one symbol being corrupted to another
    - eg. T = E E
    - Bleeps from continuity tester can spell messages

Modulation

- On-Off, or Amplitude Shift Keying is not good.
  - It must waste 3dB
- PSK is theoretically the best (multiplication by 1 or -1)
  - Maintains high duty/cycle
  - Coherency needs frequency / phase lock
  - Which can be destroyed by propagation anomalies
  - Non-linear processing for recovery throws away many of the advantages of coherent reception
  - Unless bandwidth is unimportant, needs linear transmitters
- Which leaves good old fashioned, well established FSK

Multi FSK

- Use several Tones
  - Extend these over more than the anticipated spread
  - 10’s of Hz for V/UHF.
  - 100’s of Hz for microwave
    - All well within the 3kHz SSB bandwidth.
- 4 tones give 2 bits per symbol
    - F0 = ’00’, F1 = ’01’, F2 = ’11’, F3 = ’10’ *WSPR / JT4*
- 64 tones 6 bits per symbol
    - F0 = ‘000000’, F7 = ‘000111’, F26 = ‘011010’, F63 = ‘111111’ *JT65*
  - We’ve increased our data rate at the expense of decodng complexity – that’s no problem these days

Error Correction

- Now make good use of our increased capacity / data rate
  - Could just repeat the message several times and compare each, looking for errors in each bit.
    - Three repeats allows error correction
    - Two repeats allows detection – may be enough if talkback allows a repeat request
  - Interleave the repeats to counter burst errors
  - But we can do a lot better
    - and its very mathematical

Error Correction Techniques

- Hamming Distance
  - Add enough extra parity bits so the new alphabet has a certain number of bits different between each block. Then compare each received one and look for the most probable.
    - Example is 4 bits with 3 more parity
      - Allows 1 error in a total of 7 to be corrrected
      - 2 errors can be detected
    - Simple schemes are decoded using lookup tables
- Block coding
  - More efficient longer-word schemes are in widespread use
  - Reed-Solomon, BCH
    - But the maths processing is NOT NICE
      - Galois Fields, Dividing Polynomials

Error Correction Techniques continued

- Convolutional Coding
  - Continuously spread each source over several bits of the output. Adding more for correction – eg x2 or x3
    - Continuously look for what was *most likely to have been sent* in order to generate what has *actually been received*.
  - Soft decision decoding looks at probability a received symbol is good, bad or indifferent
  - The Viterbi decoding algorithm
    - Searches back though received symbols in a trellis, looking for the most likely data that could have generated it
  - Processor intensive, adds a delay.

Another Aside
A few state-of-the art codes

- Taken from
  - http://marconig.wordpress.com/2007/07/03/the-shannon-capacity-curve/
- These are for BPSK with the coding used with several deep space (interplanetary) spacecraft:
- r=1/2 k=7 convolutional: Eb/No 4.5 dB, eff 0.5 bps/Hz
- Voyager (RS+r=1/2,k=7): Eb/No 2.4 dB, eff 0.437 bps/Hz
- Cassini (RS+r=1/6 k=15): Eb/No 0.6 dB, eff 0.146 bps/Hz
- CCSDS r=1/6 turbo large block: Eb/No 0.0 dB 0.167 bps/Hz
- Not much scope for further improvement

Timing and Frequency Errors

- Need knowledge of frequency / tuning error and timing
  - Use UTC based protocol to limit search requirements
  - Identify Start of message timing
    - To be able to identify the right symbols
    - Can't afford to spend a lot of time searching
    - Typical few seconds for PC clock errors, bit more for EME delays
  - Frequency   get within a tone bandwidth for MFSK schemes.
  - Send synchronisation Sequence
    - Unique pattern to search for that won't appear anywhere in the message.   Can give frequency and time.

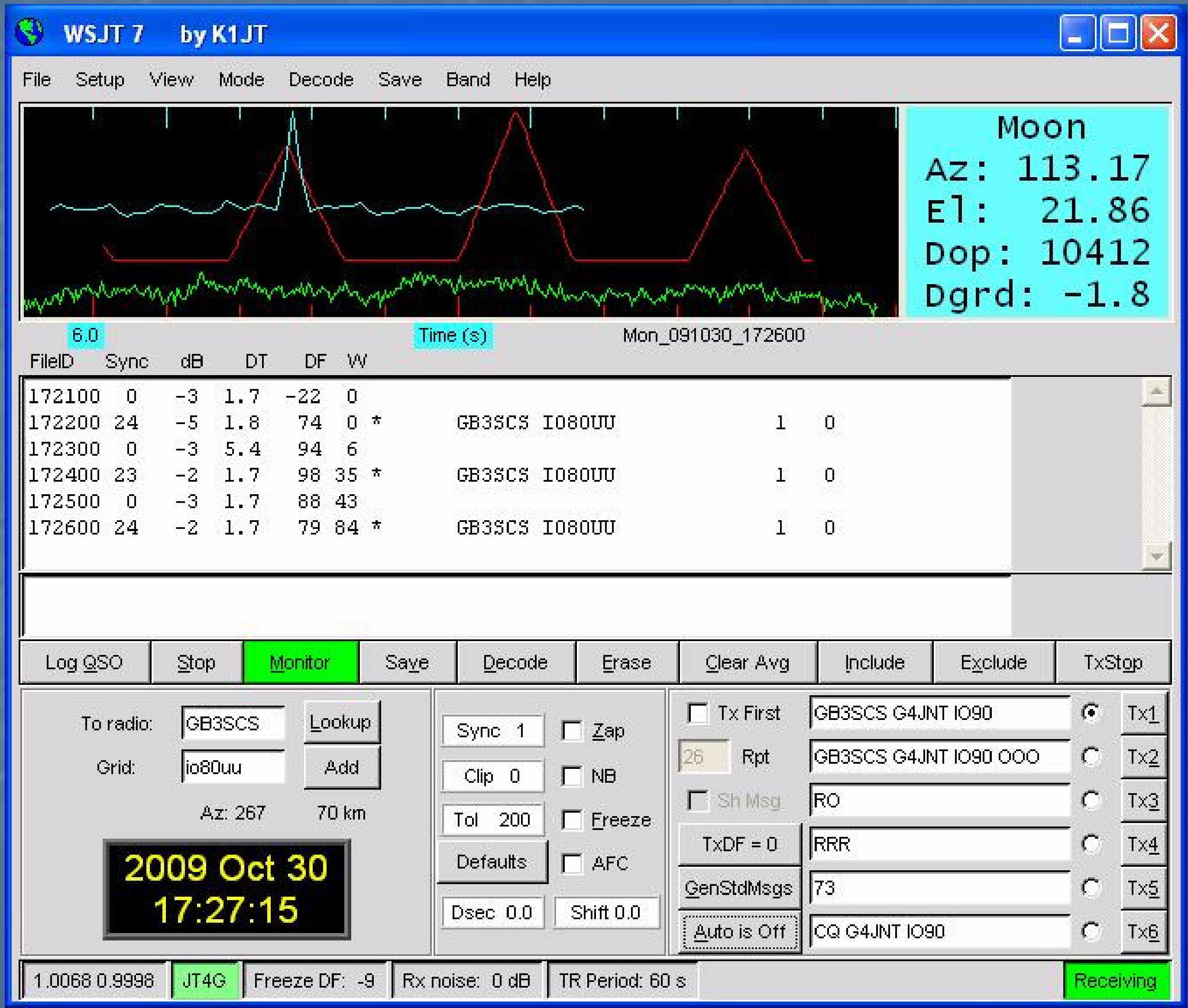
WSJT Examples

- JT65
  - 72 source Bits - 2 compressed callsigns + one 4-digit Locator OR 13 chars of plain text.
  - Block coding (Reed Solomon) expanded to 126 symbols of 64 tones (6 bits / symbol) ,and one more for sync , Pseudo Random interspersed.
  - Effectively expands a 72 bit message to an effective 441 bits
  - Big Sync overhead – 50% of the message time
  - Three tone spacings, 2.7, 5.4 and 10.8Hz

JT4 a-g and WSPR

- Both similar *coding* schemes
  - Four tones carrying two bits per symbol,
    - One bit is sync sent as a pseudo-random code
    - The other is a data bit
    - JT4 same message as JT65,
      - 72 bits expanded to 207 in a convolutional encoder
      - Sent in 48 seconds at 4.375 symbols/s
      - Tone spacing user selected from 4.4 to 315Hz
    - WSPR Different Message, new data structure
      - 50 bits expanded to 162 in a convolutional encoder
      - Sent in 110 seconds at 1.46 symbols / second
      - Tone spacing 1.46Hz

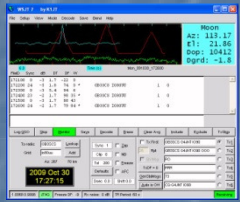
WSJT User Screen



Using WSJT

- Setup Box
  - Callsign, Locator, Com Port for Tx control
  - Make Sure sampling rate calibration is OK
    - (Only done once per PC – unless using .WAV files). Look at Self Check value. Enter into Setup, Options
- Set The right Mode (easily forgotton!)
- Set PC Clock
  - Dsec Box for fine tuning – aim for less than a second or two error from UTC
- Adjust Audio Levels
  - Need Rx or Monitor to be running

Run WSJT...........



Load in .WAV files from GB3SCX and GB3SCS

Set Rate in to 1.0068 (Saved on a different machine)

Replay .WAV files and use mic to loop round

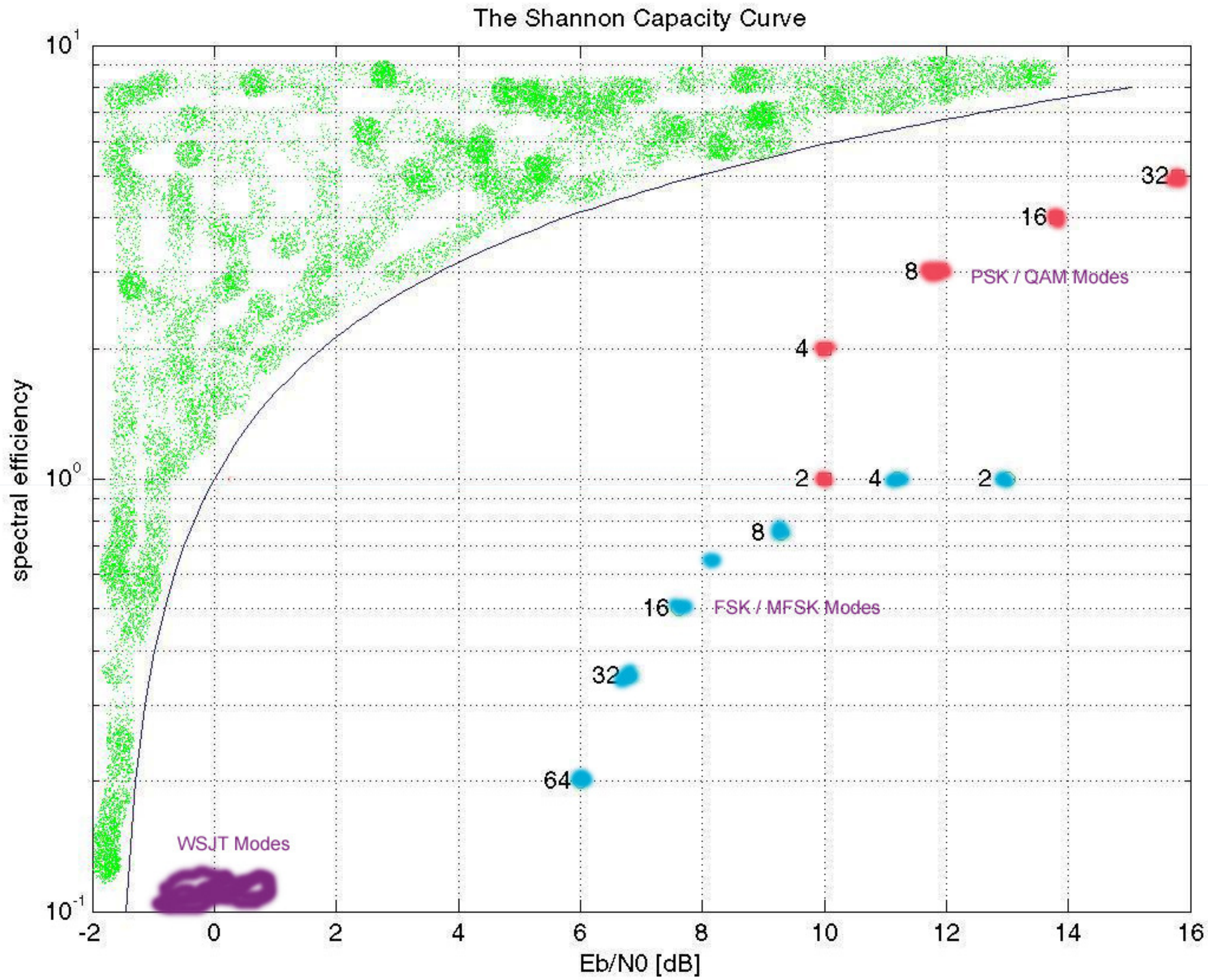
Set Options Rate-in back to to 0.9797 - check value.

(Although they were recorded on another machine at 11100Hz, check exact value!)

Use Monitor mode and start VLC replay 2 seconds early

Where to hear WSJT Signals

- Off the Moon , JT65A, B, C
- GB3SCX 10368.905MHz JT4G
- GB3SCS 2320.905MHz JT4G
  - Tune so USB carrier is 800Hz below
- GB3VHF 144.43MHz JT65B
  - Tune 1500Hz low, USB carrier 144.4285MHz
- GB3RAL 40.05/50.05/60.05/70.05 JT65B
  - Tune USB carrier Xx.0485MHz
- HF Bands JT65A, JT4A+, WSPR


The Shannon Capacity Curve
spectral efficiency
Eb/N0 [dB]
10^1
10^0
10^{-1}
-2
0
2
4
6
8
10
12
14
16
32
16
8
PSK / QAM Modes
4
2
4
2
8
16
FSK / MFSK Modes
32
64
WSJT Modes