FT4/FT8 and Diversity for WSJTX 2.1.2 DRAFT version

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Abstract

An implementation of FT8 and FT4 diversity for WSJTX program is described. Time diversity is summing up two consecutive even or odd samples, space diversity is summing up samples from two coherent receivers and two copies of WSJTX, while frame diversity is summing up decoded messages from two WSJTX instances.

Key point for described implementation is how to add up two incoherent audio samples. Solution is to shift one in time few times, so every tone gets possibility to be summed up in phase.

Diversity, as implemented, helps decode noticeable more traffic and provides significant improvement in Weak Signal communication on HAM shortwave.

1 Introduction

Diversity reception is common in all modern radio communications. Even cheapest cellular phones have a pair of antennas and receivers. CW or SSB diversity reception is becoming popular (W8JI call it stereo diversity). Simplest diversity has two receivers and logic to select one of them. More advanced techniques are common, where combining is done on bit level.

FT modes of WSJTX are extremely popular on HAM shortwave bands and we need better reception techniques to deal with interference and other obstacles contributing to weak signal reception. Better FT4 and FT8 decoding is achieved using diversity, by combining two or more RX signal sources. 2 to 5 dB S/N can be gained, enough to make some QSOs possible.

Diversity patch was implemented in WSJTX 1.9.1 and later in WSJTX 2.0.0. For WSJTX 2.1.2 FT4 was added, as well as optional faster, a bit less efficient, summing of non–coherent samples.

Results are excellent: S52D made several QSOs that would not be possible with standard FT4/FT8 decoder. Benefits are seen on empty band with only few decodes, as well as on crowded 20m band. Usually 10 % more messages are decoded using both time and space diversity.

2 RX Diversity

Details on different diversity approaches are given, followed by description how synchronization of non–coherent audio samples was realized.

WSJTX uses multiuser detection: when one frame is properly decoded, it is subtracted from audio recording, thus new detection is possible in next passes. By combining two residual audio samples (either from different time period or different receiver) more frames can be decoded.

K1JT wrote program MAP65 where two receivers are supporting EME modes, unfortunately it is not usable on HF for FT4 or FT8.

2.1 Time diversity

No additional hardware is needed, so any WSJTX user can benefit. Decoder takes two consecutive odd/even samples with residue signals and combines them with proper tone phase. For repeated messages it combines amplitude of the signal, while noise and interference is only power combined.

To put it simply, it can be said that some bits are coming from the current sample, and some from the previous sample.

Sometimes it decodes messages that were transmitted in the previous sample, occasionally both messages are decoded with current time. For example, we can see both RRR and 73 messages together. This happens when summing up helps with common bits like CALLs.

While operating FT4 or FT8, "t" marked messages are not to be trusted completely, as they might be ghosts from previous sample.

Samples are being summed up, while changing bands or just receiver QRG. Thus, old band data can be decoded as being received on the new band and reported to PSKreporter.

2.2 Frame diversity

As implemented, it simply adds messages decoded by secondary WSJTX to the primary one.

As full decode is done by one decoder, strict RX synchronization is not required and two independent radios can be used.

They have to be tuned to the same frequency, otherwise WSJTX might get confused and transmit on wrong frequency. If they are tuned to the same band with reasonable small offset, one TX frequency is fine to make QSOs on both RX windows. Also, when chasing DX, main WSJTX can be tuned to the whole band, while secondary is using 200 Hz filers to pick out only the wanted station.

Another possibility is on 160 m: second WSJTX is listening on JA subband 1908 kHz, so there is no need to bother with SPLIT operation, and at the same time it is easy to find clear TX QRG on 1840 kHz.

2.3 Space diversity

For space diversity two copies of WSJTX shall be run, each monitoring same QRG on different receivers attached to different antennas. Both radio receivers must be coherent: it is mandatory to use exactly same filters and same oscillators. Several SDR units (Afedri, Red Pitaya) supports coherent reception, as well some mainstream RIGs like K3, IC-7610.

Secondary WSJTX instance writes file to a specified directory, while primary reads it and adds it to decoding. Frame diversity is also used, adding messages decoded by secondary WSJTX and not by primary. File can be properly closed on time as enough delay is provided by time diversity on primary WSJTX.

Real space diversity requires two separated antennas in order to fight fading. Polarization diversity with one vertical and one horizontal antenna gives good results as well.

While testing using IC-7610, benefits were visible by using any pair of antennas. Some testing is needed to get feeling of how space diversity behaves on different bands at different instances.

Normalization of signal strength was tried, but there were no benefits with Icom–7610. Users with two receivers might need to adjust audio level to get best results.

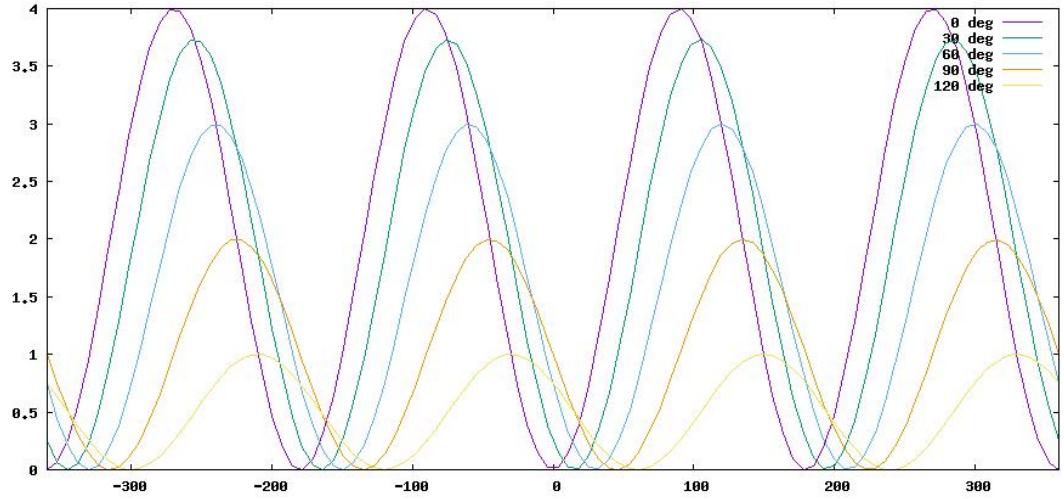
Files generated by space and frame diversity are named with time, so they must be removed every day to prevent false decoding. Those files written while primary WSJTX was transmitted, or those written too late, are not removed by primary instance.

3 Synchronization

Main challenge in diversity implementation was how to synchronize audio samples for different signals. Two instances of WSJTX do not capture audio at exactly same time. TX stations also do not transmit exactly at the same time, the main reason being the latency of the operating system.

Audio sample is sampled at 12000 Hz, so delay unit is 1/12000 seconds. WSJTX FT4/FT8 decoder subtract decoded frames from audio sample, and diversity is processing residual audio.

A sequence of 7 delays was found, that works fine for audio spectrum from 270 to 3000 Hz. It is based on a simple fact: if two signals are offset 50 degrees, then summing them up when one is delayed 410 degrees, or 770 degrees are same as delaying of 50 degrees. Since FT8 symbol length of 1/6.3 seconds is long enough, small mistakes on symbol change do not degrade decoding noticeably.



Power of two shifted tones:

$$(sin(\omega t) + sin(\omega t - \phi))^2$$

Different combinations were tested with tones from 270 to 3000 (2500) Hz with step 1 Hz and with phase shift 0 to 359 degrees with 1 degree step. When adding two signals with up to 60 degrees shift, degradation from perfect match is marginal, while shift of +/- 90 degrees is still usable.

Tables with best results for 3, 4 and 7 steps are given with percentage of samples where match is found with shift up to given angle.

sequence	bandwidth Hz	30 deg	60 deg	90 deg
0 3 6	270 – 2500	46.4 %	78.1 %	94.1 %
0 3 6	270 – 3000	47.2 %	80.9 %	95.2 %
0 4 8	270 – 2500	48.0 %	81.2 %	95.7 %
0 4 8	270 – 3000	45.4 %	75.5 %	90.4 %
0 7 14	270 – 2500	45.2 %	75.4 %	89.9 %
0 7 14	270 – 3000	45.4 %	77.1 %	91.7 %

Three shifts statistics. 0, 4, 8 is selected.

sequence	bandwidth Hz	30 deg	60 deg	90 deg
0 3 6 10	270 – 2500	57.8 %	88.5 %	98.0 %
0 3 6 10	270 – 3000	57.9 %	89.8 %	98.4 %
0 3 6 9	270 – 2500	58.1 %	87.3 %	97.4 %
0 3 6 9	270 – 3000	58.5 %	89.5 %	97.9 %
0 4 7 10	270 – 2500	57.8 %	88.5 %	98.0 %
0 4 7 10	270 – 3000	57.9 %	89.8 %	98.4 %
0 4 8 12	270 – 2500	60.1 %	91.1 %	98.8 %
0 4 8 12	270 – 3000	56.7 %	85.1 %	94.5 %
0 4 8 17	270 – 2500	58.8 %	90.6 %	99.7 %
0 4 8 17	270 – 3000	55.3 %	84.4 %	94.9 %

Four shifts statistics. 0, 4, 7, 10 is selected.

sequence	bandwidth Hz	16 deg	30 deg	60 deg	90 deg
0 10 17 20 25 30 39	270 – 3000	51.2 %	77.7 %	97.2 %	100.0 %
0 10 17 20 25 31 39	270 – 3000	50.8 %	76.9 %	97.2 %	100.0 %
0 10 20 26 31 39 17	270 – 3000	50.5 %	76.1 %	95.6 %	99.9 %
0 8 15 22 28 31 41	270 – 3000	50.5 %	76.7 %	97.7 %	100.0 %
0 8 15 22 29 31 41	270 – 3000	50.4 %	76.5 %	97.8 %	100.0 %

Seven shifts statistics. 0, 10, 17, 20, 25, 30, 39 is selected.

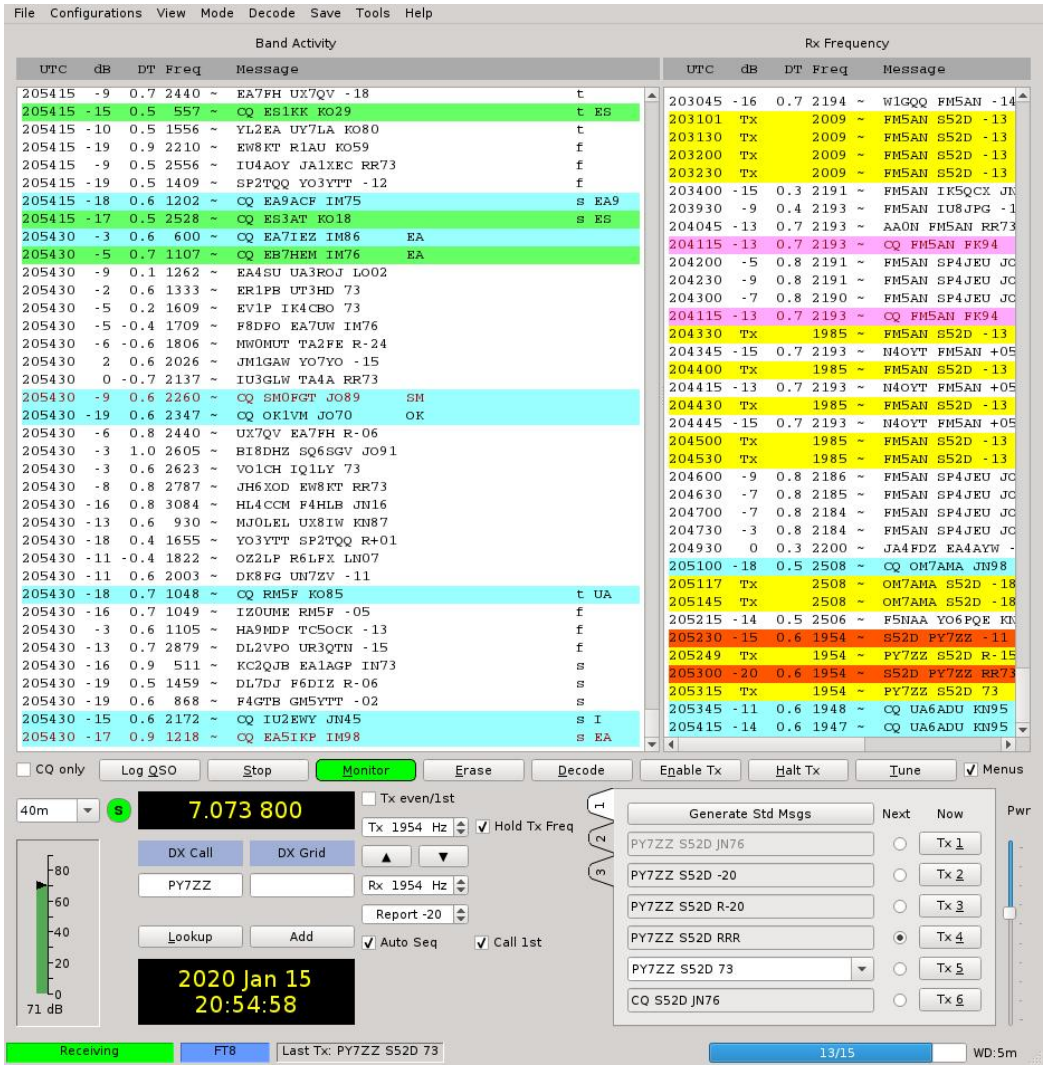
4 Operation

Just operate as with standard WSJTX.

The only visible change are frames marked with "t/f/s" on the right side, similar as "a" for apriori decoding.

Two configuration files are needed to enable data sharing between two WSJTX instances, as well as directory for temporary files. Once per day stale files shall be erased.

Start with sequence length 7. If CPU can not process frames on time, experiment with faster version of diversity patch using 3 or 4 steps for synchronization. Slightly lower number of messages can be decoded, compared to version with 7 steps.



Use normal decode. If deep decode is selected, processing time is noticeable longer, so decoding might overlap with TX period. Apriori decoding works fine and shall be selected.

4.1 Installation

Replace three files in src/wsjtx/lib directory and recompile WSJTX. Only jt9 is changed, there are no changes to C++ code. Most users will try time diversity only and it works with no additional configuration files.

For Windows users, jt9.exe will be provided as soon as somebody manages to compile diversity patch.

Those with two radios and antennas can benefit from frame diversity, while only few of us have possibility to use space diversity. Both demand two copies of WSJTX to run (use -r name), and each needs separate configuration file.

4.2 Configuration file

If there is no configuration file, only time diversity is used.

Files wsdiv.txt shall be created in a writable directory where files ALL.TXT, wsjtx.log

and others are stored for each WSJTX instance.

File wsdiv.txt has a simple format. FT4 and FT8 data are separated, manly because FT4 has shorter gap between RX and TX times. For space and time diversity, we need to select length of sync sequence. Valid numbers are 0 (no diversity), 1 (marginal), 3, 4 and 7.

The first 10 lines contain numbers for FT4/FT8 to enable and specify sequence length for time diversity, data writing, data reading for frame diversity and data reading for space diversity. 0 is for disabled, valid values are 1, 3, 4 and 7 for space/time sequence length. Selection is based on CPU power of computer, find a match producing decent results. Decoded frames shall be shown on time, not during TX period.

Primary WSJTX needs time diversity so file is read after it was written by secondary WSJTX.

Common directory where files are stored must be created when two receivers are used. Two directory names are specified, one for file writing and one for reading. Windows users shall put proper file name, like E:\div\ .

Test parameter is not used in this version of software.

Example for powerful CPU:

meaning	primary	secondary	comment
time diversity FT4	7	3	
time diversity FT8	7	0	
data writing FT4	0	1	
data writing FT8	0	1	
frame diversity FT4	1	0	
frame diversity FT8	1	0	
space diversity FT4	7	0	
space diversity FT8	7	0	
test parameter FT4	0	0	
test parameter FT8 8	0	0	
write directory	.	/tmp/div/	
read directory	/tmp/div/	.	

Example for less powerful CPU. A bit more work is allowed for FT8.

meaning	primary	secondary	comment
time diversity FT4	3	0	
time diversity FT8	4	0	
data writing FT4	0	1	
data writing FT8	0	1	
frame diversity FT4	1	0	
frame diversity FT8	1	0	
space diversity FT4	4	0	
space diversity FT8	7	0	
test parameter FT4	0	0	
test parameter FT8 8	0	0	
write directory	.	/tmp/div/	
read directory	/tmp/div/	.	

5 Code implementation

Author learned FORTRAN 4 in high school back in 1974/1975, and switched to Pascal in 1976. Learning a bit of modern Fortran was a pleasant surprise, as well as trying to understand how ft8 decoder really works.

Only three files are changed: ft8_decode.f90 and ft4_decode.f90 where real work is done and decoder.f90 where "t/f/s" annotations are generated.

There are no changes to the program structure or to procedure parameters so porting to new versions remains simple.

Brief overlook of code for FT4 (FT8 is similar) is given.

Several new variables are introduced, like:

```
   real ddd(NMAX,5) ! save 4 periods + data read from disk
   integer*2  dttablet(7), dttables(7) ! up to 7 shifts
```

When decoder is run for the first time, wsdiv.txt configuration is read and variables set properly.

```
if(first) then
   open(100,file=trim(data_dir)//'/wsdiv.txt',status='old',err=299)
   first=.false.
endif
```

Data file is opened before normal pass decodes are written.

```
if (fswriteok) then
  open(101,file=trim(divwdir)//datetime//'.dd4',access='stream',status='REPLACE'
  if (ioerr .gt. 0) divsav=.false. ! directory does not exist.
endif
```

There are new passes added to the main loop, and subtraction is activated for all three passes.

```
if (divsav .or. tdivok .or. sdivok) dosubtract=.true. ! if diversity enabled...
do isp = 1,28   ! used to be 1,nsp .10..17 time diversity, 20 frame div, 21-27 s

! isp=10 write dd to file, prepare data for time diversity
 if (isp .eq. 10) then
   write(101) 0,0,0,0,message,iaptype,qual ! mark end of decoded frames
   write(101) dd
   close(101) ! close fast, so other task can read after time diversity
 endif

 if (isp .gt. 10 .and. isp .le. (10+tdlen) ) then
  dtoffset = dttablet(isp-10)
  dd(1:NMAX-dtoffset) = ddd(1:NMAX-dtoffset,ipnow) +ddd(1+dtoffset:NMAX,ipold)
 endif

! here comes space diversity: isp 20 reads files and prepare for space diversity
```

```
 if (isp.eq.20) then
   open(102,file=trim(divrdir)//datetime//'.dd4',access='stream',status='old',io
   do
      read(102,IOSTAT=ioerr,err=199) smax,nsnr,xdt,f1,message,iaptype,qual
      if ((smax .eq. 0.0) .and. (nsnr .eq. 0.0)) goto 197 ! end of frames

      ldupe= ! find if already decoded
      if(.not.ldupe ) then !pass to WSJTX as new decode
         iaptype=iaptype+300  ! frame diversity
         call this%callback(smax,nsnr,xdt,f1,message,iaptype,qual)
      endif
   enddo

! read residual audio from another jt9 instance
197 if (sdivok) then
      read(102,IOSTAT=ioerr,err=199) ddd(:,5)
    endif
 endif

! passes 21 to 27 are for space diversity
 if (isp .ge. 21 .and. isp .le. (20+sdlen) ) then
   dtoffset = dttables(isp-20)
   dd(1:NMAX-dtoffset) = ddd(1:NMAX-dtoffset,ipnow) +ddd(1+dtoffset:NMAX,5)
 endif !isp 20..27
```

For normal passes, decodes shall be saved to file:

```
   if (divsav .and. (isp.lt.10)) then ! frame diversity, s52d
      write(101) smax,nsnr,xdt,f1,message,iaptype,qual
   endif
```

New decodes after diversity are marked as t/s:

```
    if (isp .lt. 20) then
       iaptype=iaptype+100 ! time diversity
    else
       iaptype=ipatype+200 ! space diversity
    endif
```

6 Future work

Described diversity is simplest possible from programming point of view, but demanding for CPU power.

As WSJTX decoder is working with power spectra, we might get as good results by summing up power in frequency domain (cx variable in sync8 for FT8). This might get similar results with noticeable less computation.

More integration into WSJTX would move configuration file into standard WSJTX configuration menu. By propagating exact RX QRG to decoder we can stop time diversity during QRG change. WSJTX is well balanced and works fine on a different

range of computers. Diversity patch is CPU hungry and works only on top range CPUs.

Space diversity can be made simpler, if WSJTX is capturing audio samples at exactly same time, Modifying WSJTX to work with two radios at the same time is not likely due to complexity of work to cover all possible combinations.

Unlike JT65 averaging, this implementation works on audio sample level. Other modes might benefit as well. If diversity is incorporated into mainstream package, then some additional parameters can be added to decoder functions, enabling a more universal, readable and flexible approach.

External SDR programs can be modified to feed multiple standard WSJTX instances with proper data. This is the way to handle 4 or more receivers configured for space diversity.

7 Conclusion

WSJTX decoders are on the limit of what is possible with single receiver. Result of using diversity on daily activity is positive, hence the patch deserves to enter mainstream code in some later release.

HAMs with single receiver can benefit from time diversity, while those with two might benefit from frame diversity.

Beside making several QSOs including rare DX, author learned a lot by studying WSJTX code and enjoyed every step of it.