Get going with FreeDV on HF, without fears or tears

The time has come for digital voice on the HF bands

Peter Marks VK3TPM

If you live in a suburban area, voice contacts on HF are getting harder. Solar inverters, switchmode battery chargers, LED lights and many other sources from consumer electronics, pollute our bands with broadband noise that makes single sideband listening unpleasant, to say the least. It's not uncommon to have someone say, "your signal is S9, but my noise floor is also S9."

Many hams have retreated to FT8 for DX contacts, but is it really a QSO?

Digital voice modes are well known on VHF and above. DMR, D-STAR, System Fusion, and P25 to name a few. All of these are proprietary to some extent, with most using the AMBE vocoder. DMR has become very popular due to the low cost of radios that support it.

The potential of digital voice over HF is to have a voice contact with zero background noise, high fidelity audio and good immunity to noise and fading.

Digital voice over HF has existed in the commercial space for many years. There are offerings from AOR, Codan, and Barrett but they are proprietary, and expensive for amateur radio use.

The author

Peter Marks VK3TPM has been licensed since 1978. He is a software developer who created the iOS app "WSPR Watch." Peter blogs at https://blog.marxy.org and is a regular technology commentator on ABC Radio, including the national Nightlife program. He is a member of the FreeDV Project Leadership Team.

The FreeDV logo. The new mode is making its mark.

A solution emerges

A fundamental barrier to digital voice was that the available vocoders include patented technology. This was overcome by David Rowe, VK5DGR, who did a PhD on low bit rate speech compression in the 1990s. David was encouraged by Open Source legend Bruce Perens K6BP, to create a truly open source low bit rate speech codec, which became Codec 2.

Bringing together all the pieces for users required a stand-alone application that hams could simply install on Linux, macOS, or even Windows. This happened in 2012 when Dave Witten KD0EAG collaborated with David Rowe to develop the FreeDV application.

The Dayton Hamvention awarded David with the 2013 Technical Excellence Award. The WIA board awarded the 2014 Ron Wilkinson Achievement Award to David Rowe VK5DGR, for achievement in developing the Codec 2.

Work on Codec 2 has continued and produced various modes that transmits speech over bandwidths as low as 700 Hz in the 700D mode. An amazing achievement, but some who tried it were put off by the "robotic" speech, similar to what DMR users experience.

The *Amateur Radio* article "Australian digital voice mode cracks DX on the 20m band" by Peter Wolfenden VK3RV and David Rowe VK5DGR (Vol. 88 No. 3, 2020, p15) describes success in using the FreeDV '700' modes under poor conditions. [tinyurl.com/FreeDVdx].

How it works

Rather than sending the actual audio waveform, Codec 2 uses hand-crafted software to analyse the speech audio and extract "features" such as pitch, loudness and the speech's spectrum.

The bit-rate is much lower than would be needed to send the waveform; 3 kHz of audio bandwidth is sent at just 700 baud. Amazing!

There's a modem used to send the bit stream over the radio. This uses multiple ODFM carriers (orthogonal frequency-division multiplexing), each transmitting QPSK bits (quadrature phase-shift keying). There are also some FEC

EXPLAINER

Open Source: a term that originally referred to open source software (OSS). This is computer code (software) that is designed to be publicly accessible – anyone can freely see, modify, and redistribute the modified code as they see fit. On the other hand, proprietary or closed-source software is where the code remains hidden from view.

https://en.wikipedia.org/wiki/Open_source bits (forward error correction) added to repair the errors in the data from losses over the air due to interference and fading.

At the receiving end, the demodulated bit stream is sent to a vocoder that turns the speech features back into speech audio.

AI comes to amateur radio

Recent advances in machine learning have improved the vocoder over what could be done by hand coding. Jean-Marc Valin developed FARGAN (framewise autoregressive generative adversarial network), which is a vocoder that uses a machine learning model trained on sample speech and the feature data from it to create a much more natural sounding speech result.

Jean-Marc approached David Rowe with a proposal to also apply machine learning to the modem part of the system, including the error-prone radio channel.

The latest versions of FreeDV include the radio autoencoder called RADE (radio auto encoder). It uses machine learning model for both the speech and modem systems.

The RADE encoder generates QAM symbols (quadrature amplitude modulation) that are transmitted over the channel using an OFDM (orthogonal frequency-division multiplexing) modem. These are organised into frames 120 mS long, each containing 120 QAM symbols. During most of the over, they contain just voice information.

At the end of the over, in the very last frame, we transmit classical digital QPSK symbols that contain text information (callsign, grid square, etc) with error protection provided by a low density parity check (LDPC) code. This information is then used for "Reporting."

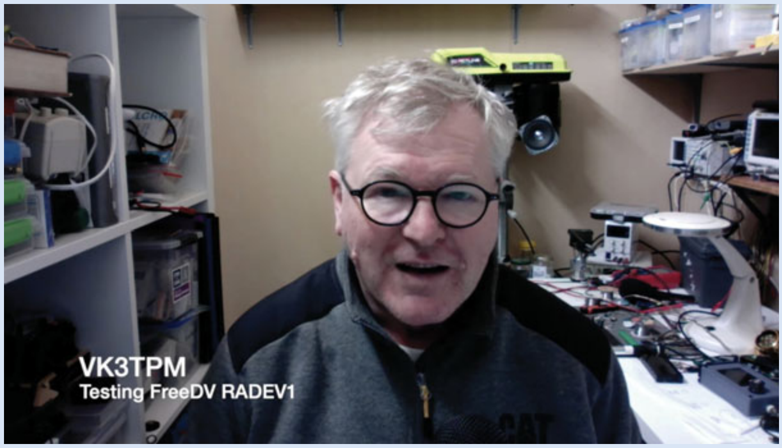
The training uses 205 hours of speech, from which "features" are extracted, like the speech spectrum and pitch. The RADE encoder and decoder is then trained to minimise the distortion in the features when passed through a simulated HF channel (fading + noise).

The FARGAN vocoder then uses those features to synthesise high quality speech at the receiver end.

Interestingly, the QPSK constellation it generates, which normally has four quadrants of phase and amplitude, just looks like noise to the human observer. We don't really understand how RADE is doing it. This is the "magic" of machine learning.

CATCH THIS CONTACT!

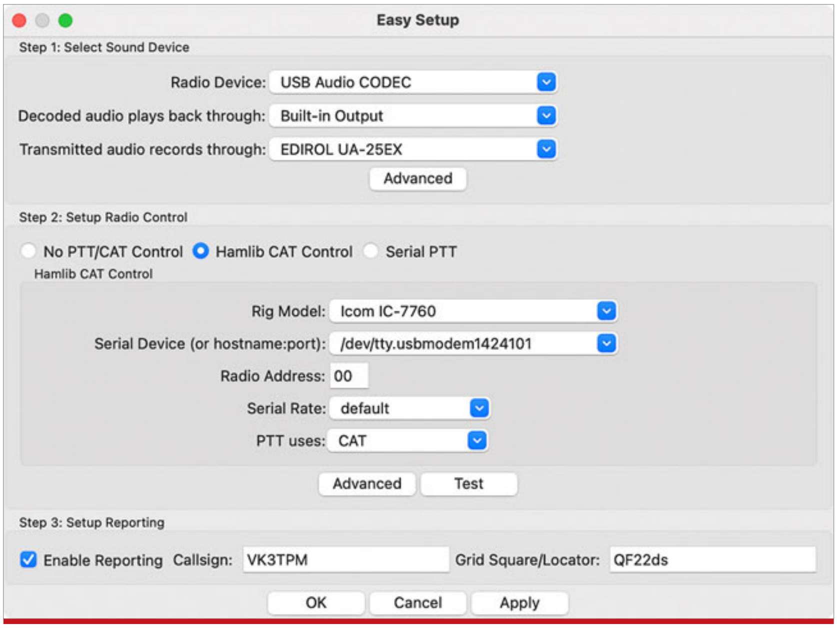
Visit – tinyurl.com/SSBvDV



Jack VK5KVA, recorded working **Peter VK3TPM** on 40m in the middle of the day over a 560 km path and a blistering noise level. Jack tests analog SSB against FreeDV RADEV1, reducing his power output from 40 W to 1 W in five steps. You'll hear how much easier and clearer it is listening to digital voice compared with analog SSB, all the way.

GLOSSARY

AMBE	Advanced Multi-Band Excitation, a type of proprietary voice compression algorithm used in a vocoder to transmit speech efficiently over digital channels.
DMR	Digital mobile radio. An international open standard for two-way digital radio communication developed by the European Telecommunications Standards Institute (ETSI).
D-STAR	Digital smart technology for amateur radio. An open protocol for digital communication developed for amateur radio voice and data communication, enabling users to connect via a global network of repeaters and even the internet.
FARGAN	Framewise Autoregressive Generative Adversarial Network. See: tinyurl.com/frgnDV
FEC	Forward error correction. Can fix transmission errors due to interference or fading.
LDPC	Low Density Parity Check. A class of powerful error-correcting codes that use a parity-check matrix to detect and correct errors in data transmitted over noisy channels.
OFDM	Orthogonal Frequency-Division Multiplexing. A method for sending high-speed data by splitting it into multiple low-speed streams. See: tinyurl.com/OFDMdv
P25	Project 25 – a suite of standards for interoperable land mobile radio.
QAM	Quadrature Amplitude Modulation. A digital modulation technique that combines both amplitude and phase modulation to transmit digital data efficiently over a communication channel. See: tinyurl.com/quadDV
QPSK	Quadrature Phase-Shift Keying. See: tinyurl.com/ENqpSK
RADE	Radio Auto Encoder. An open source digital voice mode for HF amateur radio that uses machine learning and digital signal processing (DSP) to provide high-quality speech at low signal-to-noise ratios.
Vocoder	An algorithm that analyses and synthesises human speech by breaking it down into its essential components.



The Easy Setup window. The radio device audio selection is both audio to-and-from the radio. If they are not a pair, the software recognises that you might need to click the "Advanced" button for more control.

Using machine learning (ML) has made FreeDV's architecture look simpler as things like FEC and QPSK generation have been figured out by the model. The upshot is that RADEV1 works better than the hand-crafted codec and sounds more natural and high fidelity than existing systems.

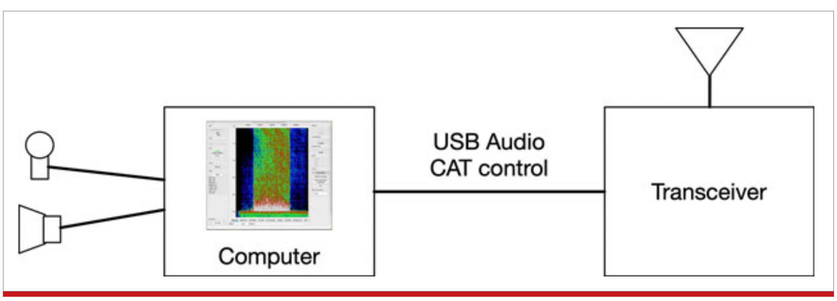
The signal is 1.5 kHz wide and yet the speech sounds like it's higher fidelity than anything over single sideband, which would be double that bandwidth on air.

FreeDV activity on air is increasing and there are now regular nets in several parts of the world, including Australia. They are listed on the freedv.org page. I think it's particularly applicable for many hams who suffer from local radio interference as they can get good sounding speech with no background noise.

RADEV1 is now competitive with single sideband over similar poor signal-to-noise conditions. There is a video demonstrating a contact between VK5 and VK3 with power reducing from 30 Watts down to 1 Watt, at: tinyurl.com/SSBvDV

Getting started

While there's complexity under the hood, actually setting up and using FreeDV is quite simple, particularly



Connection diagram. The simplest configuration is similar to other digital modes where the transceiver's audio in and out, along with CAT controls, are connected to a computer via a USB cable. I recommend a USB audio interface for speaker and microphone as a proper microphone, rather than just the built-in mic in a laptop, makes a big difference to the fidelity.

RADE V1 is the first known real-world deployment of a neural codec – an important milestone that the Ham community can be proud of.

David VK5DGR in a paper on RADEV1 at WASPAA 2025 Workshop (waspaa.com).

if you have a transceiver with USB (Universal Serial Bus) audio and control, such as the IC-7300. If you use digital modes such as FT8, you're probably all set already.

Download the FreeDV app for Linux, macOS, or Windows from https://freedv.org/

There are many Linux distributions so, currently, an AppImage is offered, which will run on Ubuntu or Fedora based systems. For other Linux distributions, there's a script which will automagically build from source.

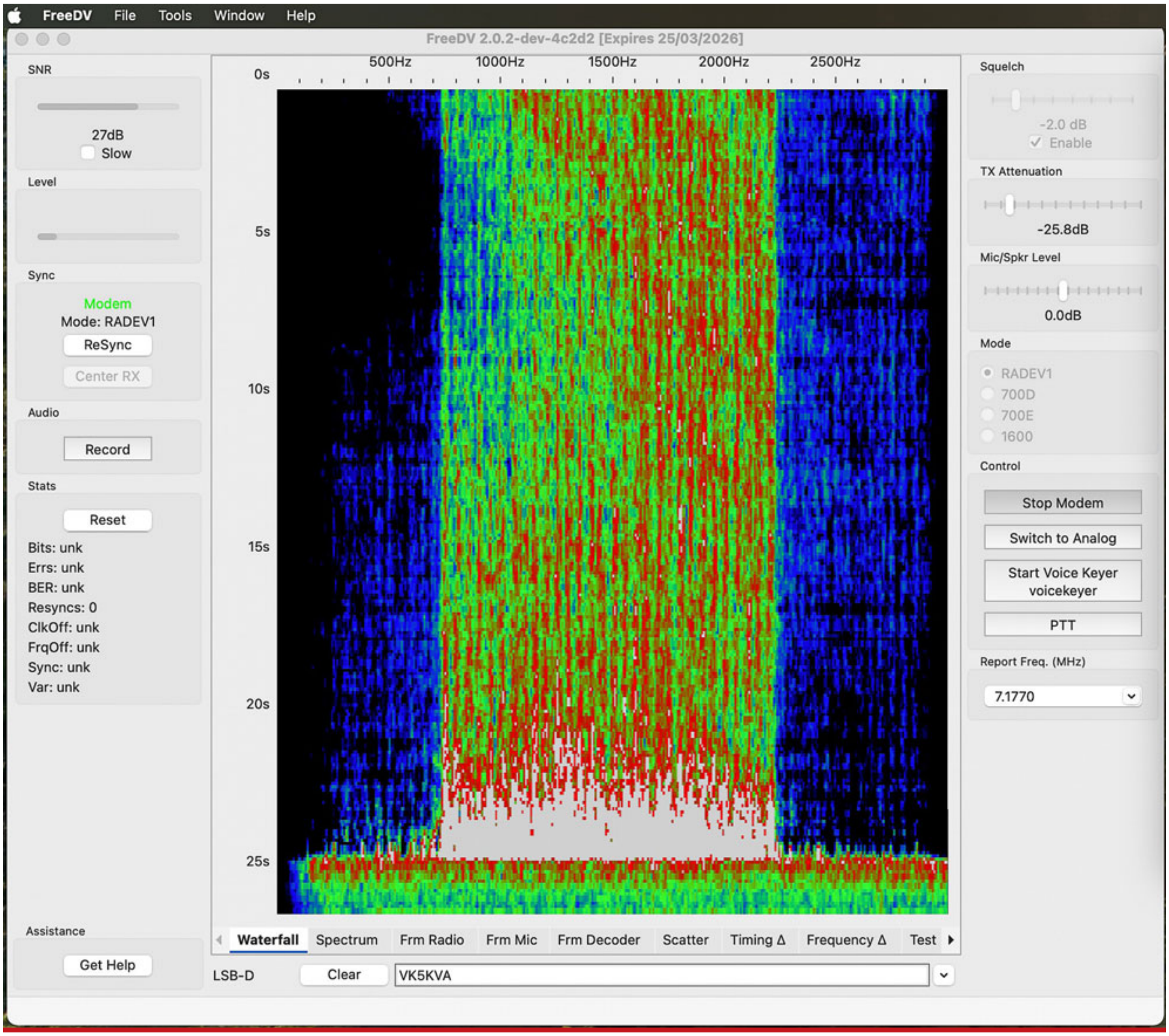
Transmitted audio is your microphone, which I recommend be a mic placed close to the operator for best results.

Rig control is via the Hamlib library, as used by other popular software, such as FLDigi.

Enabling reporting of your callsign and location means that, when you are receiving (or transmitting) you'll be visible in the FreeDV Reporter window at: https://qso.freedv.org/
<body text>

When first run, FreeDV will display the **Easy Setup window.** The following needs to be configured:

- The radio's audio interface. Either native, or perhaps an external interface, such as a SignaLink USB or DigiRig.
- The output, to play decoded audio.
- The input from your microphone. (I tend to use an external mic input for better quality).
- Rig control, which uses the Hamlib library commonly used with WSJT-X or FLDigi. (Press the Test button and check that your transceiver transmits).



Receiving FreeDV RADEV1. The waterfall shows a typical OFDM multi-carrier transmission. It's not uncommon to see deep fading diagonally across the carriers. Top left is the signal-to-noise (SNR) of the received signal – this is, I think, more useful than just signal strength as it measures how far above the noise a station's signal is.

- Reporting is valuable as there's a built-in window that lists who's on, called "FreeDV Reporter."

That's it! There are advanced windows for further control of audio and rig control, if needed, but for most users, the Easy Setup is all you need. Note that FreeDV adopts the same sideband for each band as per the convention with single sideband operation; lower on 40m and upper on 20m, for example.

Receive

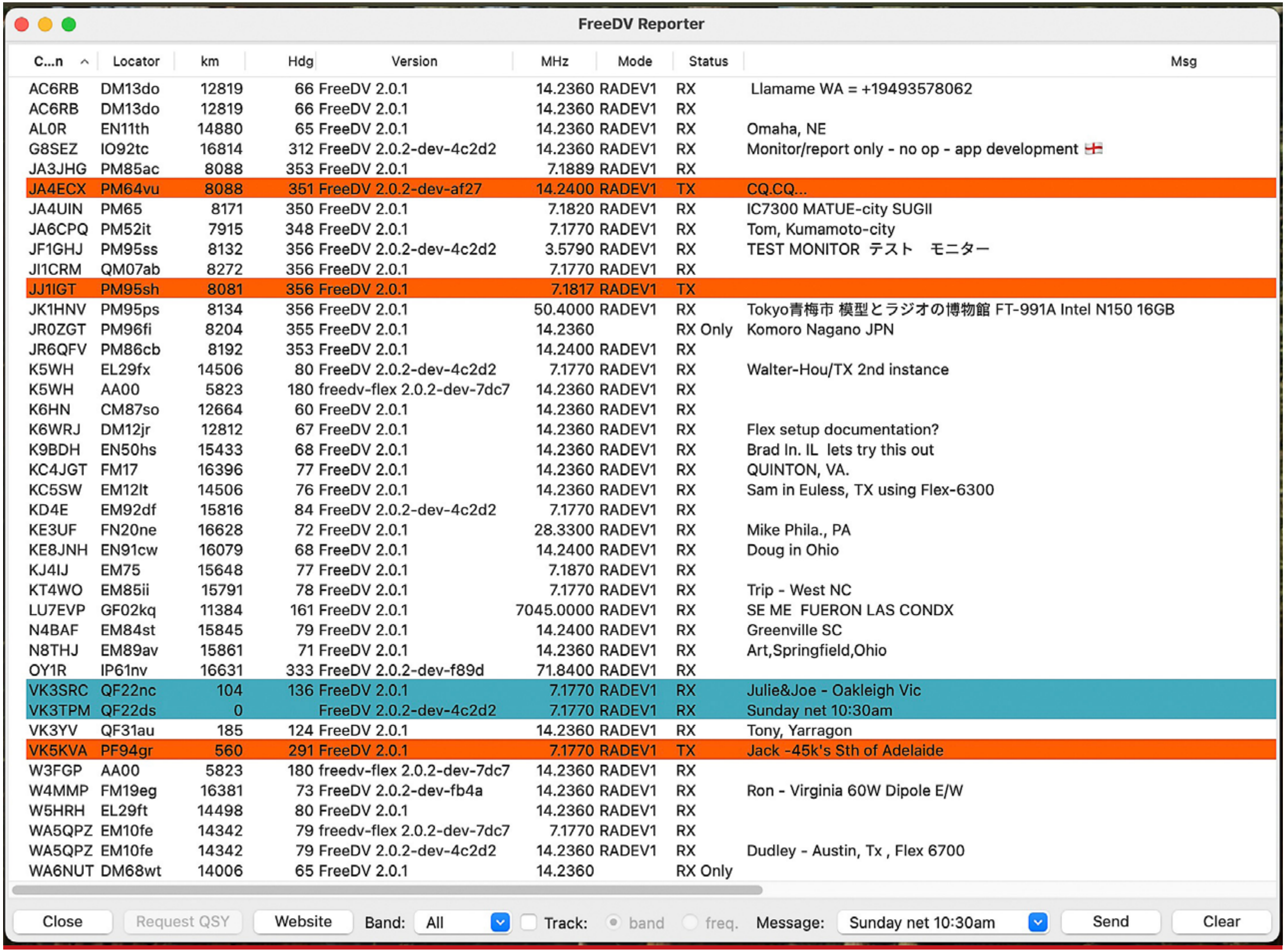
Click the Start button and choose one of the common frequencies from the Frequency menu to tune. (Figure 2 "Receiving FreeDV RADEV1")

The list is global and can be overwhelming. Narrow it down by tracking by band, or even by frequency. I typically sort either by callsign or km distance to see local stations.

To see who's on, choose "FreeDV Reporter" from the main menu. You can sort by distance or callsign to group local stations together. You can also narrow the display to just your current band and even track just your frequency. Double-click on a station to tune to their frequency.

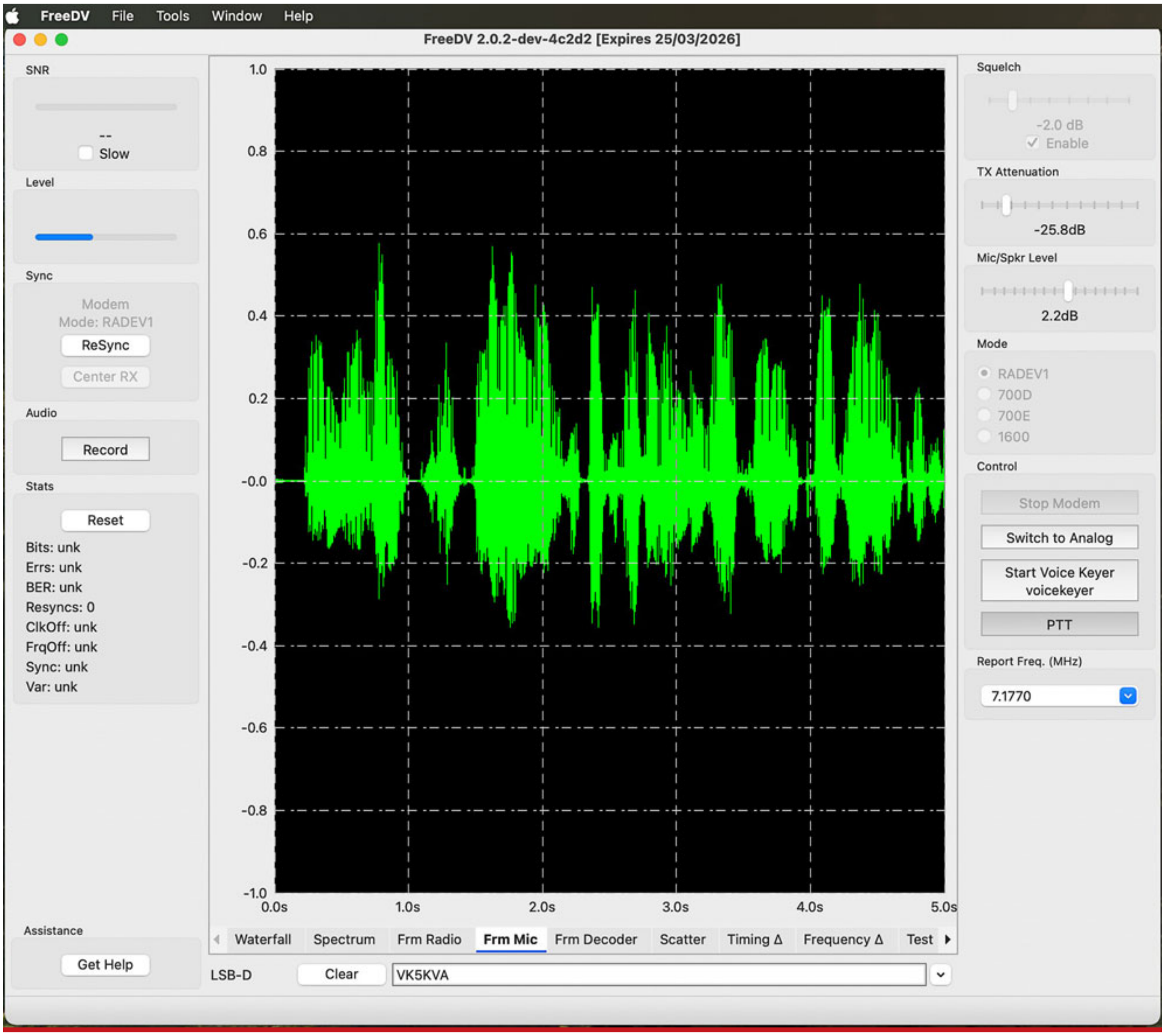
When a station transmits they turn red. You can see who can receive you. Enter a message to display your name or other comments to other users.

The measure of the quality of reception is signal-to-noise ratio in dB. This is a better measure than your S-meter as it shows how far the signal is above (or below) the noise floor. FreeDV RADEV1 can even work right down to below 0 dB SNR.



C...n	Locator	km	Hdg	Version	MHz	Mode	Status	Msg
AC6RB	DM13do	12819	66	FreeDV 2.0.1	14.2360	RADEV1	RX	Llamame WA = +19493578062
AC6RB	DM13do	12819	66	FreeDV 2.0.1	14.2360	RADEV1	RX	
AL0R	EN11th	14880	65	FreeDV 2.0.1	14.2360	RADEV1	RX	Omaha, NE
G8SEZ	IO92tc	16814	312	FreeDV 2.0.2-dev-4c2d2	14.2360	RADEV1	RX	Monitor/report only - no op - app development
JA3JHG	PM85ac	8088	353	FreeDV 2.0.1	7.1889	RADEV1	RX	
JA4ECX	PM64vu	8088	351	FreeDV 2.0.2-dev-af27	14.2400	RADEV1	TX	CQ.CQ...
JA4UIN	PM65	8171	350	FreeDV 2.0.1	7.1820	RADEV1	RX	IC7300 MATUE-city SUGII
JA6CPQ	PM52it	7915	348	FreeDV 2.0.1	7.1770	RADEV1	RX	Tom, Kumamoto-city
JF1GHJ	PM95ss	8132	356	FreeDV 2.0.2-dev-4c2d2	3.5790	RADEV1	RX	TEST MONITOR テスト　モニター
JI1CRM	QM07ab	8272	356	FreeDV 2.0.1	7.1770	RADEV1	RX	
JJ1IGT	PM95sh	8081	356	FreeDV 2.0.1	7.1817	RADEV1	TX	
JK1HNV	PM95ps	8134	356	FreeDV 2.0.1	50.4000	RADEV1	RX	Tokyo青梅市 模型とラジオの博物館 FT-991A Intel N150 16GB
JR0ZGT	PM96fi	8204	355	FreeDV 2.0.1	14.2360		RX Only	Komoro Nagano JPN
JR6QFV	PM86cb	8192	353	FreeDV 2.0.1	14.2400	RADEV1	RX	
K5WH	EL29fx	14506	80	FreeDV 2.0.2-dev-4c2d2	7.1770	RADEV1	RX	Walter-Hou/TX 2nd instance
K5WH	AA00	5823	180	freedv-flex 2.0.2-dev-7dc7	14.2360	RADEV1	RX	
K6HN	CM87so	12664	60	FreeDV 2.0.1	14.2360	RADEV1	RX	
K6WRJ	DM12jr	12812	67	FreeDV 2.0.1	14.2360	RADEV1	RX	Flex setup documentation?
K9BDH	EN50hs	15433	68	FreeDV 2.0.1	14.2360	RADEV1	RX	Brad In. IL lets try this out
KC4JGT	FM17	16396	77	FreeDV 2.0.1	14.2360	RADEV1	RX	QUINTON, VA.
KC5SW	EM12lt	14506	76	FreeDV 2.0.1	14.2360	RADEV1	RX	Sam in Euless, TX using Flex-6300
KD4E	EM92df	15816	84	FreeDV 2.0.2-dev-4c2d2	7.1770	RADEV1	RX	
KE3UF	FN20ne	16628	72	FreeDV 2.0.1	28.3300	RADEV1	RX	Mike Phila., PA
KE8JNH	EN91cw	16079	68	FreeDV 2.0.1	14.2400	RADEV1	RX	Doug in Ohio
KJ4IJ	EM75	15648	77	FreeDV 2.0.1	7.1870	RADEV1	RX	
KT4WO	EM85ii	15791	78	FreeDV 2.0.1	7.1770	RADEV1	RX	Trip - West NC
LU7EVP	GF02kq	11384	161	FreeDV 2.0.1	7045.0000	RADEV1	RX	SE ME FUERON LAS CONDX
N4BAF	EM84st	15845	79	FreeDV 2.0.1	14.2400	RADEV1	RX	Greenville SC
N8THJ	EM89av	15861	71	FreeDV 2.0.1	14.2360	RADEV1	RX	Art,Springfield,Ohio
OY1R	IP61nv	16631	333	FreeDV 2.0.2-dev-f89d	71.8400	RADEV1	RX	
VK3SRC	QF22nc	104	136	FreeDV 2.0.1	7.1770	RADEV1	RX	Julie&Joe - Oakleigh Vic
VK3TPM	QF22ds	0		FreeDV 2.0.2-dev-4c2d2	7.1770	RADEV1	RX	Sunday net 10:30am
VK3YV	QF31au	185	124	FreeDV 2.0.1	14.2360	RADEV1	RX	Tony, Yarragon
VK5KVA	PF94gr	560	291	FreeDV 2.0.1	7.1770	RADEV1	TX	Jack -45k's Sth of Adelaide
W3FGP	AA00	5823	180	freedv-flex 2.0.2-dev-7dc7	14.2360	RADEV1	RX	
W4MMP	FM19eg	16381	73	FreeDV 2.0.2-dev-fb4a	14.2360	RADEV1	RX	Ron - Virginia 60W Dipole E/W
W5HRH	EL29ft	14498	80	FreeDV 2.0.1	14.2360	RADEV1	RX	
WA5QPZ	EM10fe	14342	79	freedv-flex 2.0.2-dev-7dc7	7.1770	RADEV1	RX	
WA5QPZ	EM10fe	14342	79	FreeDV 2.0.2-dev-4c2d2	14.2360	RADEV1	RX	Dudley - Austin, Tx , Flex 6700
WA6NUT	DM68wt	14006	65	FreeDV 2.0.1	14.2360		RX Only	

FreeDV Reporter. The list of stations who are running FreeDV and have enabled reporting. Stations in red are transmitting, stations in green are receiving a signal. Scrolling to the right will show the SNR and callsign they are receiving.



Transmitting FreeDV. When transmitting, for best results, your mic level should be around 0.4 on the waveform. The level meter on the left will also show a “clipping” warning.

Transmit

Set your radio’s transmit power to about 50%, as the digital modem output is a high average power compared to sideband. On the transceiver, display the ALC (automatic level control) level.

Click PTT to transmit and adjust the “TX Attenuation” slider so that your ALC is just showing – not heavily acting. Speak into the microphone and adjust the Mic Level slider so you’re averaging around 0.4 on the “Frm Mic” plot as shown.

The TX Attenuation control should be set so that your transmitter’s ALC is just showing but not operating heavily.

There are multiple visualisations available that can be dragged by their tab name up in the central area, if desired.

Ensuring a good microphone audio level, but not clipping, is important for good audio.

The future

RADEV1 is currently implemented using the Python PyTorch ML modules which means that the FreeDV app must include a bundled python interpreter. Work is under way to not only improve how it works but also re-write the Python in C so it will be more compact and easier to install.

RADEV2 is coming, which will also improve on the algorithm and probably won’t be backward compatible. There will be a generous period of support for current users when the time comes to upgrade.

The project is funded by a generous grant from Amateur Radio Digital Communications (ARDC).

The grant outlines a list of objectives for the project and funds part-time employment of David

Rowe, who works on core code, and Mooneer Salem, who develops the FreeDV application. A condition of the grant is that there be a Project Leadership Team (PLT) that meets regularly to direct the project.

Australian net

There is activity somewhere almost all the time but, on Sunday mornings at 10:30am eastern time (EAST), there is a net on 40m run by VK3TPM from central Victoria. The frequency is generally 7.177 MHz but often moves to avoid analog stations or interference. Use the FreeDV Reporter to see where the net has moved.

Joining the net is a great place to get started and make adjustments.

References and Resources

FreeDV site with download links: https://freedv.org/

FreeDV Reporter: https://qso.freedv.org/

Example of audio quality: www.youtube.com/watch?v=m_voqX9Vx5A

FreeDV User manual: https://github.com/drowe67/freedv-gui/blob/master/USER_MANUAL.pdf

QEX Article *Practical HF Digital Voice*: www.arrl.org/files/file/Technology/tis/info/pdf/0056x003.pdf

Friendly introduction to RADEV1: https://github.com/drowe67/radae/blob/main/doc/rade_intro_waveform.pdf

Source code: https://github.com/drowe67/freedv-gui

The FARGAN vocoder: https://arxiv.org/abs/2405.21069

Presentation on RADEV1 by David Rowe: www.youtube.com/watch?v=LxjcAF7Vy0Y

ARDC Grant: www.ardc.net/apply/grants/2023-grants/enhancing-hf-digital-voice-with-freedv/