Decoding EbNaut Transmissions with Stacking

Garry Hess, K3SIW
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This note describes a Windows stacking procedure to improve decoding sensitivity of EbNaut transmissions. Other procedures exist but require Linux operations (see Appendix A) or *spectrum lab* (SL) FFT export files (see Appendix B). This procedure uses .wav files generated by SL scheduling, an easy and more reliable means of establishing the real file start times. It relies on two FreeBasic routines[1] written by Markus Vester, DF6NM and run through a Windows command prompt.

Consider data collected Oct 29-30, 2018 by monitoring the SIW lowfer beacon on 185.185... kHz. A 10' shielded loop[2] provides signal to an SDR-IQ receiver whose external clock is referenced to GPS. The receiver connects to SL via a virtual audio cable, running on a DELL3020 PC with Windows 7, 64-bit operating system. Figure 1 is a screenshot of the data collection setup used. The SL .usr file is too large to sensibly include in an Appendix but will be available for download by request to the author.

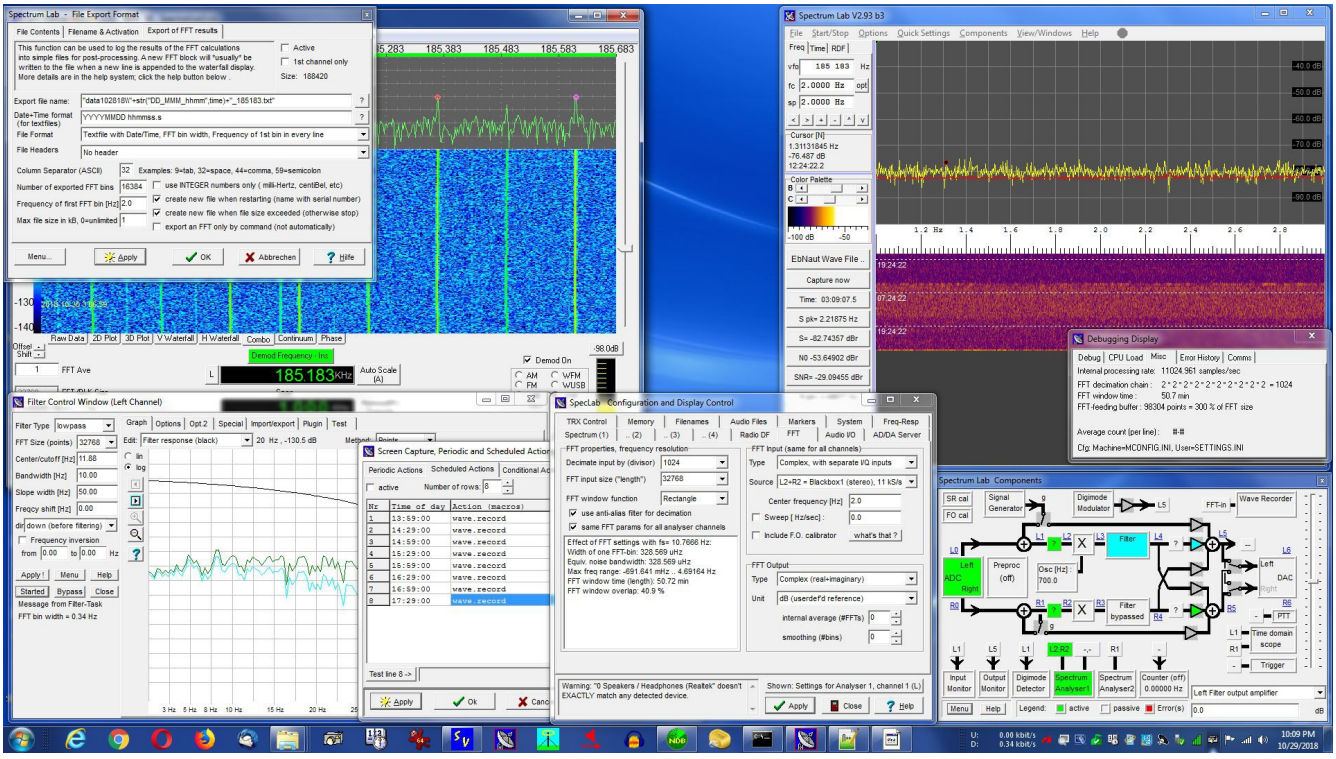


Figure 1 Screenshot of SDR-IQ and SL setup for data collection.

1 Addwav1.exe and norm1.exe, available for download by request.
2 https://qsl.net/ve7sl/loop.html

Note that despite the signal being strong when the loop is aimed at the source (165 deg heading) the spectrum and waterfall barely hint at its presence here with the loop aimed at 80 deg. Also note the active scheduling window that sets up storage of 8 .wav files at half-hour intervals.

Those .wav files can be analyzed individually by running the decoder program ebnaut-rx.exe in Windows. Figure 2 shows the result using file EbNaut_20181029_235900.wav for the input (loop aimed at 80 deg). The lowfer transmission uses 8K19A coding, 16 bit CRC, and 4 second symbols. The start offset is found as follows. First run the decoder program briefly using an arbitrary value to let the program itself indicate when the file really starts. Note he difference between that start time and the start of the transmission (on the hour). Then add 0.3 seconds to account for additional delay introduced by the transmit program ebnaut-tx.exe used at the lowfer beacon and 4 divided by the sampling rate also stated by the ebnaut-rx.exe trial run. Figure 2 shows the final run results.

Consider stacking 2 .wav files separated by ½ hour with the loop aimed at 85 deg. The files involved are EbNaut_20181029_202900.WAV and EbNaut_20181029_205900.WAV. Both decode the message “SIW” correctly individually, with carrier SNRs of 14.79 and 15.80 dB, respectively. However, stacking them with addwav1.exe yields a .wav file with 17.70 dB SNR. Adding a thrid file, EbNaut_20181029_212900.WAV whose individual SNR is 15.05 dB further improves the stacked SNR to 18.63 dB.

For a second example the loop is aimed at 80 deg to further weaken the signal. The 3 combined files are EbNaut_20181029_232900.WAV (13.34 dB, false decode), EbNaut_20181029_235900.WAV (13.81 dB, correct decode), and EbNaut_20181030_002900.WAV (12.88 dB, false decode). Combined with addwav1.exe they give a correct decode with carrier SNR increased to 15.19 dB.

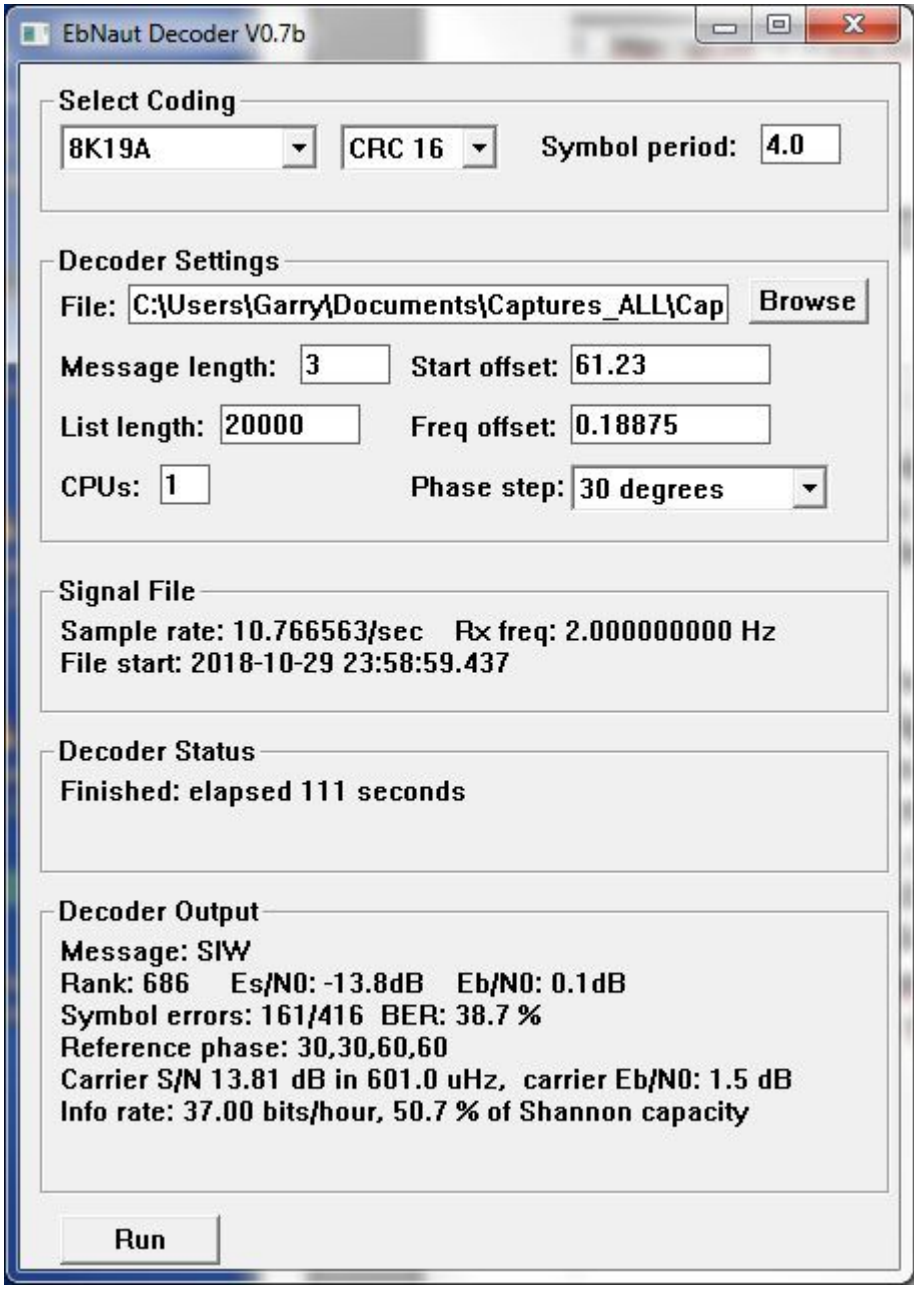


Figure 2 Single .wav file input (EbNaut_20181029_235900.wav), no stacking example with loop aimed at 80 deg to weaken the signal.

Figure 3 Stacking example 1, 2 files.

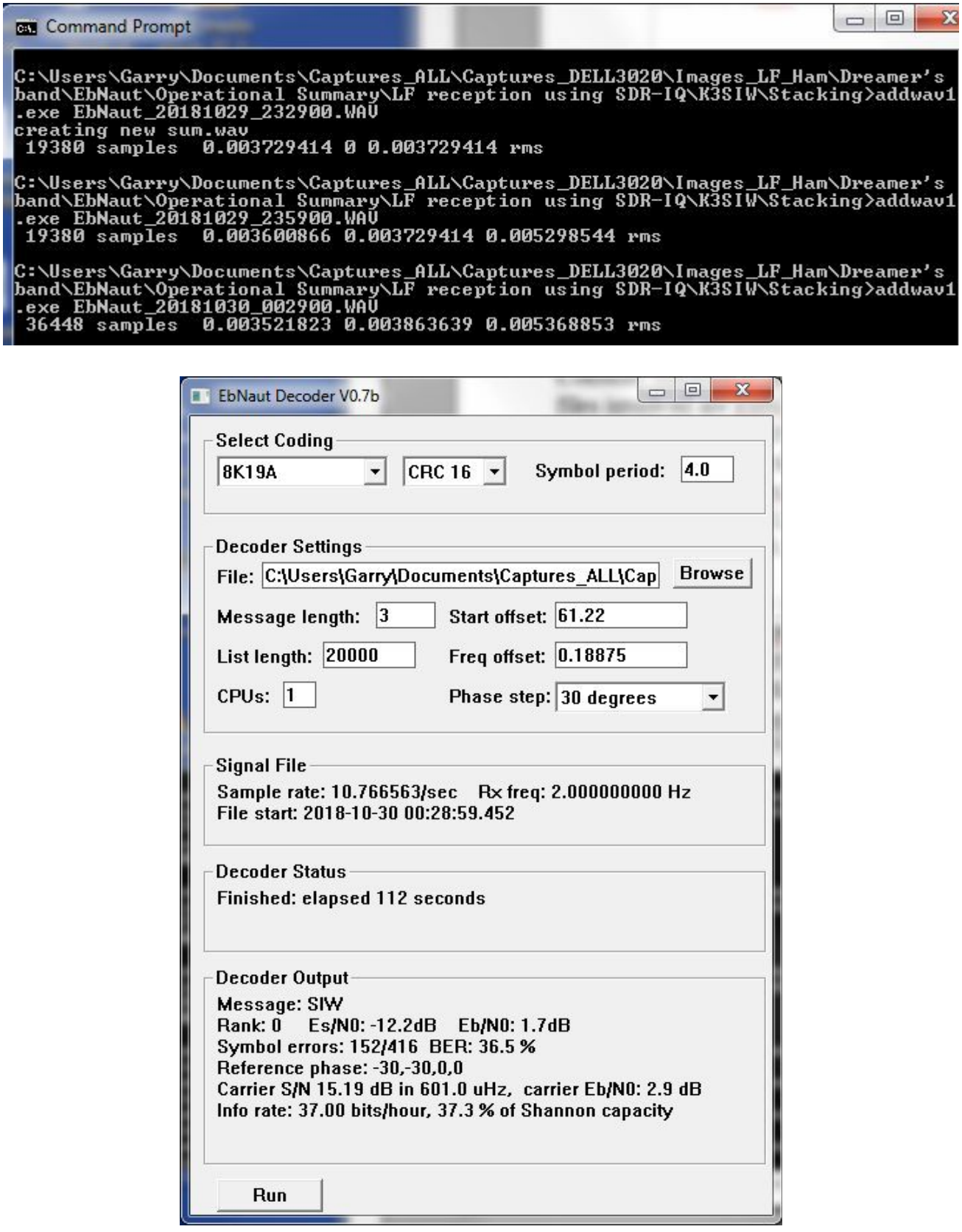


Figure 4 Stacking example 2, 3 files.

Appendix A EbNaut .wav File Stacking with Linux

Stacking is a procedure to extend message decode sensitivity. Adding data from multiple files gathered similarly on successive transmissions can improve the signal-to-noise ratio if the signal adds coherently and the noise adds incoherently. For coherent signal addition the data file samples must be taken at nearly identical times for their respective transmit periods. Also, the phase of the transmitted signal likely varies for data files collected over days and such data might require adjustment for that to realize the maximum benefit of stacking. A stacking procedure for data collected by SL and Windows is as follows:

1. Copy the .wav files to a folder shared with Linux[3].

2. Convert the files to .vt format, then to ASCII format using
   sudo vtwavex filen.wav > filen.vt ,where n=1,2,...
   sudo vtraw -oa < filen.vt > filen.txt

3. Open each filen.dat file with gedit and delete the initial lines up to the desired start time if necessary (typically one minute before the transmission begins); save them as filen.txt

4. Join the files with paste, then use awk to save time from the first file (arbitrarily chosen as the reference) and save the sample sums for in-phase and quadrature data columns; a 2 file example is:
   sudo paste file1.txt file2.txt | awk '{print $1, ($2+$5),($3+$6)}' > file_date_stacked.dat

5. Analyze with ebnaut (VO1NA example transmission):
   sudo ebnaut -d -F1.02145 -N1 -k8 -p 16K21A -S60.0 -T60.0 -r31.788826 -c1 -L196 -PS -v < file_date_stacked.dat > decode_date_stacked1.dat

To illustrate the above procedure, consider stacking example 1 in the main text:

```
garry@garry-VirtualBox://media/VboxShare/EbNaut/K3SIW/Stacking/Linux$ sudo
vtwavex EbNaut_20181029_202900.WAV > EbNaut_20181029_202900.vt
[sudo] password for garry:
garry@garry-VirtualBox://media/VboxShare/EbNaut/K3SIW/Stacking/Linux$ sudo
vtwavex EbNaut_20181029_205900.WAV > EbNaut_20181029_205900.vt
garry@garry-VirtualBox://media/VboxShare/EbNaut/K3SIW/Stacking/Linux$ sudo
```

3 Caution! If different-sized FFTs are used for the files to be combined they will have different sampling rates. Presumably they can be resampled to a common rate with the vtresample program. However, this will fail to produce exactly the rate specified with the -r option, even when the -q option is set to 2 for the best quality conversion. Instead, vttime -m none must then be used to create files with exactly the desired sampling rate (check with vtstat -i).

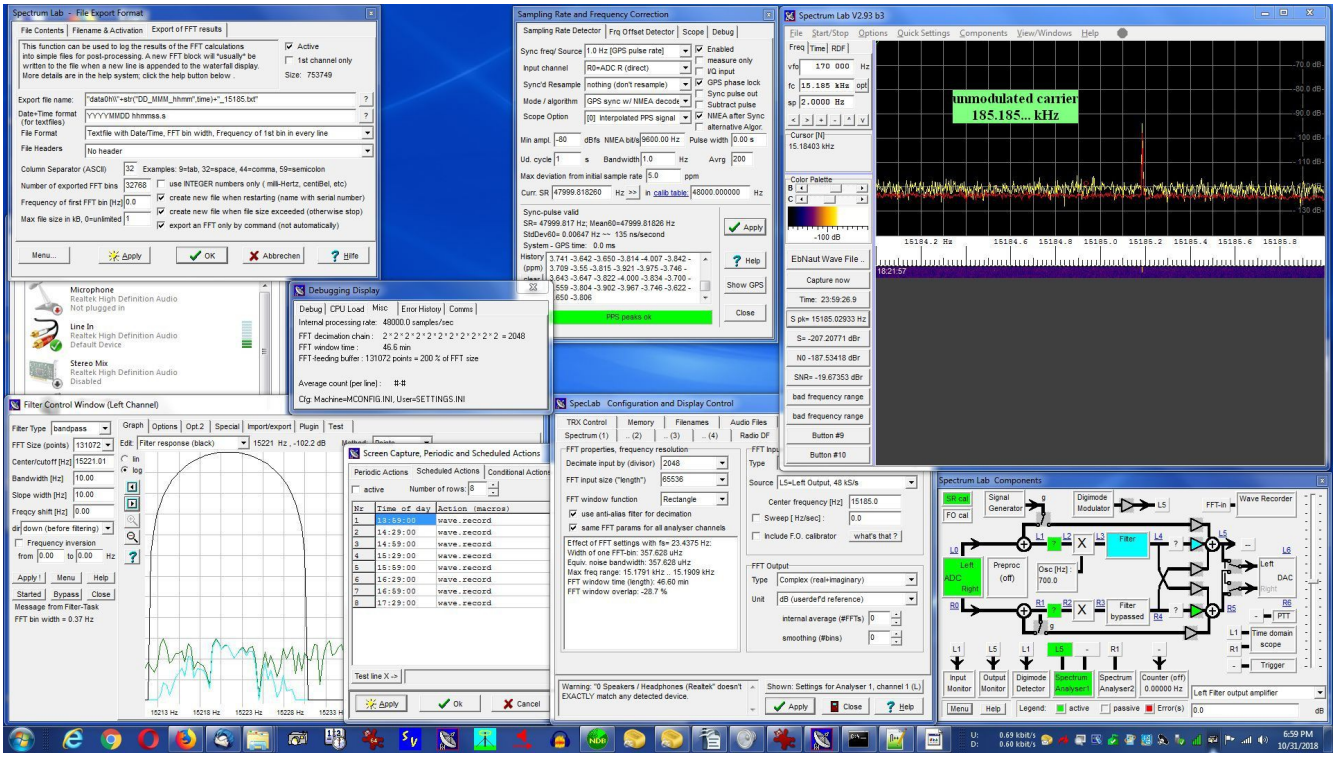
```
vtraw -oa < EbNaut_20181029_202900.vt > EbNaut_20181029_202900.txt
garry@garry-VirtualBox://media/VboxShare/EbNaut/K3SIW/Stacking/Linux$ sudo
vtraw -oa < EbNaut_20181029_205900.vt > EbNaut_20181029_205900.txt
garry@garry-VirtualBox://media/VboxShare/EbNaut/K3SIW/Stacking/Linux$ sudo
paste EbNaut_20181029_202900.txt EbNaut_20181029_205900.txt | awk '{print
$1,($2+$5),($3+$6)}' > EbNaut_20181029_stacked.dat
garry@garry-VirtualBox://media/VboxShare/EbNaut/K3SIW/Stacking/Linux$ sudo
ebnaut -d -F0.18875 -N3 -k16 -p 8K19A -S4.0 -T61.34 -r10.766563 -c1 -L20000
-PS -v < EbNaut_20181029_stacked.dat > decode_201829_stacked1.dat
skipped 61.300900 seconds to start
initial reference phase -83.9 amplitude 3.006e-01
phase   0    0    0    0    0
phase   1  180  180  180  180
carrier phase: -10.6 deg
carrier Eb/N0: 4.6 dB
carrier Es/N0: -9.27 dB
carrier S/N: 16.92 dB in 601.0 uHz, -15.29 dB in 1Hz, -49.27 dB in 2.5kHz
elapsed 4
phase   2   30   30   30   30
phase   3 -150 -150 -150 -150
phase   4  -30  -30  -30  -30
phase   5  150  150  150  150
phase   6   60   60   60   60
phase   7 -120 -120 -120 -120
phase   8  -60  -60  -60  -60
phase   9  120  120  120  120
phase  10   90   90   90   90
phase  11  -90  -90  -90  -90
phase  12   30   30    0    0
phase  13 -150 -150  180  180
phase  14   60   60   30   30
phase  15 -120 -120 -150 -150
phase  16    0    0  -30  -30
phase  17  180  180  150  150
phase  18   90   90   60   60
phase  19  -90  -90 -120 -120
phase  20  -30  -30  -60  -60
phase  21  150  150  120  120
phase  22  120  120   90   90
phase  23  -60  -60  -90  -90
phase  24    0    0   30   30
phase  25  180  180 -150 -150
carrier phase: -23.7 deg
carrier Eb/N0: 5.3 dB
carrier Es/N0: -8.59 dB
carrier S/N: 17.60 dB in 601.0 uHz, -14.61 dB in 1Hz, -48.59 dB in 2.5kHz
elapsed 43
phase  26   30   30   60   60
phase  27 -150 -150 -120 -120
phase  28  -30  -30    0    0
phase  29  150  150  180  180
carrier phase: 6.3 deg
carrier Eb/N0: 5.3 dB
carrier Es/N0: -8.59 dB
```

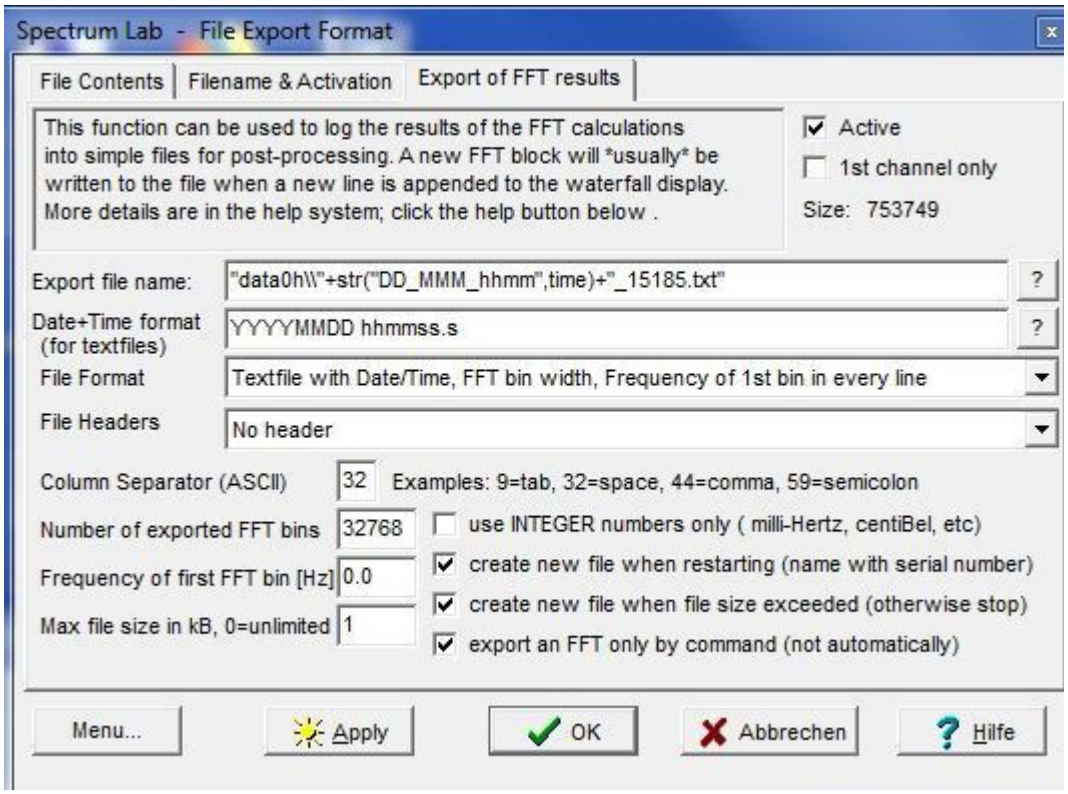
```
carrier S/N: 17.60 dB in 601.0 uHz, -14.61 dB in 1Hz, -48.59 dB in 2.5kHz
elapsed 49
phase  30   60   60   90   90
phase  31 -120 -120  -90  -90
phase  32  -60  -60  -30  -30
phase  33  120  120  150  150
phase  34   90   90  120  120
phase  35  -90  -90  -60  -60
phase  36   30    0   30    0
phase  37 -150  180 -150  180
phase  38   60   30   60   30
phase  39 -120 -150 -120 -150
phase  40    0  -30    0  -30
phase  41  180  150  180  150
phase  42   90   60   90   60
phase  43  -90 -120  -90 -120
phase  44  -30  -60  -30  -60
phase  45  150  120  150  120
phase  46  120   90  120   90
phase  47  -60  -90  -60  -90
phase  48   60   30   30    0
phase  49 -120 -150 -150  180
phase  50   90   60   60   30
phase  51  -90 -120 -120 -150
phase  52   30    0    0  -30
phase  53 -150  180  180  150
phase  54  120   90   90   60
phase  55  -60  -90  -90 -120
phase  56    0  -30  -30  -60
phase  57  180  150  150  120
phase  58  150  120  120   90
phase  59  -30  -60  -60  -90
phase  60   30    0   60   30
phase  61 -150  180 -120 -150
phase  62   60   30   90   60
phase  63 -120 -150  -90 -120
phase  64    0  -30   30    0
phase  65  180  150 -150  180
phase  66   90   60  120   90
phase  67  -90 -120  -60  -90
phase  68  -30  -60    0  -30
phase  69  150  120  180  150
phase  70  120   90  150  120
phase  71  -60  -90  -30  -60
phase  72    0   30    0   30
phase  73  180 -150  180 -150
phase  74   30   60   30   60
phase  75 -150 -120 -150 -120
phase  76  -30    0  -30    0
phase  77  150  180  150  180
phase  78   60   90   60   90
phase  79 -120  -90 -120  -90
phase  80  -60  -30  -60  -30
phase  81  120  150  120  150
```

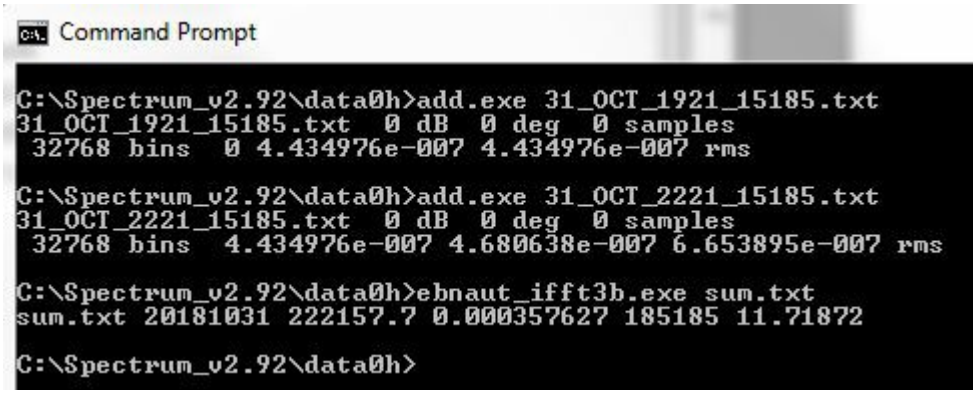
```
phase  82   90  120   90  120
phase  83  -90  -60  -90  -60
phase  84   30   60    0   30
phase  85 -150 -120  180 -150
phase  86   60   90   30   60
phase  87 -120  -90 -150 -120
phase  88    0   30  -30    0
phase  89  180 -150  150  180
phase  90   90  120   60   90
phase  91  -90  -60 -120  -90
phase  92  -30    0  -60  -30
phase  93  150  180  120  150
phase  94  120  150   90  120
phase  95  -60  -30  -90  -60
phase  96    0   30   30   60
phase  97  180 -150 -150 -120
phase  98   30   60   60   90
phase  99 -150 -120 -120  -90
phase 100  -30    0    0   30
phase 101  150  180  180 -150
carrier phase: -7.8 deg
carrier Eb/N0: 5.4 dB
carrier Es/N0: -8.49 dB
carrier S/N: 17.70 dB in 601.0 uHz, -14.51 dB in 1Hz, -48.49 dB in 2.5kHz
elapsed 165
phase 102   60   90   90  120
phase 103 -120  -90  -90  -60
phase 104  -60  -30  -30    0
phase 105  120  150  150  180
phase 106   90  120  120  150
phase 107  -90  -60  -60  -30
vstack: max height 37
garry@garry-VirtualBox://media/VboxShare/EbNaut/K3SIW/Stacking/Linux$


found rank 0 ber 3.6779e-01 Eb/N0 1.5 M -5.252033234e+00 ph 1
180,180,180,180 [SIW]
found rank 0 ber 3.6298e-01 Eb/N0 1.8 M -5.287595749e+00 ph 25 180,180,-
150,-150 [SIW]
found rank 0 ber 3.4375e-01 Eb/N0 3.0 M -5.738894463e+00 ph 29
150,150,180,180 [SIW]
found rank 0 ber 3.4375e-01 Eb/N0 3.0 M -5.790026665e+00 ph 101
150,180,180,-150 [SIW]
```

(note: get the r value by differencing successive entries in the stacked.dat file;
get the T value from Windows analysis of single .wav files)

Appendix B EbNaut .txt File Stacking with add.exe and ebnaut_ifft3b.exe in Windows command prompt.





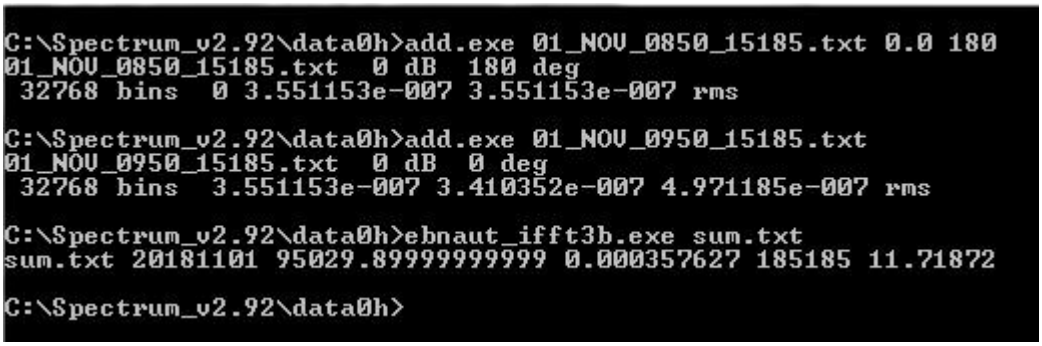


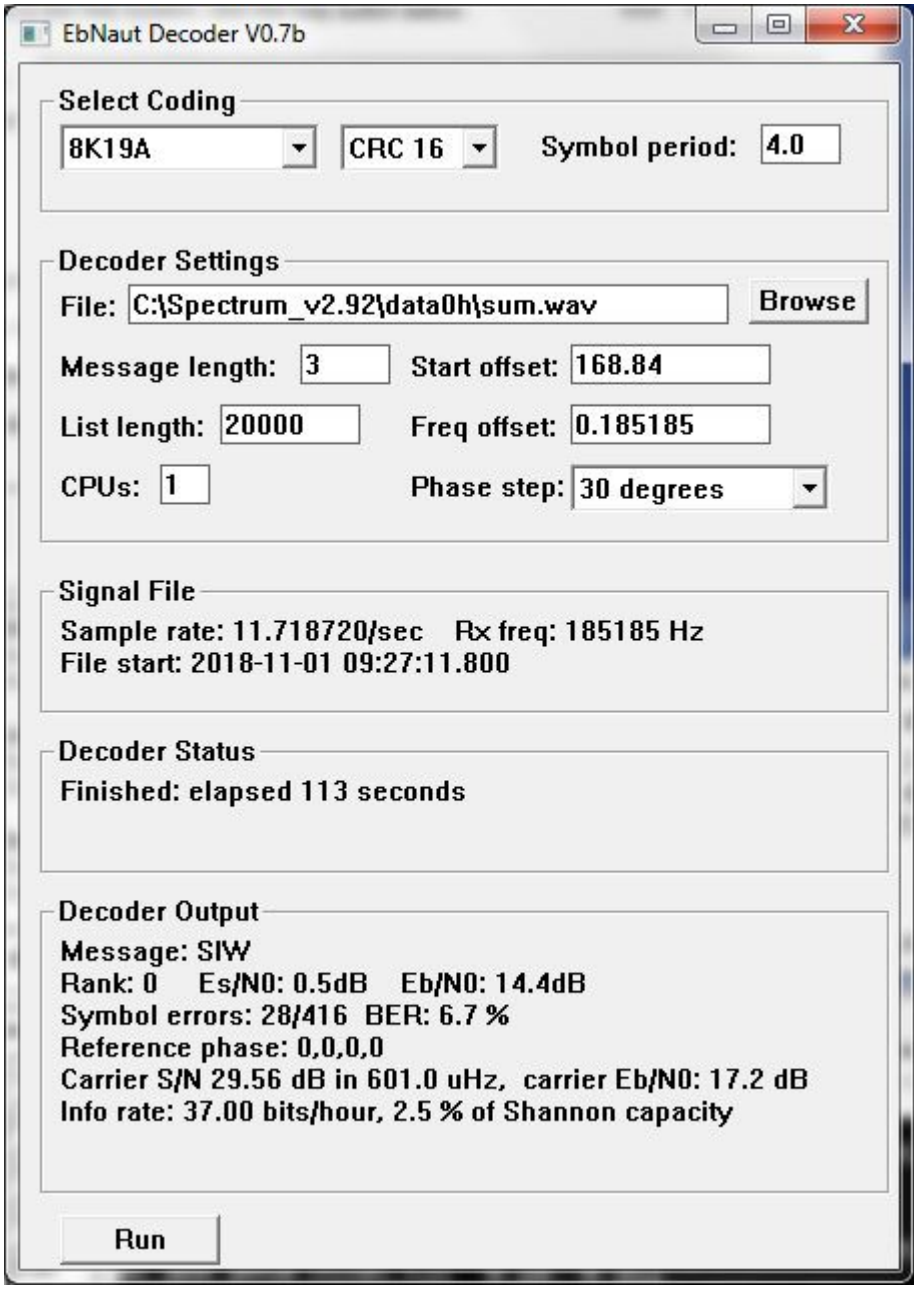
Carrier SNR 31_Oct_1921_15185.txt = 30.66 dB

Carrier SNR 31_Oct_2221_15185.txt = 31.52 dB

Stacked Carrier SNR = 33.92 dB (av stacking gain = 2.83 dB

Collected .txt files may vary by 180 deg in reference phase. In such cases the phase shift option of add.exe is necessary. For example, the signal file 01_NOV_0950_15185.txt has a decoded reference phase of 0,0,0,0 and SNR=27.09 dB while the signal file 01_NOV_0850_15185.txt has a decoded reference phase of 180,180,180,180 and SNR=27.66 dB. If they are combined without phase adjustment the stacked SNR is only 22.78 dB but if the latter is first shifted by 180 deg the stacked SNR is 29.56 dB, an average improvement of 2.19 dB.




EbNaut Decoder V0.7b
Select Coding
8K19A
CRC 16
Symbol period:
4.0
Decoder Settings
File:
C:\Spectrum_v2.92\data0h\sum.wav
Browse
Message length:
3
Start offset:
168.84
List length:
20000
Freq offset:
0.185185
CPUs:
1
Phase step:
30 degrees
Signal File
Sample rate: 11.718720/sec Rx freq: 185185 Hz
File start: 2018-11-01 09:27:11.800
Decoder Status
Finished: elapsed 113 seconds
Decoder Output
Message: SIW
Rank: 0 Es/N0: 0.5dB Eb/N0: 14.4dB
Symbol errors: 28/416 BER: 6.7 %
Reference phase: 0,0,0,0
Carrier S/N 29.56 dB in 601.0 uHz, carrier Eb/N0: 17.2 dB
Info rate: 37.00 bits/hour, 2.5 % of Shannon capacity
Run