6dB Better than CW

Weak Signal Modes and How They Work

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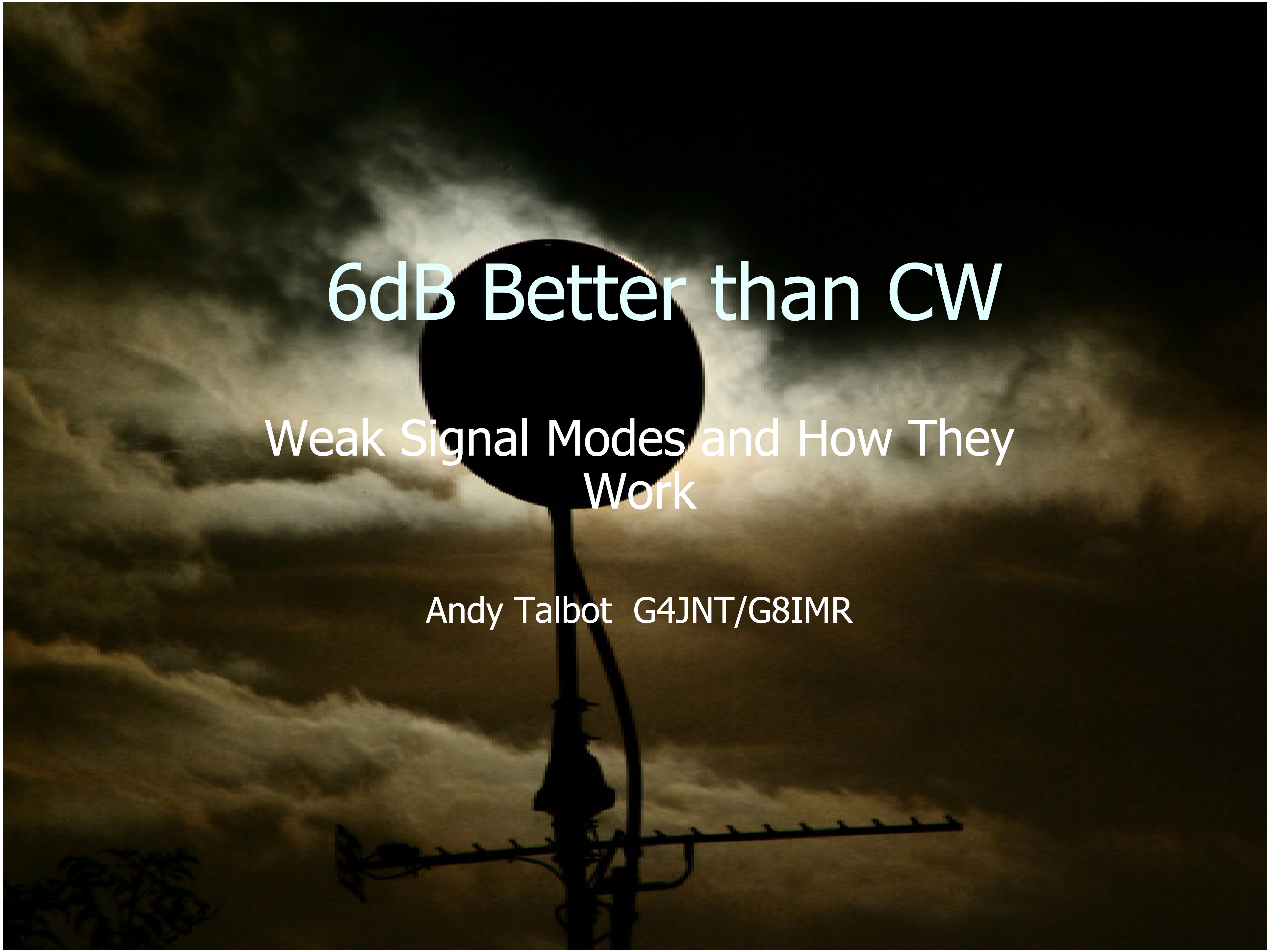


Why Work with Weak Signals

- That rare Dx station
- Low power / poor antennas
- Cost of big PAs
- Extreme propagation - Moonbounce / EME
- Traditionally MORSE the weak signal mode of choice.
  - Compared to SSB voice

What's right with Morse?

- The Ear / Brain combination is very good at picking out what it expects to hear
  - Experienced OPs show amazing decoding ability in the presence of massive QRM and pile ups
  - But not when very weak and buried in noise
  - Half decent source coding
- Great for contests, pileups, strong QRM
- The fallback from SSB when things go bad

So What's wrong with CW / Morse ?

- Like having to learn a foreign language
  - OK when it was compulsory for the Class-A licence, but not now.
- Limited range of speeds, ~ 10 – 30WPM.
- On-off pulses are difficult in noise
- OLD FASHIONED, outdated IMAGE.

Some numbers

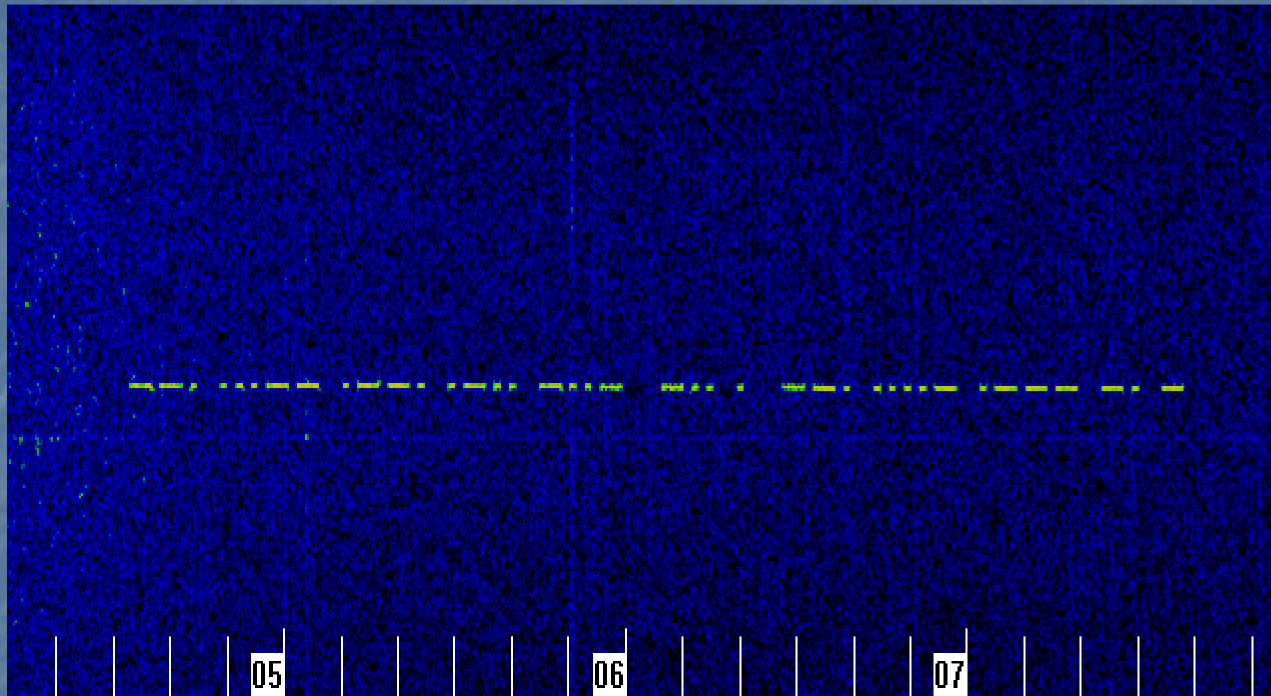
- 12WPM morse is ~10 dot/gaps, or symbols, per second,
  - so can be said to occupy 10Hz bandwidth.
  - Noise is proportional to bandwidth.
- Ear / brain combination filters to 25 – 100Hz for an optimum tone frequency.
  - We're wasting capability by sending too slow

Signal / Noise ratio

- In any *specific signalling bandwidth* signal need to be *significantly above the noise* to *absolutely guarantee* is it there or not
  - Human listening needs something like 6dB in the ear bandwidth of 50Hz to do this.
  - And that is after years of practice !
  - Ears and software have *about* the same signal detection capability *given optimum settings* and <u>nothing is known about it beforehand</u>

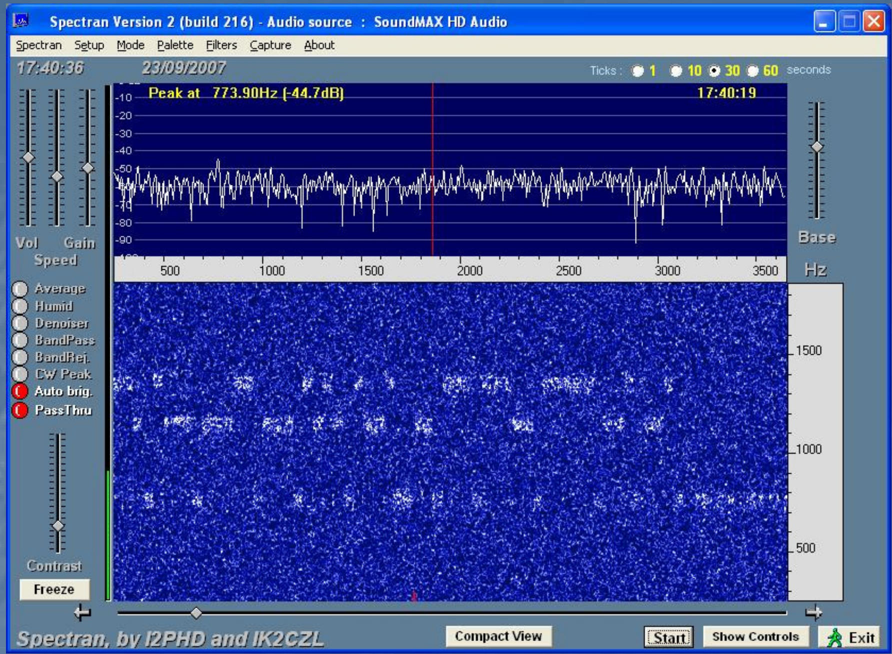
Go Narrow Band

- If noise is proportional to bandwidth, why not just go slower?
  - We do ! QRSS at LF uses CW on a visual display in bandwidths down to micro-Hz. Dual / triple Frequency CW
- It takes a lot longer to send a message. Minutes or hours for a callsign
- But allows really weak signal copy.



The first ever QRSS QSO on 73kHz

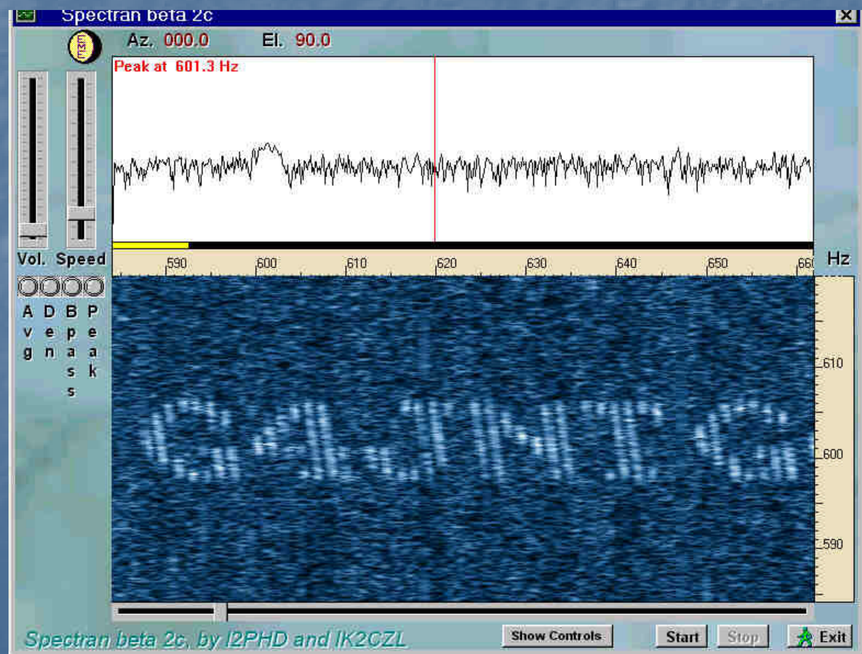
- 3 hours for two callsigns
- 0.04Hz bandwidth



DFCWi

(sending GB3SCX IO80UU)

SMT Hell



So why not go narrower ?

- We haven't got all day.
- Propagation won't always support it
  - HF Doppler shift and fading, > few Hz
  - VHF / microwave doppler and scatter, 100 Hz
- Works well at LF.
  - 137kHz generally 0.2 - 0.01Hz is the lower limit.
    - 50s per dot – hours for a callsign.

Relative Signal/Noise

Speed / bandwidth trade-off, introduces the concept of Normalised S/N referenced to the symbol rate. Bits/second/Hz or Eb/No (Energy per Bit)

24WPM CW in 20Hz bandwidth is identical performance to 1 dot per second in 1Hz QRSS

Trade off time-to-send against weak signal detectability.

In all cases, we need around 4 – 8dB S/N in that bandwidth

So what can we do ?

- Send the information digitally coded onto a transmitted waveform
- Optimise signals and waveform to work with the lowest (normalised) S/N possible
- Frequency spread may not be all that important – we can spread out for resilience
  - THIS IS NOT THE SAME AS INCREASED BANDWIDTH

Data Mode Basics

- Chose an optimum Modulation
  - Must match the RF path
- Compress the Source Information
  - Reduce the information sent to save time
- Add Error Correction
  - Minimise the chance of wrong decoding
- Use additional information
  - Time, special message formats

Data Modes

- Select a modulation type and coding to match the path and wanted data rate
- Select a symbol period compatible with propagation
  - Few tens of Hz for HF, Sub-Hz for LF
  - If we want a faster data rate, work out a way of stacking multiple slow / narrow carriers – increases occupied band.

Modulation Type

- Vary Frequency, Phase or Amplitude
  - Or a combination ?
  - All work, but with reservations
- Phase shift keying, with 0/180 deg is theoretically the best in noise.
  - But practical carrier recovery issues throw away much of the advantage.
- Amplitude shift keying
  - Works, but is complicated by fading and levels

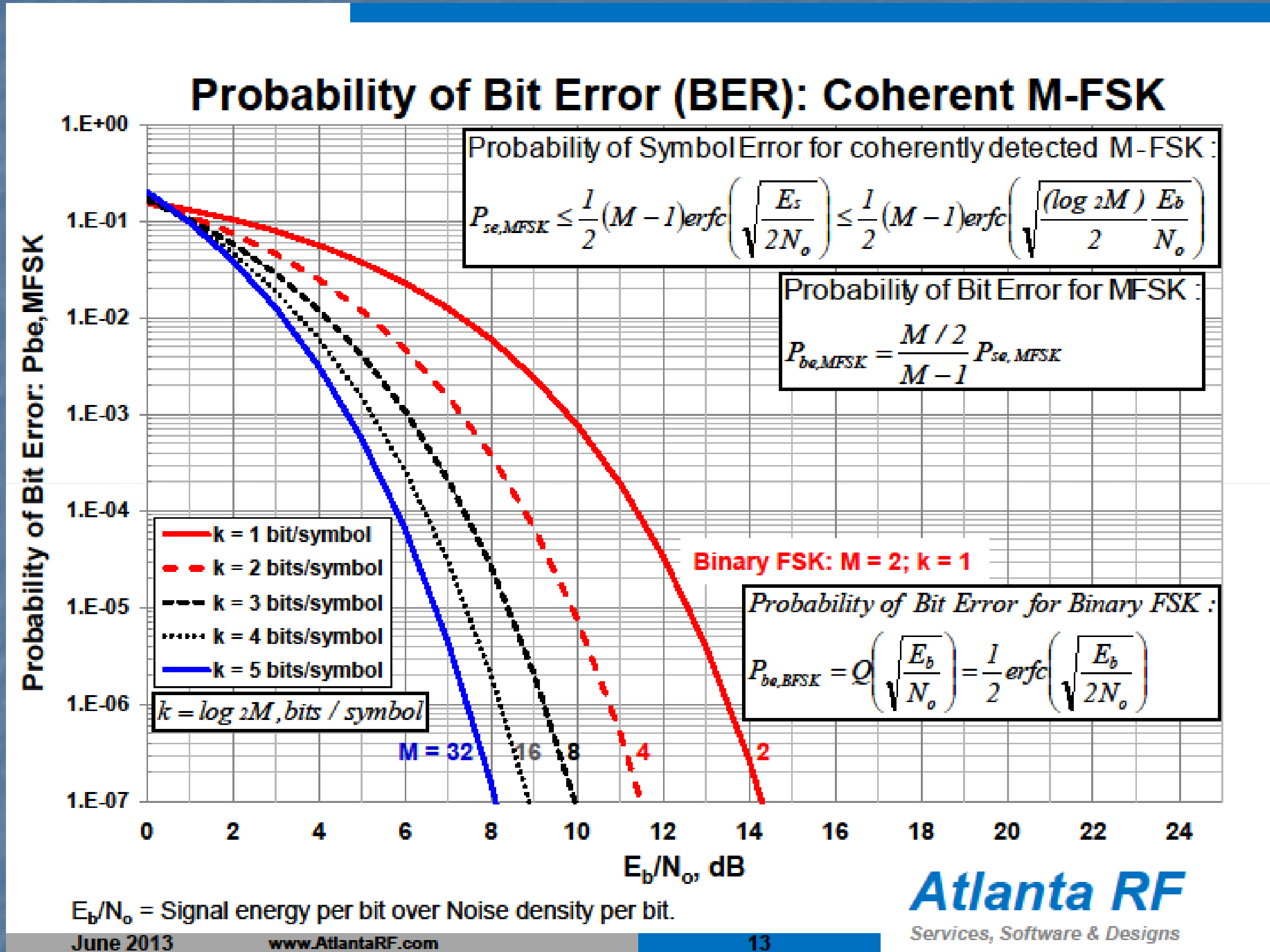
FSK

- Frequency Shift is like amplitude shift but with the advantage of comparing one tone against another.
  - Simplest form is two tones. 100% duty cycle, compared with 50% for on-off
  - IF peak power is the criteria, frequency exchange keying wins over ampl. by 3dB
  - If TOTAL POWER is the criteria, Amplitude / Frequency shift keying are equal.

Source Compression

- Most information is redundant and can be reduced
  - Callsigns only fit into a few formats
  - Letters and numbers only
  - Fitted into 28 bits
- Make use of this to reduce the amount of data to be sent

The Effect of Errors



- At 6 bits per letter, 0.1 Bit Error rate means majority of letters are wrong!
- 0.01 or 1.E-02 BER is 1 in 16 letters wrong, or about one word in three
- 1.E-03 BER is about one word in every 30 wrong

- A short piece of text to demonstrate the effect of bit errors on readability. This file uses 8 bit ASCII characters so a Bit Error rate (BER) of 0.01 will corrupt about one letter in every 12 characters. To improve readability of the final result, control characters like [cr] and [lf] are left uncorrupted. ABCDEFGHIJKLMNOPQRSTUVWXYZ 123456789 The quick brown fox jumped over the lazy dog
- No errors

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- 28 Bit errors in 386 ASCII Characters Actual BER = 0.00907

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- 142 Bit errors in 386 ASCII Characters Actual BER = 0.04598

Error Correction

- On CW, info is repeated many times
- But software can do error correction much better than humans repeating things.
  - Add redundant information that is mathematically related to the transmitted data in a special way
- Allows signals to be 100% copied at relative S/N in the region of 3 - 4dB

Additional Info

- Use accurate real time for symbol framing
  - Or even for carrier recovery
- Special messages, such as CQ, Roger, and signal reports can be specially coded in very few (strong) bits.

Some Non-weak signal modes

- PSK31, 31Hz, 31 Bit/s second – plain text
  - Quite good in pure noise, typically 10dB S/N
  - Lockup time, poor fading and HF Doppler capability, no error correction.
  - ‘about’ the same as CW, overall.
- RTTY   50B/s – plain text, limited alphabet
  - >15dB S/N (50Hz) . Stop start signalling, very susceptible to noise
  - No error correction

Better Examples

- Modern soundcard modes stack several slow symbol rate tones together to speed up the total net flow
- At the expense of overall occupied bandwidth.
- BUT this is not the same as the noise bandwidth. So avoid the phrase "signal BW"
- 64 tones modulated at 10Hz take up 640Hz, but the noise bandwidth is still 10Hz
- Error correction stacked across tones and time – gives incredible resillience to QRM

WSJT Modes

- These are probably the best overall weak signal performers, targeted especially at some of the Dx propagation paths we are interested in.

- A lot of thought and design went into optimising the coding and modulation to exactly match practical as well as propagation issues

JT65

- Heavily source coded
  - Callsign, Locator and preformatted ‘QSO messages’
- Transmited as a sequence of one of 64 tones (6 bits per tone) in 1 minute slots
- Symbol rate / noise BW 2.7Hz
- 50% sync. Tone overhead – half the slots
  - Massive error correction capability – 50% lost

JT65 continued

- 2.7 symbols / second for 48 seconds.
  - Capable of 100% copy in ~4dB S/N Based on the symbol rate .
  - This means decoding at a S/N that is inaudible, and certainly not readable as CW
- HF to VHF / microwave versions with different tone spacing
  - No great difference in S/N, just signal width.

WSPR

- Preformatted message with callsign, locator and Tx power – for personal beacons
- 4 tones, 1.5Hz spacing and symbol rate
- 50% sync overhead,
- 4dB S/N in that bandwidth for perfect copy

- WSPR-15 version for LF, with 0.2Hz Bandwidth

Opera

- On/Off keying, so an inherent 3dB penalty on peak power rating over FSK
- Many speed / data rate settings
- Heavy source coding and error correction
- Only slightly worse normalised S/N perfomance as WSJT modes based on mean power.
  - But... 3dB worse if based on peak power.

Summary so far...

- Optimise data sent, add error correction, match modulation + speed to the path.

- Normalising data rate to the bandwidth, we can show that a properly designed data mode can show about 6dB better than CW in the hands of a highly experienced operator.
- And a LOT better if the OP. is not experienced !

CW effective Data rate

- Assume 18WPM in 30Hz ear/brain bandwidth (a 'good' operator)
  - Needs about 10dB S/N in this bandwidth.
  - A word has 5 chars, 5 (ish)bits / char (plain text) so about 7.5Bits /second equiv data rate
  - Repeating the message for redundancy gives around 3 Bits/second overall.
- Now normalise to reference bandwidth
  - 3 Bits/second in 30Hz = <u>0.1B/s/Hz.</u>

JT65 Data Rate

- Pre-format two callsigns plus locator
  - Before compression (if it were to be sent in CW it would be plain text) needs 80 bits
  - Sent in a one minute window = 1.33 Bits/s
- Normalise to the Noise B/W of 2.7Hz
  - Means 0.5 Bits/second/Hz
  - Which is 5 times better than CW can manage, or 7dB.
  - Calling it 6dB looks more reasonable!

WSPR Coding Efficiency

- Callsign + Locator + Power level
- If sent in plain text, needs ~14 chars or ~70 bits
- Compressed and sent in 110s window = 0.64B/s
- Normalise to the Noise B/W of 1.5Hz
  - Means <u>0.43 Bits/second/Hz</u>
  - Which is 4 times or 6dB better than CW can manage

Others, Keyboard Modes

- Olivia, MFSK63, ROS, and many, many more. Need to be faster
- Often stacked paralleled carriers for keyboard typing speed
- Can be quite wide (SSB bandwidth)
- Inherent delay for FEC – often annoying
- But most are VERY robust, allowing copy on almost inaudible tones.

A few caveats

- Most data modes do not allow arbitrary trade off of speed vs. Bandwidth
  - Telling the other end what your are using is not easy.
- So like-for-like comparisons aren't easy
- Limits on Occupied bandwidth
  - 3kHz SSB radios, regulatory, licences etc.
- But shows what can be done if the software can be written

The Shannon Limit