Mike Richards takes a look at the next generation of direct sampling receiver from Elad, the FDM-S2.

- Mike Richards reviews the ELAD FDM-S2 direct sampling SDR receiver
- All diagrams and images supplied by the author

Elad FDM-S2

Although the original Elad FDM-S1 arrived quietly on the software defined radio (SDR) scene, it was a surprisingly good and very compact SDR receiver. While the new FDM-S2 has many similarities because it is a direct sampling design, the new model has some significant technical advances, hence the higher price tag. The FDM-S2 is USB powered and provides continuous coverage from 9kHz through to 52MHz and an undersampling range that extends up to 160MHz. I'll explain a bit more about undersampling later. The receiver comes with its own bespoke software package that supports two independent in-phase and quadrature (IQ) channels, with each IQ channel supporting up to four receivers.

Connecting-Up

Although larger than the FDM-S1, the FDM-S2 is still a very compact receiver measuring just 40 x 110 x 90mm. As you can see from the photos, the receiver is housed in a rather swish anodised, brushed aluminium case. The front panel is very simple, with just two light emitting diodes (LED) indicating power and the USB connection. The rear panel housed the external connections. There were two SMA sockets for antennas, one HF and the other for VHF. Antenna switching was managed in software, with the HF socket used for the 9kHz to 52MHz range and the VHF socket used for the undersampled VHF coverage. Both antenna connectors were excellent quality and SMA to BNC adapters were supplied in the box, which was handy if, like me, you use BNCs for general shack interconnections. The USB connection employed a standard USB A connector and was used to supply power and to transfer the 16-bit IQ samples to the computer software for processing and demodulation. This makes for a very neat and compact installation that's good for use in the shack or with a laptop

The Elad FDM-S2 with supplied accessories.

The FDM-S2's rear panel.

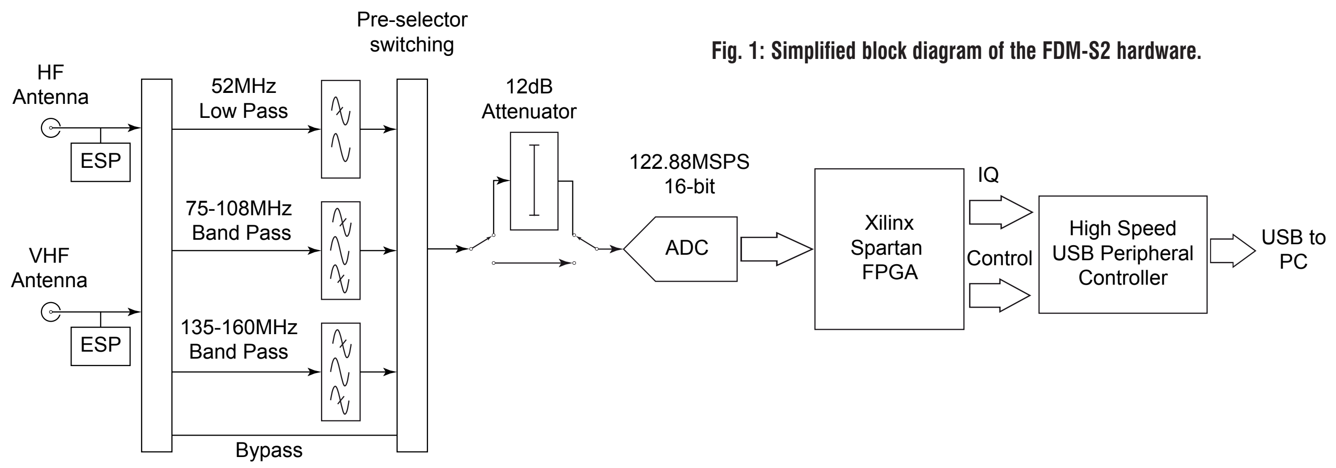

Fig. 1: Simplified block diagram of the FDM-S2 hardware.

Table 1: IQ Sampling Rates versus Tuning Ranges

Sampling Rate (kSPS)	Tuning Range (kHz)
192	153.6
384	307.2
768	614.4
1536	1228.6
3072	2457.6
6144	4951.2

Table 2: Extract of the Specification for the FDM-S2

Receiver type:	Direct sampling receiver based on 122.88MHz 16-bit single channel ADC converter
Frequency Range:	9kHz to 52MHz, 74MHz to 108MHz and 135 to 160MHz
Sensitivity	
9kHz to 52MHz:	HF: MDS: -132dBm @14MHz, Clipping lev -8dBm
74MHz to 108MHz:	FM: Sensitivity <2uV 12dB SINAD @98MHz, Clip lev -3dBm
135MHz to 160MHz:	VHF: MDS -137dBm @145MHz, Clipping level -19dBm
Max DDC bandwidth:	6.144MHz (Aliasing free viewable bandwidth up to 5MHz)
Antenna HF:	9kHz to 52MHz
Antenna VHF:	FM/VHF/bypass ranges
Bit streams:	192kSPS 32-bit, 384kSPS 32-bit, 768kSPS 32-bit, 1536kSPS 32-bit, 3072kSPS 32-bit and 6144kSPS-16-bit
Double DDC mode:	Two x 384kHz bandwidth to be placed within one of the input ranges.
Virtual Receivers:	Four virtual receivers freely tunable within DDC window
Receive Modes:	CWU, CWL, USB, LSB, AM, SAM, FM, WFM, DSB, RTTY, DRM and RDS
CAT Control:	Universal CAT control and OmniRig integration
Noise reduction:	Noise Blanker, Adaptive Noise Reduction and auto notch, special 2 manual notches (directly placed in DDC spectrum)
External control:	Proprietary Ext IO bus for accessory equipment, also offering 8 DC lines for universal switching (*via SFE1.0 board)
Dimensions (H x W x D):	40 x 110 x 90mm
Weight:	360g
In the Box:	Two BNC to SMA adapters, USB cable, USB double cable adapter, CD and safe bag

when travelling. In addition, on the real panel there was a 9-pin D connector for the external input/output (I/O) line. This is a real bonus for experimenters because it can be used to switch external filers, preamps and so on.

Inside Story

I've shown a simplified block diagram in **Fig. 1**. One of the major differences with the FDM-S2 is the use of a new analogue to digital converter (ADC) to sample the entire 9kHz to 52MHz spectrum in one hit. This is achieved by running the ADC at a sample rate of 122.88 million samples per second (MSPS). In addition, the resolution of the samples has been increased to 16-bits, thus providing an extended dynamic range.

The output from the ADC comprises a data stream supplying 16-bit samples at 122.88MSPS, which amounts to a data rate of 1.96608 gigabits per second (Gbps) – that's fast! The only way to process that amount of data is to use a field-programmable gate array (FPGA) and the FDM-S2 employs a Xilinx Spartan device. FPGAs are particularly good at this type of high-speed digital signal processing (DSP) number crunching because they can be configured to carry out multiple operations in parallel.

The main purpose of the FPGA in the FDM-S2 is to extract (or downsample) a more manageable slice of spectrum from the output of the ADC and then to deliver it as an IQ data stream to the computer. In the case of the FDM-S2, you have a choice of six IQ sample rates ranging from 192 to 6144kSPS, as shown in **Table 1**.

The FDM-S2 also includes a two-channel mode that provides two independently tuneable IQ streams at 384kSPS. This effectively transforms the FDM-S2 into a dual-channel receiver. As shown in Table 1, the tuning range from all the IQ sample streams is slightly less than the sample rate.

The 16-bit IQ samples are sent over a standard USB link, where the FDM-SW2 SDR software handles the final processing and demodulation.

In addition to the main sampler board, the FDM-S2 contains a software switched filter board that provides inductance and capacitance (LC) filtering for the main band along with filters for the 74 to 108MHz and 135 to 160MHz undersampling bands.

Table 2 contains an extract of the specification for the FDM-S2.

Sampling

The FDM-S2 is one of the few SDR receivers on the market that provides the option to use the ADC in undersampling mode. To help you understand the benefits of this, I will give you a quick recap of the sampling process. Sampling is the technique employed to convert an analogue signal into a stream of binary numbers that can be processed by a computer. The actual technique employed is to sample (measure and record) the amplitude of the analogue voltage of the signal. To get an accurate representation of the analogue signal, you need to take lots of samples – the question is, how many? This is where **Harry Nyquist's** theorem steps in. Harry Nyquist was a brilliant Swedish born mathematician and scientist. His most significant work was captured in his 1928 publication *Certain Topics in Telegraph Transmission Theory*. In that paper, he introduced the theory that stated the sampling frequency must be at least twice the frequency of the highest frequency component in the signal. This work was further developed by one of the founders of modern communication theory, **Claude Shannon**. The resultant theorem is widely used in all forms of modern digitisation. In most practical systems, the sample rate is chosen to be slightly higher than twice the highest frequency. As an example, Hi-Fi music signals containing frequencies up to 20kHz are often sampled at a rate of 44.1kSPS (44.1kHz).

What happens if a signal higher than the Nyquist frequency reaches the ADC? This signal will appear as a spurious response in the digitised output. The frequency of the spurious response can be calculated by subtracting the signal frequency from the sample rate. Here's a practical example. Let's assume you have an ADC designed to digitise the 0 to 30MHz band using a sample rate of 60MSPS. If a signal of 35MHz gets through to the ADC, it will appear as a spurious signal at 25MHz (60MHz minus 35MHz). Similarly, if a 50MHz signal reached the ADC, it would appear at 10MHz (60MHz minus 50MHz). This effect is known as aliasing and is normally an unwanted product of the sampling process. These unwanted

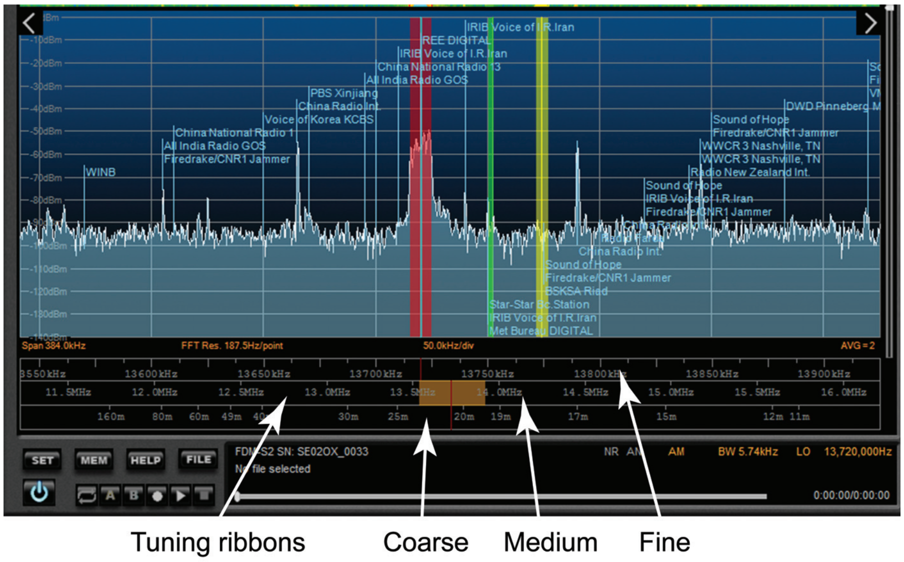

Fig. 2: The ingenious tuning ribbons in the FDM-SW2 software.

signals are usually controlled by placing low-pass (anti-aliasing) filters ahead of the ADC.

Although aliasing effects are usually unwanted, they can be harnessed to extend the frequency range of a system, providing the ADC has a wide enough frequency range. This still complies with the general Nyquist theorem because that requires the sample rate to be twice the frequency of the sampled bandwidth. The technique is commonly known as aliasing, undersampling or super-Nyquist sampling. Providing filters are used to eliminate unwanted frequency bands, this technique can be used to make significant frequency extensions. In the case of the FDM-S2, the ADC has a frequency response that extends to 160MHz so we can use the undersampling technique and additional filters to extend receiver coverage to 160MHz.

SDR Software

A number of popular SDR packages such as HDSDR, SDR-Console version 2, Winrad and Studio 1 support the FDM-S2. However, for this review I stuck with the bespoke Elad software, FDM-SW2. This software is under constant development and I used FDM-SW2 version 1.09 along with hardware v1.0 and firmware v2.6.

Getting Around the Bands

One of the great things about SDR is the innovative tuning systems that have been developed. Elad has opted for an ingenious set of three scrolling ribbons to provide a quick way to change frequency. The ribbons are shown in **Fig. 2**, where you will see that the lower ribbon covers from just a few kHz through to around 30MHz. The middle bar covers a 5MHz span, while the top bar covers whatever IQ bandwidth you have selected. For large frequency changes, you click and drag the lower ribbon to move the required frequency range to the centre of the display. You then refine the selection using the middle ribbon and complete the process either with the top ribbon or simply by clicking on the desired station. When using a wide IQ sample, I found the top ribbon was often too coarse so I used the zoom tool at the top of the display to zoom-into the required band so that the point and click tuning was more accurate.

As an alternative to the ribbons, I could also use direct frequency entry. A double-click on the frequency display opened up the direct entry box where I could enter the frequency in Hz, kHz or MHz and get straight to the frequency.

One of the big plus points of the FDM-SW2 software is the facility to integrate external databases to help identify stations. For broadcast listening, I was able to download the EiBi database of short wave schedules as a comma-separated values (CSV) file and connect it to the FDM-SW2 software. Once installed, I could view the database via the information window in the right-hand panel and tune in using a double click. I was also able to set the software to display station names in the spectrum display. This made station identification extremely simple but in some cases, the display became rather cluttered. An alternative but equally effective technique was to have the names displayed at the cursor position. This kept the display clear but still gave access to the full database information. Because the software used a simple CSV file, it was very easy for me to create my own custom frequency lists. For those readers with an interest in amateur radio, the FDM-SW2 software can connect directly to most of the popular DX clusters to provide instant 'mouse click' tuning to new stations as they appear.

Multichannel Receiver

As I mentioned earlier in the review, the FDM-S2 hardware includes the facility to send two separate 384kSPS IQ streams to the computer. The two streams can be set anywhere in the FDM-S2's pass band so you have genuine dual-channel monitoring – see **Fig. 3**. During the review, I was able to set one channel monitoring NAVTEX on **518kHz**, while I used the other channel to explore some of the DX on the 10m band. The only thing to watch here is that both channels use the same ADC, so the attenuator setting and pre-selection filters affect both channels but that's all.

In addition to the twin IQ channels, each channel can have up to four receivers activated, providing they are all tuned to frequencies within the selected IQ bandwidth. For example, when using the largest 6144kSPS setting you have a 5MHz tuneable bandwidth available, so each of the four receivers could be tuned anywhere within that band. I've shown an illustration in **Fig. 4**. I found the easiest way to see activity in each channel was to open an intermediate frequency (IF) spectrum window for each receiver. Not only does that let you see the activity but it also allows you to fine-tune and adjust the filter width for each receiver.

Audio Versatility

While dual-channel, multi-receiver reception is very appealing, you can't sensibly listen to four or more stations at the same time. However, you can mix the receive modes and make use of multiple receivers that way. As we're enjoying some good conditions on the 10m amateur band I used two receivers to monitor ROS and V4Chat on 20m, while using two more receivers to hunt around for interesting single sideband (SSB) activity on 10m. In order to do this, you need to use the flexible audio routing that's built into FDM-SW2 software (**Fig. 5**). Using the settings panel, you can route each of

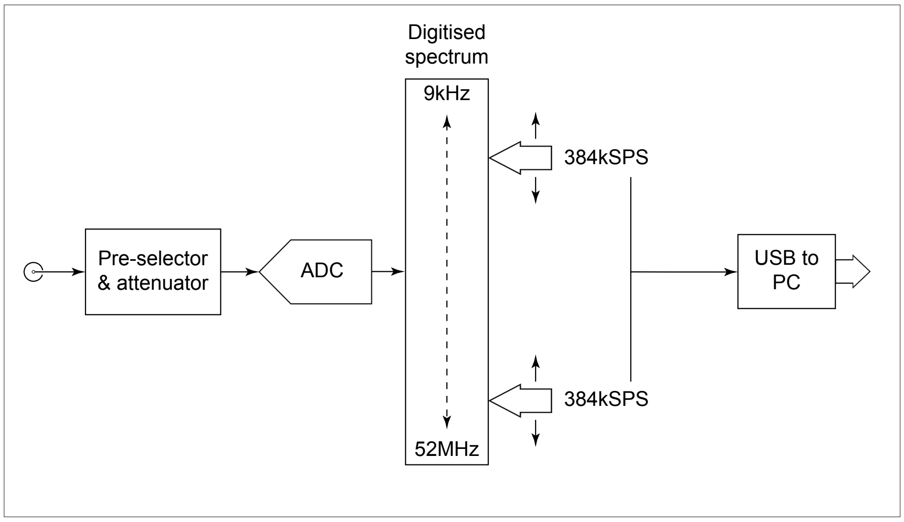

Fig. 3: Illustration of the dual-channel capabilities of the FDM-S2.

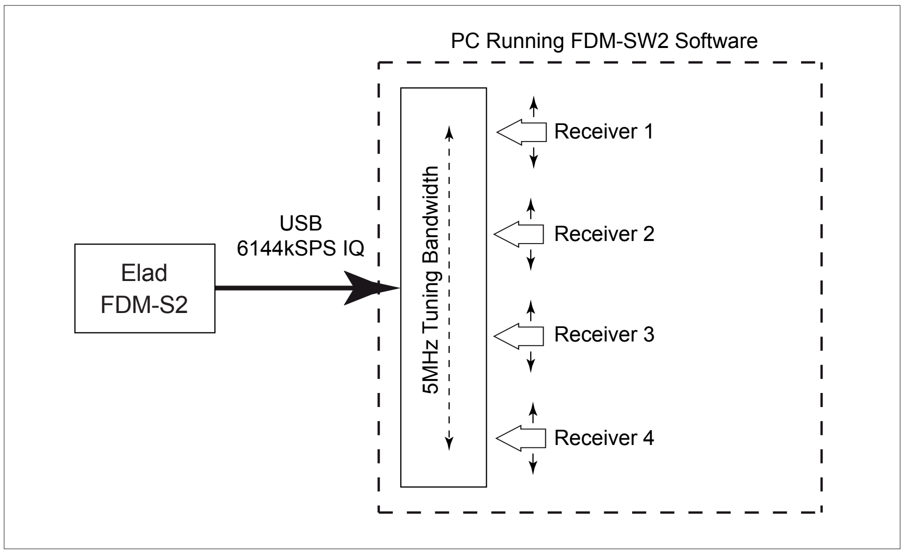

Fig. 4: Illustration of the FDM-SW2 multiple receivers operating with a 6144kSPS single channel IQ stream.

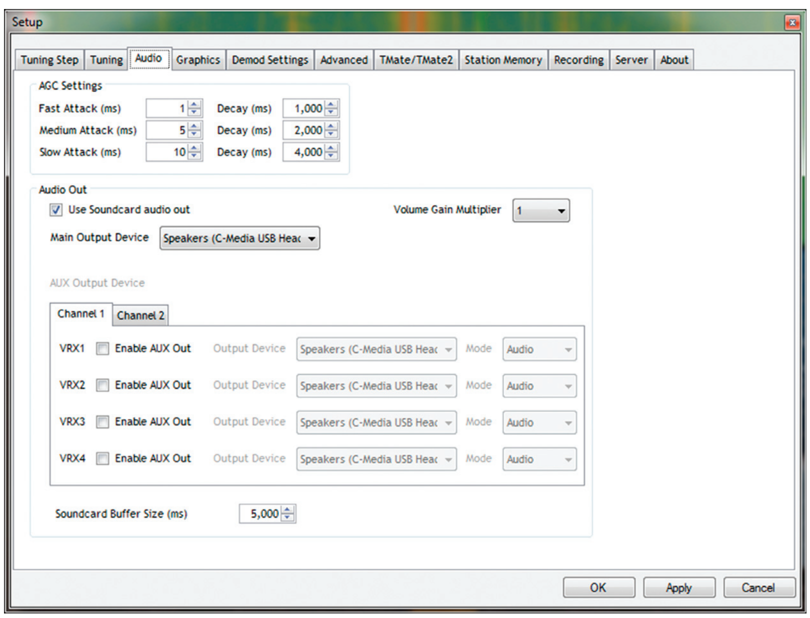

Fig. 5: FDM-SW2 audio signal routing options.

the four receivers to different audio devices with a separate volume control for each one. For utility work the audio can be routed to a Virtual Audio Cable (VAC) to provide the link between the FDM-S2 and the decoding software without having to convert to analogue and back. The FDM-SW2 software also allows selection of four different output formats, which can be Audio, 192kHz IF, 48kHz IF or wideband FM Multiplex for connecting to a stereo decoder.

IQ Recording

To complete the armoury of SDR tools the FDM-SW2 software includes a well-specified recorder. This can be set to record either the current IQ spectrum or the audio signal. The IQ recording is the most powerful option because you can record up to 5MHz of radio frequency (RF) bandwidth for replay and demodulation at a later time. The recording format is 16-bit WAV and the software can be set to split the recording into more manageable file sizes. The software handled this extremely well and provided seamless playback when using a multiple file recording. To complete the recorder there was a built-in schedule, which was useful for catching broadcasts when you're otherwise occupied.

Integrated DRM

The FDM-SW2 software now includes an integrated Digital Radio Mondiale (DRM) decoder, thus providing easy access to these high quality short wave broadcasts. The DRM decoder was very easy to use and included a useful DRM status panel that displayed the station name along with any text messages and decoder status information. When DRM is selected, a schedule icon appears in the right-hand panel and a single click on this starts a download of the latest DRM schedule – see **Fig. 6**. This makes finding DRM signals so much easier. Once you've found the desired station, a double click on the schedule and the receiver instantly re-tunes. The integrated decoder and schedule made DRM listening a real pleasure.

DRM Schedule

StartStopTimeUTC	Days	Frequency	Target	Power	Programme	Language	Site
0000-2400	Daily	909	Nuernberg	0.1	biteXpress	German	Dillberg
0000-2400	Daily	15896	Erlangen	0.1	biteXpress	German	Erlangen
0000-2400	Daily	26010	Italy	0.1	Radio Maria	Italian	Andrate
0000-2400	Daily	26060	Roma	0.2	Raiway Roma	Italian	Vatican City
0015-0430	Daily	1080	India	25	AIR	Urdu/ Sindhi	Rajkot
0100-0300	Daily	19000	Pacific	40	R. Australia	English	Shepparton
0115-0215	Daily	9950	Europe	50	AIR	Hindi	Khampur
0215-0400	Daily	9950	India	50	AIR	various	Khampur
0300-0400	Daily	6175	Asia	90	RTM	English	Kajang
0300-0400	Daily	15340	SE Asia	90	RRI	English	Tiganesti
0400-0430	Daily	21540	China	90	RRI	Chinese	Tiganesti
0415-0615	Daily	11645	Europe	50	AIR	English	Khampur
0430-0500	Daily	7390	E Europe	90	RRI	Russian	Tiganesti
0459-0650	Daily	13730	Pacific	25	RNZI	English	Rangitaiki
0500-0700	Daily	3955	Europe	100	BBC World Service	English	Woofferton
0500-0900	Daily	9780	Europe	100	REE	Spanish	Noblejas
0630-0700	Daily	9600	Europe	90	RRI	French	Galbeni
0651-0758	Daily	11690	Tonga	25	RNZI	English	Rangitaiki
0700-0800	Daily	11715	Nepal	50	AIR	Nepali	Khampur

Fig. 6: FDM-SW2 DRM schedule.

Undersampling Modes

The FDM-S2 is supplied with two undersampling ranges covering 74 to 108MHz and 135 to 160MHz. The 74 to 108MHz band was ideal for VHF/FM broadcast monitoring and included a stereo FM decoder and radio data system (RDS) display. The sensitivity was excellent at around 2µV for 12dB SINAD, so this could provide the basis of a good VHF DX setup. The 135 to 160MHz range covers the 137MHz weather satellite band along with the 2m amateur band and some of the marine band.

When using these undersampled bands, the software automatically handles the filter switching and frequency calculations, so operation is seamless. For experiments, the software includes a bypass mode that switches-out the front-end filtering, so you can add your own external filters.

During the review, I couldn't resist using the FDM-S2 out of band for the 108 to 136MHz airband and I was pleasantly surprised by its performance. Although the software displayed an out of band warning, it was perfectly usable throughout the airband, except for a very sharp peak at the ADC sampling frequency of 122.88MHz.

CAT

Thanks to the inclusion of the popular Omnirig control system, the FDM-SW2 software can be linked to the computer aided transceiver (CAT) port on your receiver or transceiver. This makes the FDM-S2 ideal for radio amateurs, where it could be used as a panoramic adapter (panadapter) with a suitable IF output or simply as a second receiver that automatically tracks the main rig.

USB Web Server

The Elad USB web server is a rather good add-on software package that provides basic control of the receiver using a web browser anywhere on your local network. To use this, you need to download the USB web server software from the Elad website and use the Set panel in the receiver software to start the server. Once it is all up and running, you can do basic tuning and mode setting from any computer that can run the Firefox web browser. With this running, I could operate the FDM-S2 using my Blackberry Playbook in the lounge.

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summary

As you can see, the Elad FDM-S2 is an excellent and very powerful SDR system. The 16-bit direct digital sampling technique provides easy access to the entire low frequency (LF), medium frequency (MF), HF and lower VHF spectrum. The supplied software worked extremely well and provided simple access to the multi-channel features of the hardware. It was also good to see that Elad has encouraged other software developers to support their hardware, thereby giving customers a wide choice of software solutions. The facility to bypass the front-end filtering leaves the user free to experiment with external filter boards to provide coverage of any frequency between 9kHz and 160MHz, excluding the sample frequency of 122.88MHz.

The FDM-S2 is available from **ML&S Martin Lynch and Sons** and costs £449.95 including VAT. **Martin Lynch & Sons Ltd., Outline House, 73 Guildford Street, Chertsey, Surrey KT16 9AS**.
Tel: 0345 2300 599
www.hamradio.co.uk

My thanks to ML&S for the loan of the review model.