Multi-channel Monitoring – The ARINC-635 Experience (and more)

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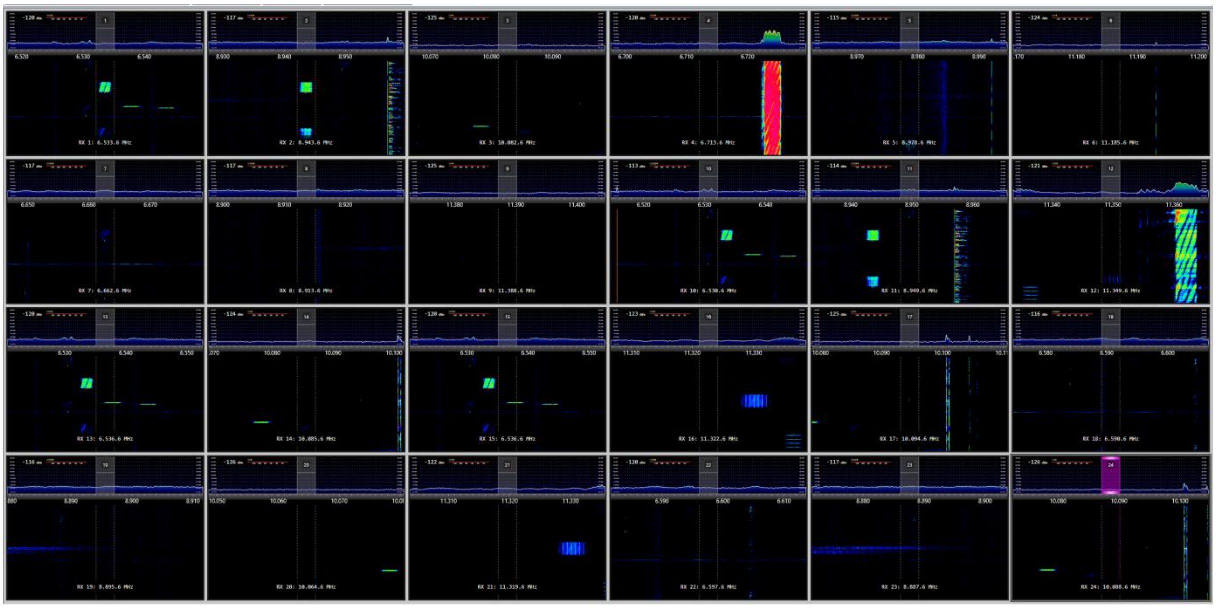


Matrix of 24 ARINC channels, received in parallel within a HF bandwidth of 5 MHz. Receiver is ELAD FDM-S2, software SDR-COM V3 by Simon Brown.

This paper shows how to monitor many HF channels in parallel over a wide frequency range. For this, I used three SDRs FDM-S2 from ELAD in parallel. Also other SDRs may be used, of course, according to their specification. Simon Brown's software SDR-COM V3 (beta release) largely triggered the idea of parallel monitoring up to 24 channels with a budget receiver; with even more channels to come.

First, I will give a general introduction into the wide-range, multi-channel monitoring. This will also cover broadcast and amateur radio as well. Then I will dive deeper into one example, namely monitoring and analyzing many ARINC channels in parallel. ARINC is a worldwide aero network, communicating between air and ground with a robust mode and an open protocol. In fact, it's the biggest network on HF which can be closely followed also with free software, like PC-HFDL (decode) and PC-HFDL-Display (organizing the ten thousands of messages received during 24 hours).

Eventually, I gave some other examples, e.g. MIL-STD-188-144A and broadcast plus hints on amateur radio.

Of course, you may extend these examples to your needs and applications.

Comments welcomed!

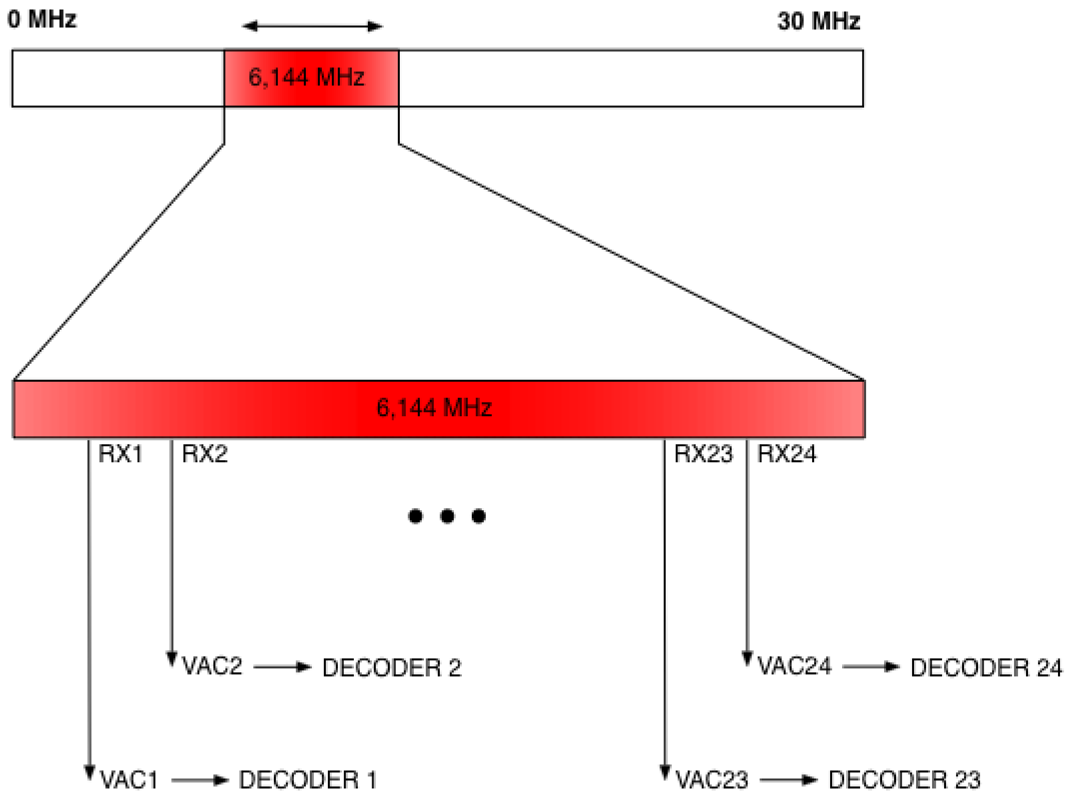
Multi-channel monitoring – a short introduction

Traditional monitoring has been stuck to one channel in real time. Even with recording this channel, it had been difficult to even slightly change some parameter (e.g. pitch or AGC) of a recorded signal as this recording was made after demodulation.

SDRs completely changed this situation, since Pieter Ibelings of RF Space introduced his SDR-14 some ten years ago.

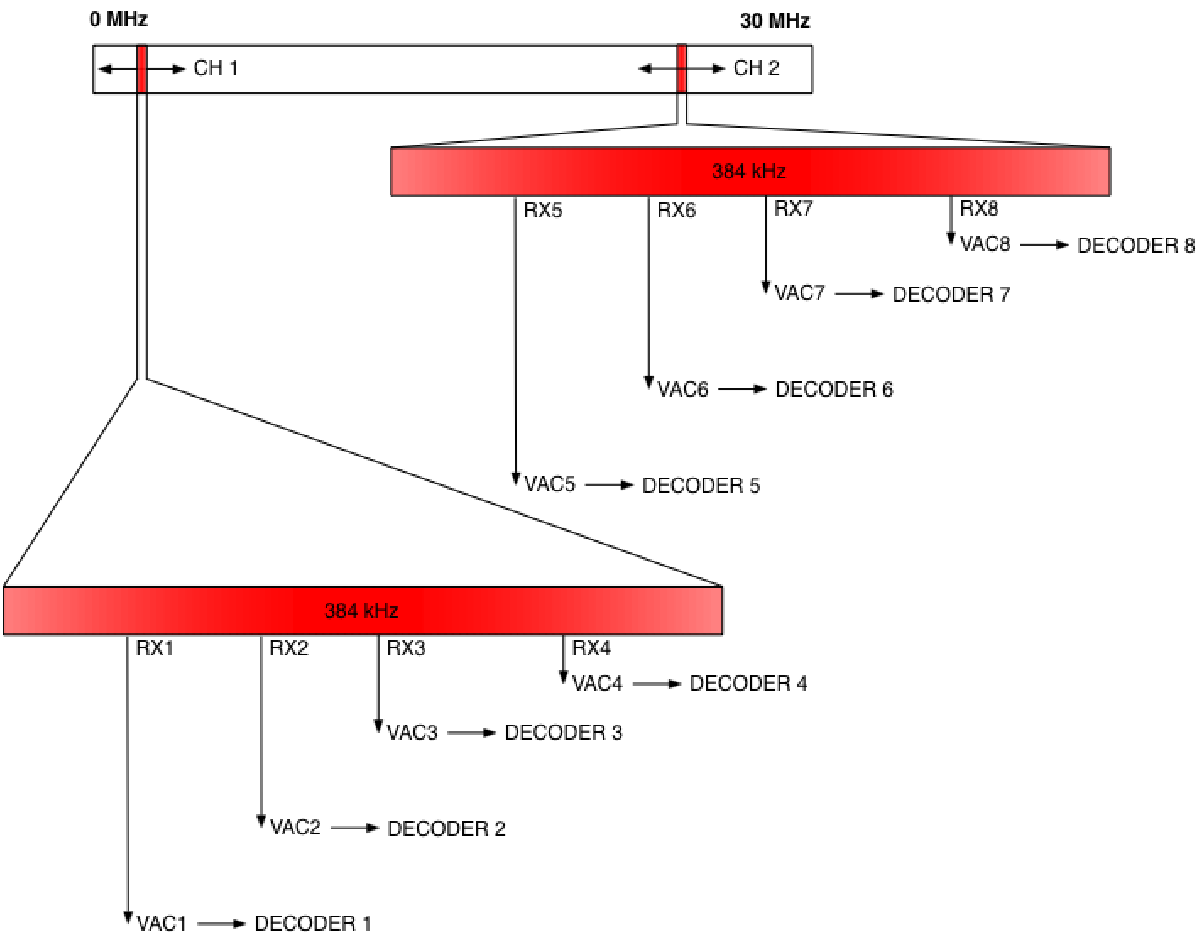
Since then, software has been developed to receive more than one channel in a given HF bandwidth. This concept had trickled down from professional projects like TitanPRO by ENABLIA with its up to 40 channels to even simple SDRs and free software, like SDR-COM V3 (beta).

The illustration below shows such a concept with one FDM-S2 as receiver and 24 decoder outputs (virtual radio) of SDR COM V3 software.



Receiver FDM-S2 features a band of up to 6,144 MHz width, of which nearly 5 MHz are alias-free. This band can be freely tuned within the whole HF range from 0 to 30 MHz. Software SDR COM V3 provides up to 24 demodulators, or virtual channel receivers (VRX), which may be freely placed and configured with e.g. each individual settings of mode, bandwidth and AGC.
For decoding, the input of each demodulator must be fed to a different virtual audio card, or VAC. I am using software VAC for this purpose.
Each VAC output may be used to feed a different decoder input. By this configuration you may decode up to 24 channels within a 5 MHz HF bandwidth in parallel.

ELAD's original software also has a nice and much used approach to multi-channel monitoring. The most interesting feature is to define two channels of each 384 kHz width. Each of these ranges can be independently tuned throughout the complete HF range. You may define four demodulators in each of the two ranges. This will result to 8 virtual radios which will feed VAC1 … VAC8 to feed in turn DECODER1 … DECODER8. Please find an illustration of this concept below. This paper will make use of both methods, software SDR COM V3, as well as Elad's original software [FDM-SW2](FDM-SW2).



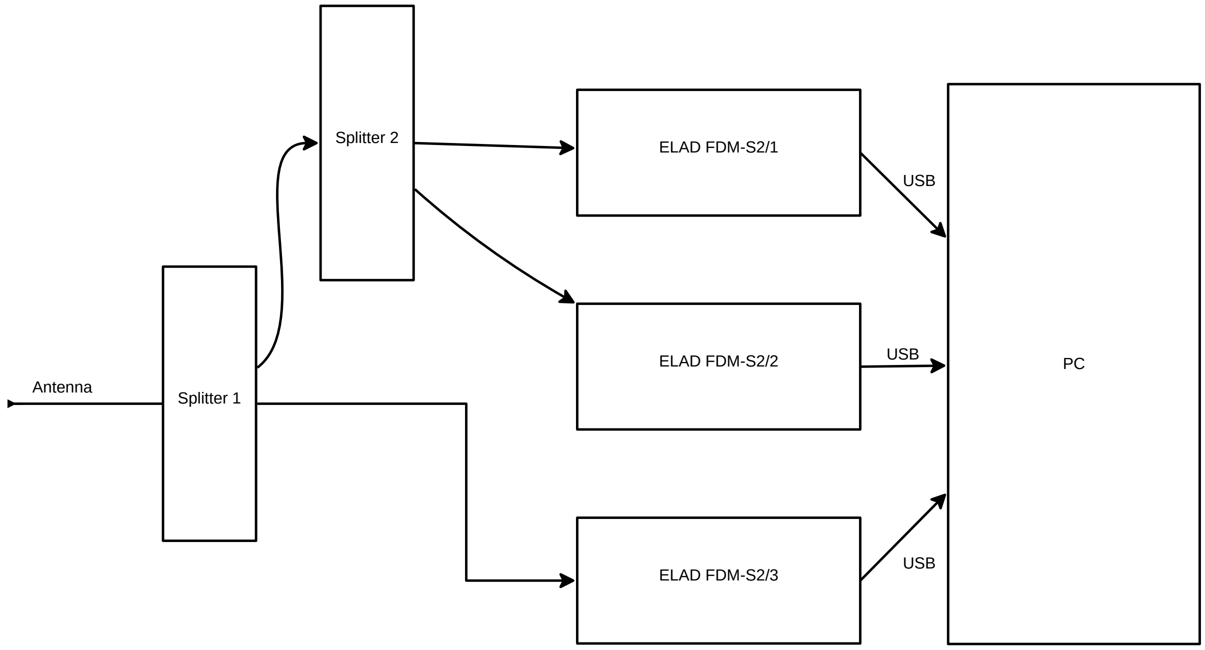
With Elad's software FDM-SW2, you may define up to two ranges of 384 kHz each which may be independently tuned within the whole HF range from 0 to 30 MHz.
Each of the two ranges offers up to four demodulators (RX 1 to RX4, RX to RX8) which may in turn feed DECODER1 … DECODER8 via VAC1 … VAC8.

More HF – more receivers

If you want a wider range of HF, than you either have to use another receiver with a wider range or to connect more than one receiver to your PC. Please observe the resolution of the A/D converter as this is the bottleneck of dynamic range. In my experience, you need 14 to 16 bit resolution for serious HF work. The lower the resolution, the higher the bandwidth at the same speed of the connection between SDR and PC. For instance, HackRFOne delivers nearly 20 MHz bandwidth, but at just 8 bit resolution. I tried this set also on HF (with converter), and it is very delicate to get good copy of weaker signals in congested bands.

Hence, for demanding HF work, I am using a set of 3 x FDM-S2. BTW: This solution is cheaper than a semi-professional communications receiver (like Drake's SPR-4) in the 1970s.

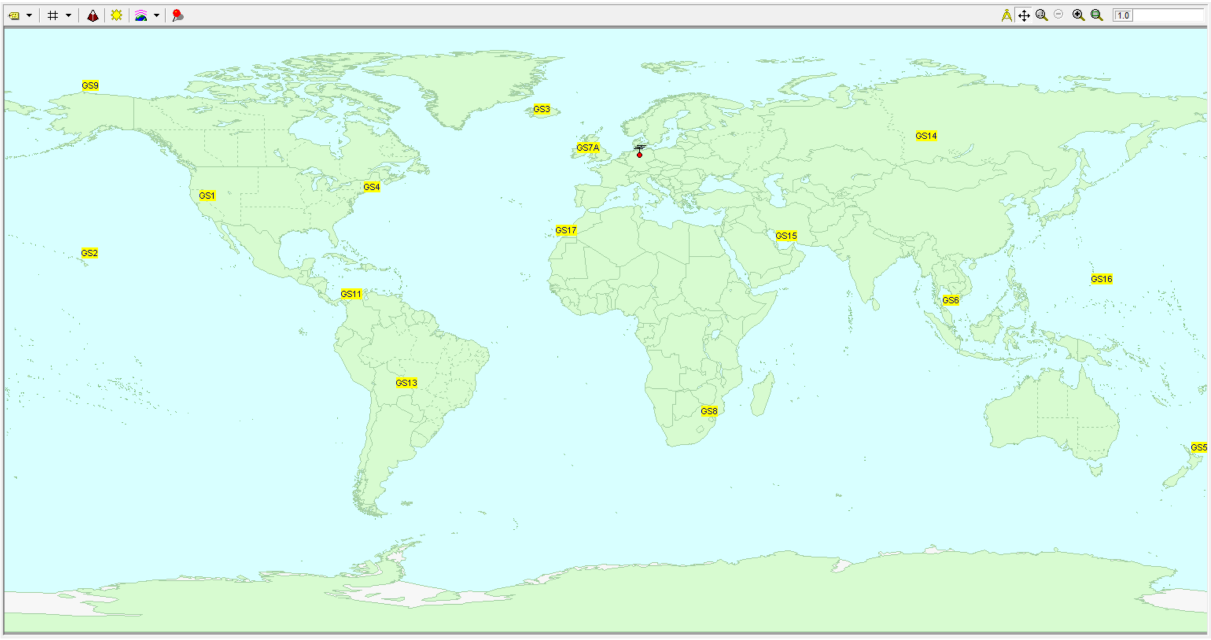
If you have, like me, only one antenna, you have to connect this by splitters. I may recommend these made by Heros, namely the VLF version. With my antenna being a quad loop of 20 m circumference producing some steam, I in practice didn't noted the attenuation of 6 or even 12 dB. It's a good practice to feed the receiver with the highest frequency from the output the lowest attenuation, and vice versa. This would be "ELAD FDM-S2/3" in the illustration below:



Three FDM-S2 will give you up to 3 x 5 MHz bandwidth from one antenna. A bottleneck may be the USB 2.0 connectors at your PC: They must power each receiver, and they have to cope with the 6,144 MHz bandwidth. It works best with a separate USB card for each connector. Try out all USB connectors at your PC, or reduce the bandwidth.

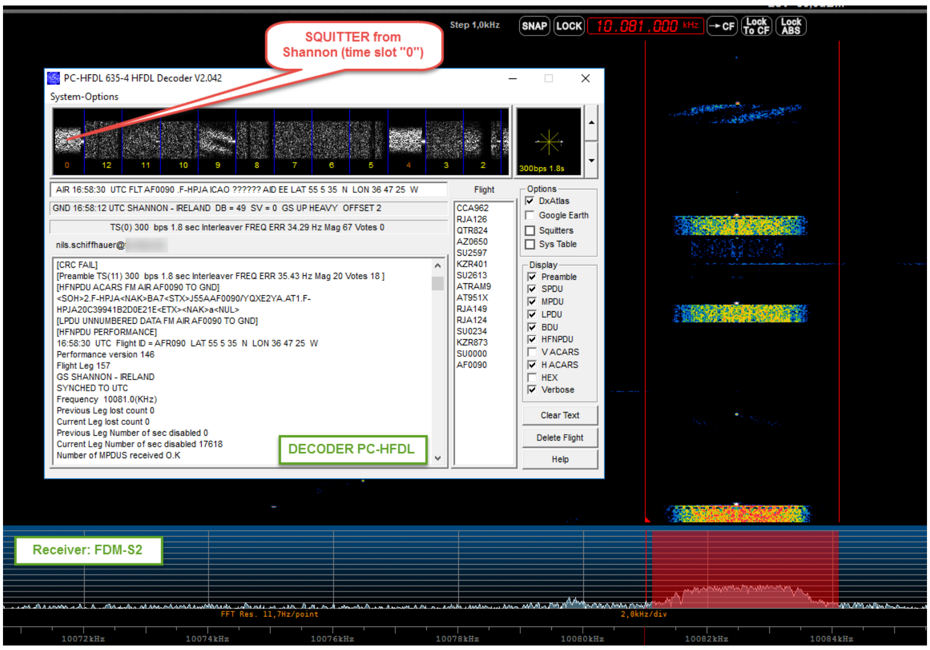
ARINC – Perfect for a Multi-channel Case Study

As already said in the introduction on page 1, ARINC is perfect for a multi-channel approach. You will find an excellent introduction into this system in this PDF. The system comprises of Ground Stations (GS) scattered all over the world:



Software DX Atlas showing all 15 active Ground Stations. The icon "antenna" is my location.

The illustration below shows a typical reception, here on just one channel (Shannon, 10.081 kHz), decoded with PC-HFDL:

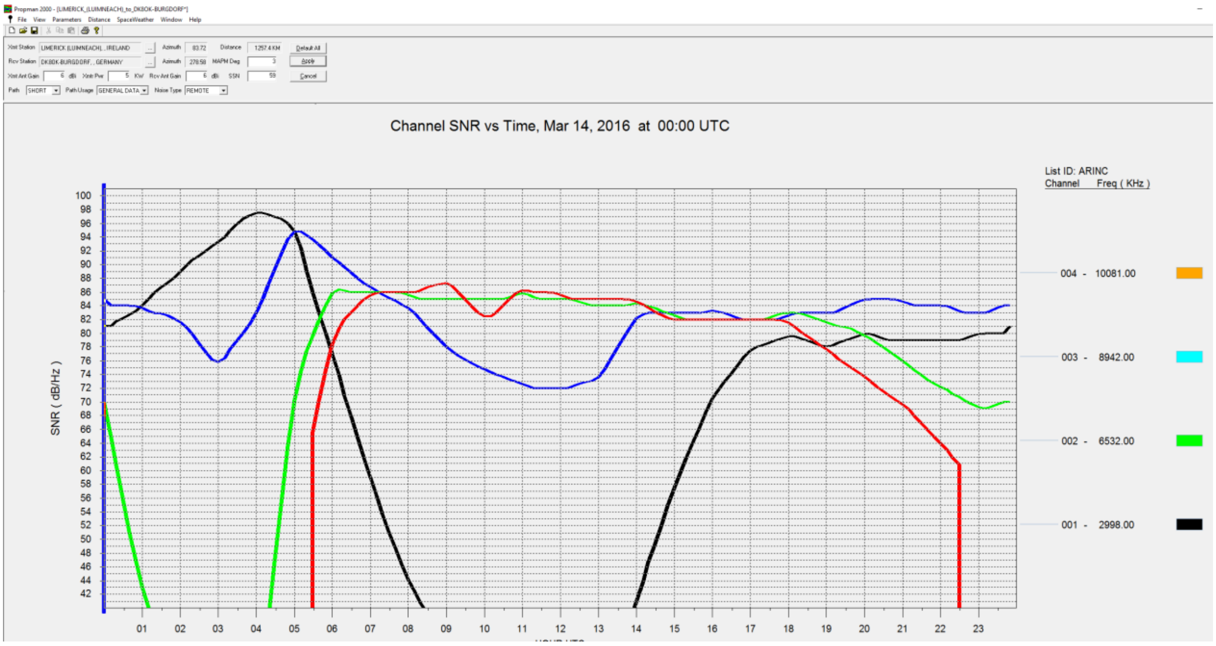


In the foreground you see the window of PC-HFDL, in the background the GUI of the FDM-S2 receiver.

Get all active Frequencies

In the first step, you have to get all active frequencies to set up your equipment like receiver, decoders, VACs …:

- Tune your receiver into ARINC frequencies which is good for (almost) continuous reception over 24 hours. In Europe, a perfect candidate will be Shannon 8.942 kHz which actually is used here:



The blue line shows good reception of Shannon on its 8.942 kHz channel over 24 hours at my location. Even more important: Shannon is also transmitting on this channel over 24 hours! If your favorite stations do change frequency, you have to follow. Software: [PropMan™ 2000 V2](#) by Rockwell Collins.

- Setup *PC-HFDL* for decode on this channel. All data will be saved in the log file folder of this software, split up in files of 24 hours length. Month and date will be set automatically (e.g. a file's name will be "March 14.txt")
- Connect this file to software *PC-HFDL-Launcher*.
- Let the combination collect data for at least 24 hours.
- Then look up the frequencies in *PC-HFDL-Dis*play (Database → Show Freqs used → Load → Radio Utilities/Display Launcher/Reports/FrequsInUse.txt), see illustration below:

Frequencies in use

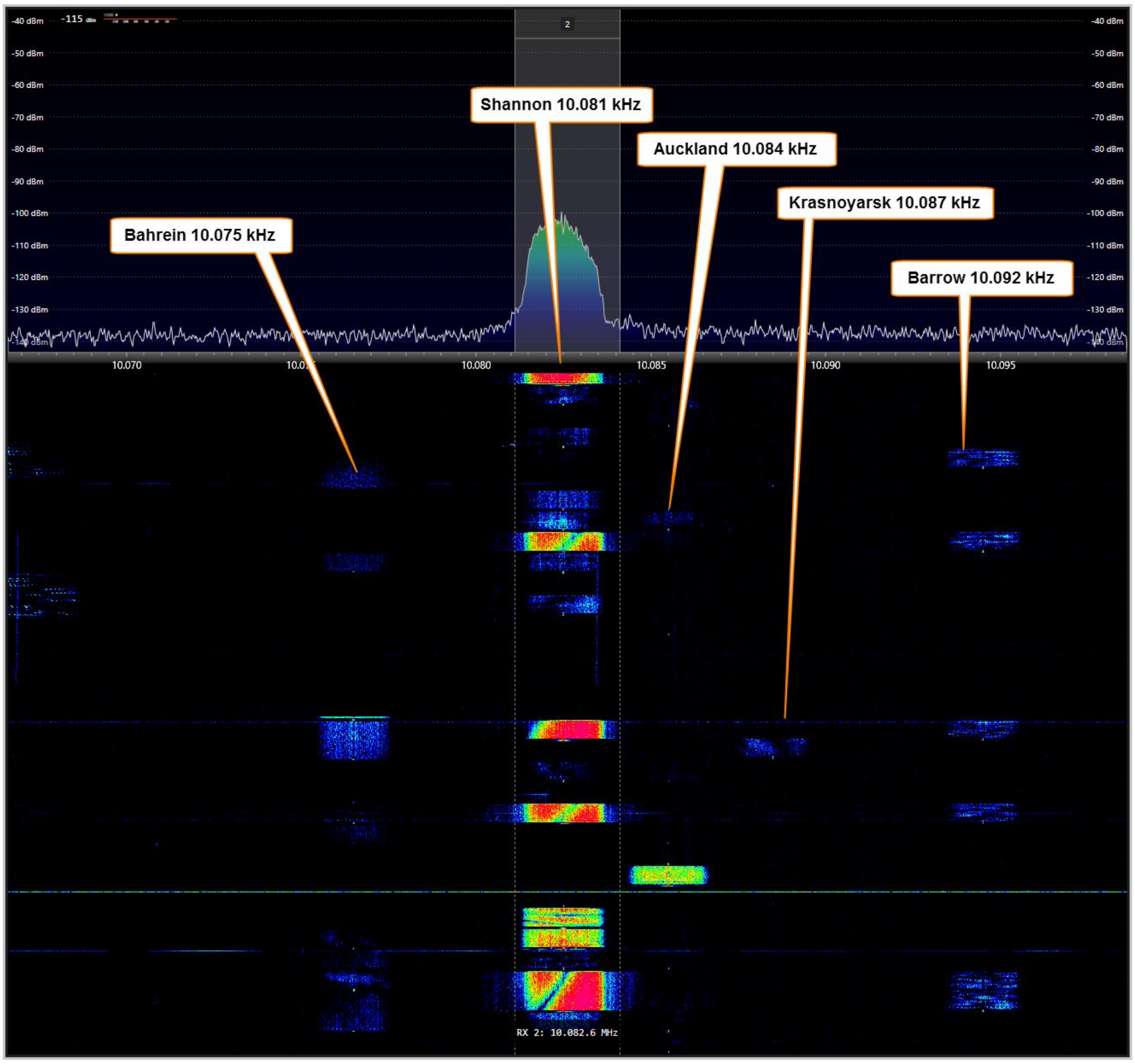
	S.Francisco	Molokai	Reykjavik	Riverhead	Auckland	Hat Yai	Shannon	Jo'burg	Barrow	Albrook	Santa Cruz	Krasnoyarsk	Al Muharraq	Agana	Canarias
201603040000z	21934 13276	21937 17919 13324	17985 11184 8977	21931 11387	13351 10084	13270 5655	10081 8942	11321 4681	10093 5544	17901	21997 11318	8886 5622	10075 8885	11306 8927	17928 13303
201603040100z	21934 13276	21937 17919 13324	17985 11184 8977	21931 11387	13351 10084	13270 5655	10081 8942	11321 4681	10093 5544	17901	21997 11318	8886 5622	10075 8885	11306 8927	17928 13303
201603040200z	21934 13276	21937 17919 13324	17985 11184 8977	21931 11387	13351 10084	13270 5655	10081 8942	11321 4681	10093 5544	17901	21997 11318	8886 5622	10075 8885	11306 8927	17928 13303
201603040300z	21934 13276	21937 17919 13324	17985 11184 8977	21931 11387	13351 10084	13270 5655	10081 8942	11321 4681	10093 5544	17901	21997 11318	8886 5622	10075 8885	11306 8927	17928 13303
201603040400z	21934 13276	21937 17919 13324	17985 11184 8977	21931 11387	13351 10084	13270 5655	10081 8942	11321 4681	10093 5544	17901	21997 11318	8886 5622	10075 8885	11306 8927	17928 13303
201603040500z	21934 13276	21937 17919 13324	17985 11184 8977	21931 11387	13351 10084	13270 5655	10081 8942	11321 4681	10093 5544	17901	21997 11318	8886 5622	10075 8885	11306 8927	17928 13303
201603040600z	21934 13276	21937 17919 13324	17985 11184 8977	21931 11387	13351 10084	13270 5655	10081 8942	11321 4681	10093 5544	17901	21997 11318	8886 5622	10075 8885	11306 8927	17928 13303
201603040700z	10081 6559	11312 10027 8936	8977 5720 3900	8912 6661	17916 10084	13270 6535	8942 2998	21949 11321	10093 5544	8894	13315 11318	21990 17912	17967 10075	21928 17919	11348 6529
201603040800z	10081 6559	11312 10027 8936	8977 5720 3900	6661 5652	17916 10084	13270 6535	8942 6532	21949 11321	10093 5544	8894	13315 11318	21990 17912	21982 17967	21928 17919	8948 6529
201603040900z	10081 6559	11312 10027 8936	8977 5720 3900	6661 5652	17916 10084	13270 6535	8942 6532	21949 11321	10093 5544	6589	13315 11318	21990 17912	21982 17967	21928 17919	17928 8948
201603041000z	6559 5508	11312 10027 8936	11184 6712 5720	6661 5652	17916 10084	13270 6535	10081 8942	21949 11321	10093 5544	5589	13315 11318	17912 10087	21982 17967	21928 17919	21955 13303
201603041100z	6559 5508	11312 10027 8936	11184 8977 6712	6661 5652	13351 10084	13270 6535	10081 8942	21949 11321	10093 5544	5589	13315 11318	17912 10087	21982 17967	21928 17919	21955 13303
201603041200z	6559 5508	11312 10027 8936	11184 8977 6712	6661 5652	13351 10084	13270 6535	10081 8942	21949 11321	10093 5544	5589	21997 11318	17912 10087	21982 17967	21928 17919	21955 13303
201603041300z	6559 5508	10027 8936 6565	17985 11184 8977	11387 6661	13351 10084	13270 6535	10081 8942	21949 11321	10093 5544	8894	21997 11318	17912 10087	21982 17967	21928 17919	21955 13303
201603041400z	6559 5508	10027 8936 6565	17985 11184 8977	13276 8912	13351 10084	13270 6535	10081 8942	21949 11321	10093 5544	10063	21997 11318	13321 8886	21982 17967	21928 17919	21955 13303

Load Save Exit

Part of the table "Frequencies in use"

Frequency clusters

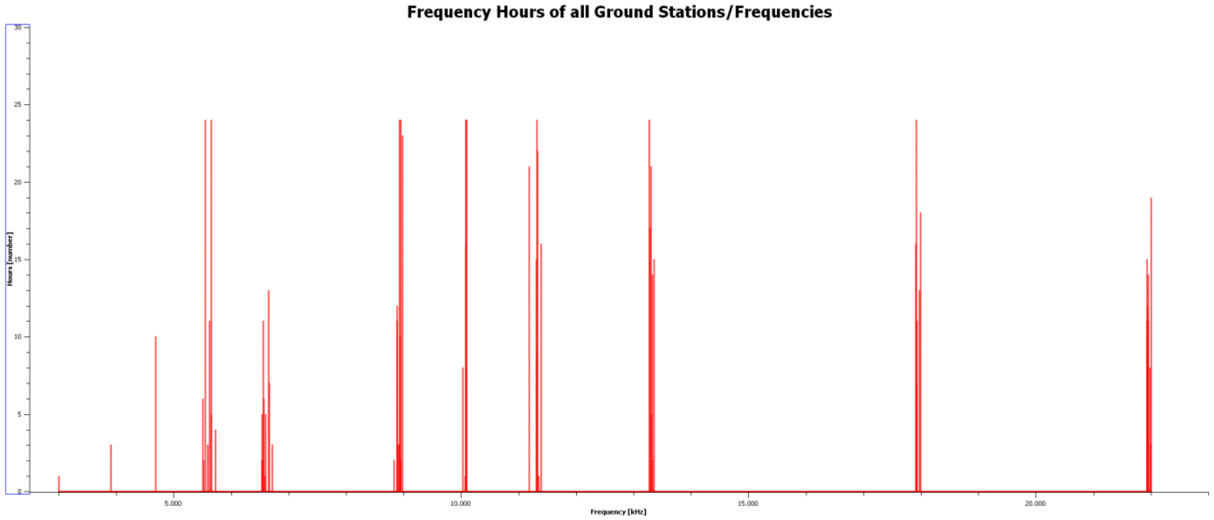
As you soon will realize, ARINC stations are organized in clusters, see below a screenshot around 10.081 kHz:



Within a small frequency span, you often find a couple of different ARINC stations. You will hear each ground station each 32 seconds with the other eleven time slots reserved for the planes calling with frames of 1,8 seconds of 4,2 seconds length.

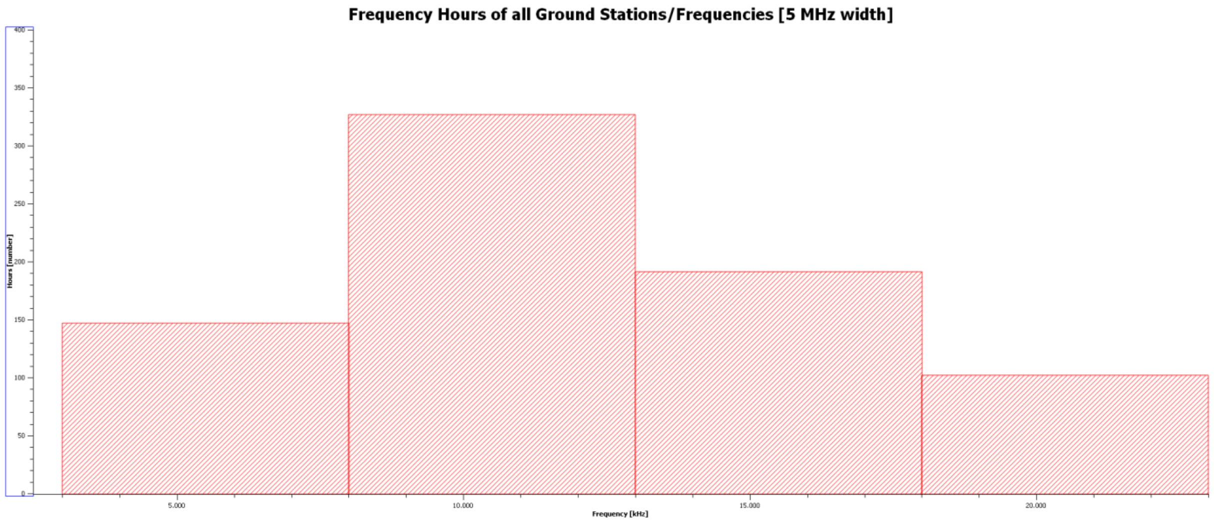
These clusters play an important role in setting up an efficient monitoring plan. For this you have to optimize the decoded frequency hours, i.e. to get the most out of the limits of your hardware.

“Frequency hours” simply means: how many hours is one channel being occupied. The following illustration gives quite an impression of clusters as well as of frequency hours:

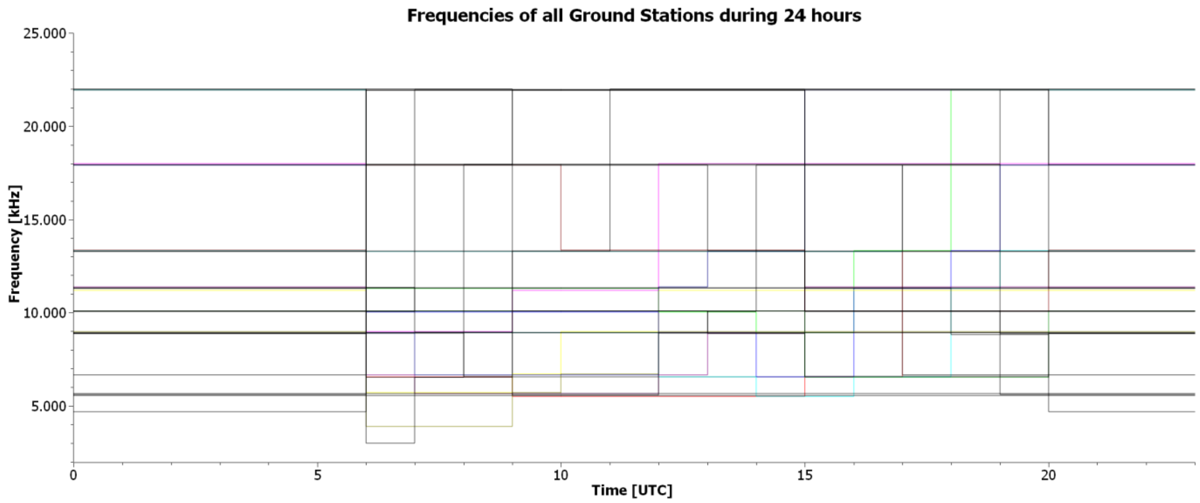


In this illustration, you see seven clusters with a high number of frequency hours, one with a lower number plus three discrete frequencies with a (very) low number of frequency hours.

If you have four receivers of 5 MHz bandwidth each, this will cover *all* channels (see below):



The illustration below shows how long each stations stays on each frequency during 24 hours:



Monitoring Plan

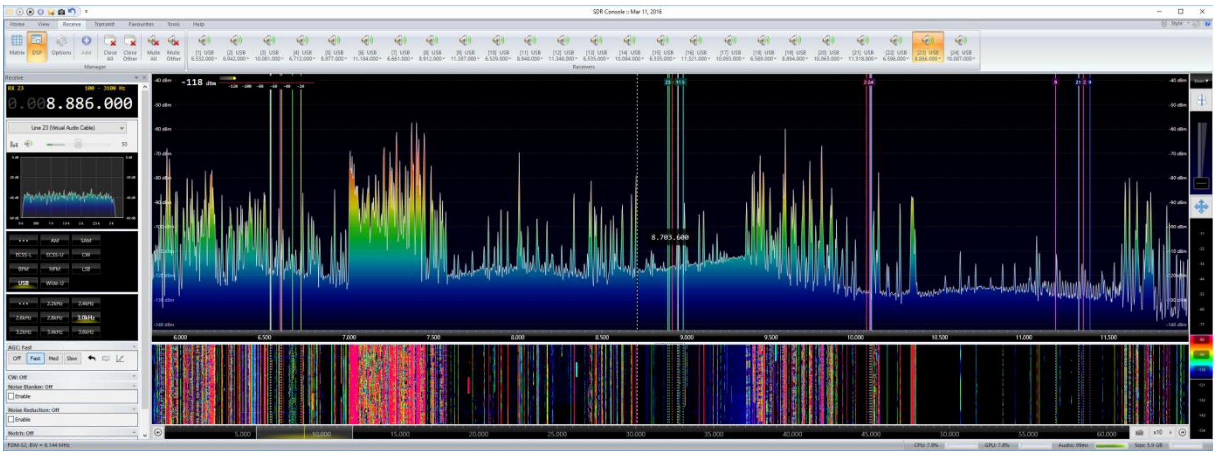
Set up your monitoring plan accordingly. It should contain receiver (RX) number, software being used, center frequency (CF), Ground Stations, virtual audio cable output (VAC), and frequency. Believe me: You get lost without such red tape:

RX	Software	Width	CF	GS	VAC	Frequency [kHz]
1	V3	5 MHz	8900	**Shannon**	1	6532
				Shannon	2	8942
				Shannon	3	10081
				Reykjavik	4	6712
				Reykjavik	5	8977
				Reykjavik	6	11184
				Riverhead	7	6661
				Riverhead	8	8912
				Riverhead	9	11387
				Canarias	10	6529
				Canarias	11	8948
				Canarias	12	11348
				Auckland	13	6535
				Auckland	14	10084
				Hat Yai	15	6535
				Johannesburg	16	11321
				Barrow	17	10093
				Albrook	18	6589
				Albrook	19	8894
				Albrook	20	10063
				Santa Cruz	21	11318
				Krasnoyarsk	22	6596
				Krasnoyarsk	23	8886
				Krasnoyarsk	24	10087
2	V3	5 MHz	19950	**Riverhead**	25	21931
				Canarias	26	21955
				Santa Cruz	27	21997
				Johannesburg	28	21949
				Reykjavik	29	17985
				Albrook	30	17901
				Canarias	31	17928
				Bahrein	32	17967
3	FDM-CH1	350 kHz	13300	**Riverhead**	37	13276
				Canarias	34	13303
	FDM-CH2	350 kHz	5700	**Reykjavik**	41	5720
				Riverhead	46	5652

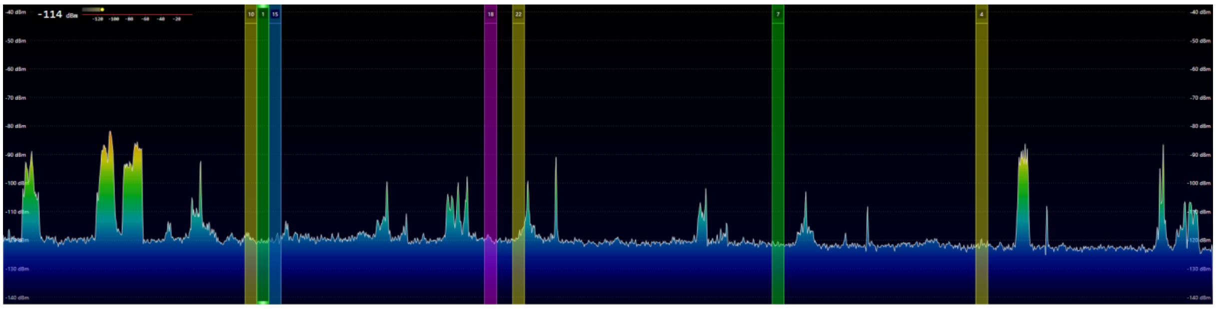
Monitoring plan with 36 channels set up with a focus on strong(er) signals.

Setup Receiver and Software

As you see from the preceding page, I used two receivers with 5 MHz bandwidth each plus one receiver covering 2 x 384 kHz. First I set up the 24 channels in a 5 MHz bandwidth, using software SDR COM V3, and see below:



Here 24 channels had been tuned to their frequencies from the Monitoring Plan of the preceding page, each set to USB at 3,0 kHz bandwidth and AGC fast for not be deafened by a strong signal. Each virtual receiver VRX is feeding a different virtual audio cable VAC.



A cluster around 6,6 MHz had been zoomed to show how densely clusters are populated.

The second receiver is also used with one 5 MHz HF bandwidth, covering the higher channels, thus centered on 19.950 kHz.

To cover also the ranges around 13,3 MHz and 5,7 MHz, the third receiver had been set to 2 x 384 bandwidth, using the original software FDM-SW2 in its two-channel mode according to its manual.

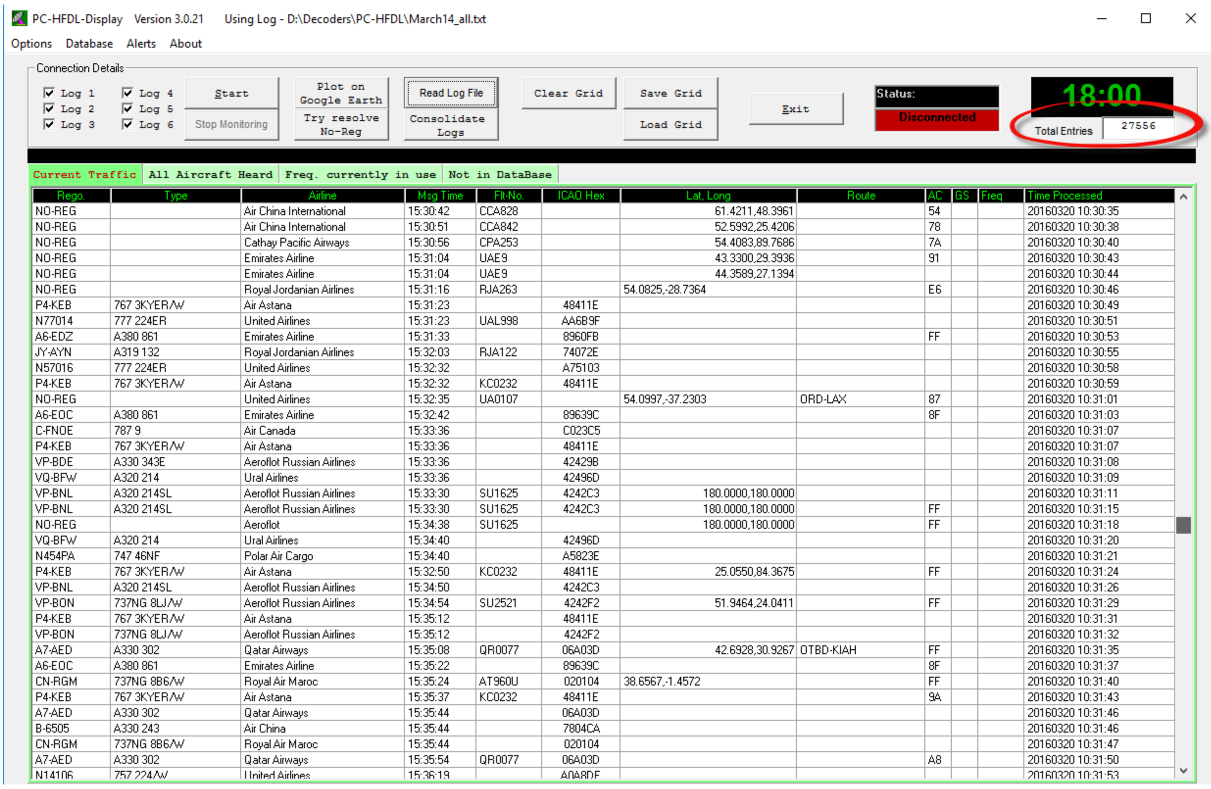
That's for the receiving part. Now for decoding:
This is done with 35 instances of PC-HFDL software:

- Copy the software package PC-HFDL in 35 separate folders, named PC-HFDL1 … PC-HFDL35
- Open each folder, locate the .exe file, and rename it according to the folder, e.g. PC-HFDL32.
- Open each instance PC-HFDL1 … PC-HFDL35 one after another and choose the appropriate VAC as input – PC-HFDL1 to VAC1, PC-HFDL2 to VAC2 … PC-HFDL-35 to VAC35. (As FDM-SW2 software presents you with just a choice of all VACs, you may follow a slightly different strategy, as reflected also in this example at receiver #3.) You have to this only once.
- Start each decoder, and also decoding from the designated VAC input will start. All data is written into the Log files folder within the appropriate folder of each PC-HFDL instance.

Harvesting the Logs

After such a session, you have as many Log files .txt files as frequencies with decoded signals. Of course, you may start software PC-HFDL-Display during live reception with the main up to six channels. This will give you a real time impression on conditions and activity. But to get the big picture, you may put all Log files into one .txt file to feed the software with some real beef: The combined files of the 24 hours on March 14th, 2016, piled up to a file of 30,7 MB of pure, raw .txt.

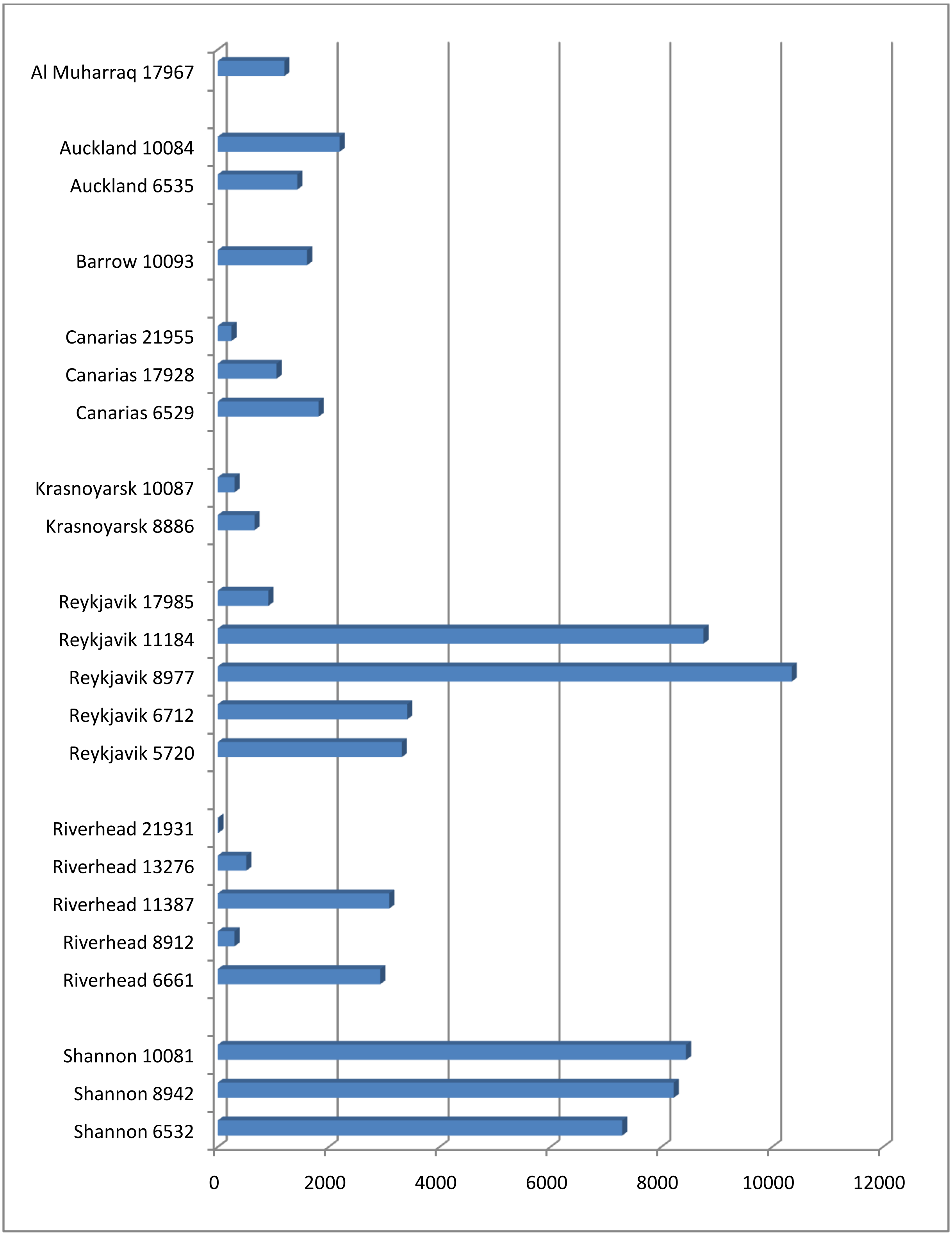
With such a file, PC-HFDL-Display has a lot to do stripping the relevant information from these we don't need in this case. It may take some hours. Your patience is rewarded with a perfect view on all decoded messages – see illustration below:



Analyzing the Logs

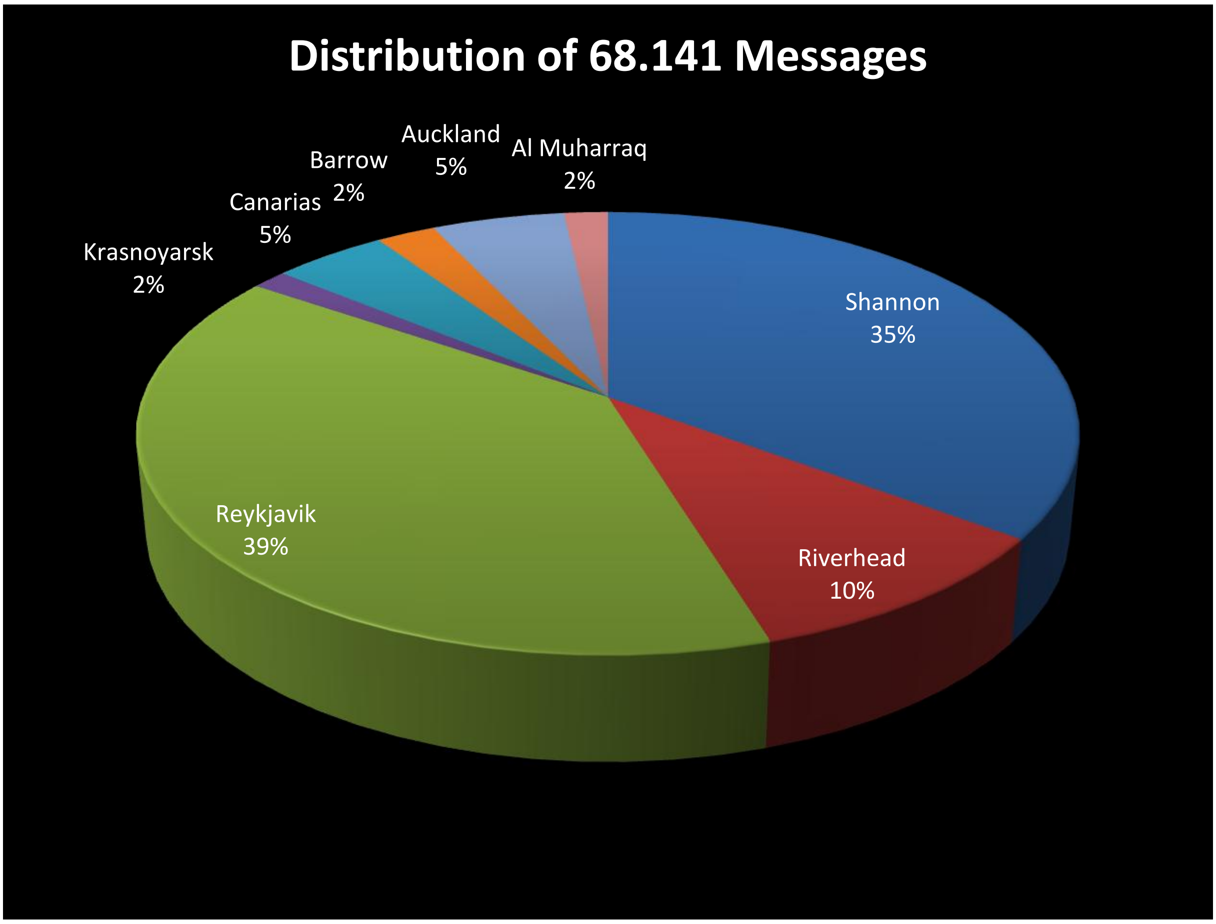
If you have a couple of log, you may apply some interesting statistics on these data; some examples:

Below you see an overview of the distribution of most of all 68.141 logs. At only little surprise, the number of logs from Reykjavik and Shannon (one hop from my location) are prevailing:



Number of logs (ground & airborne) vs. locations/areas.

Below all channels of each station have been summed up and given in percent of all 68.141 logs:

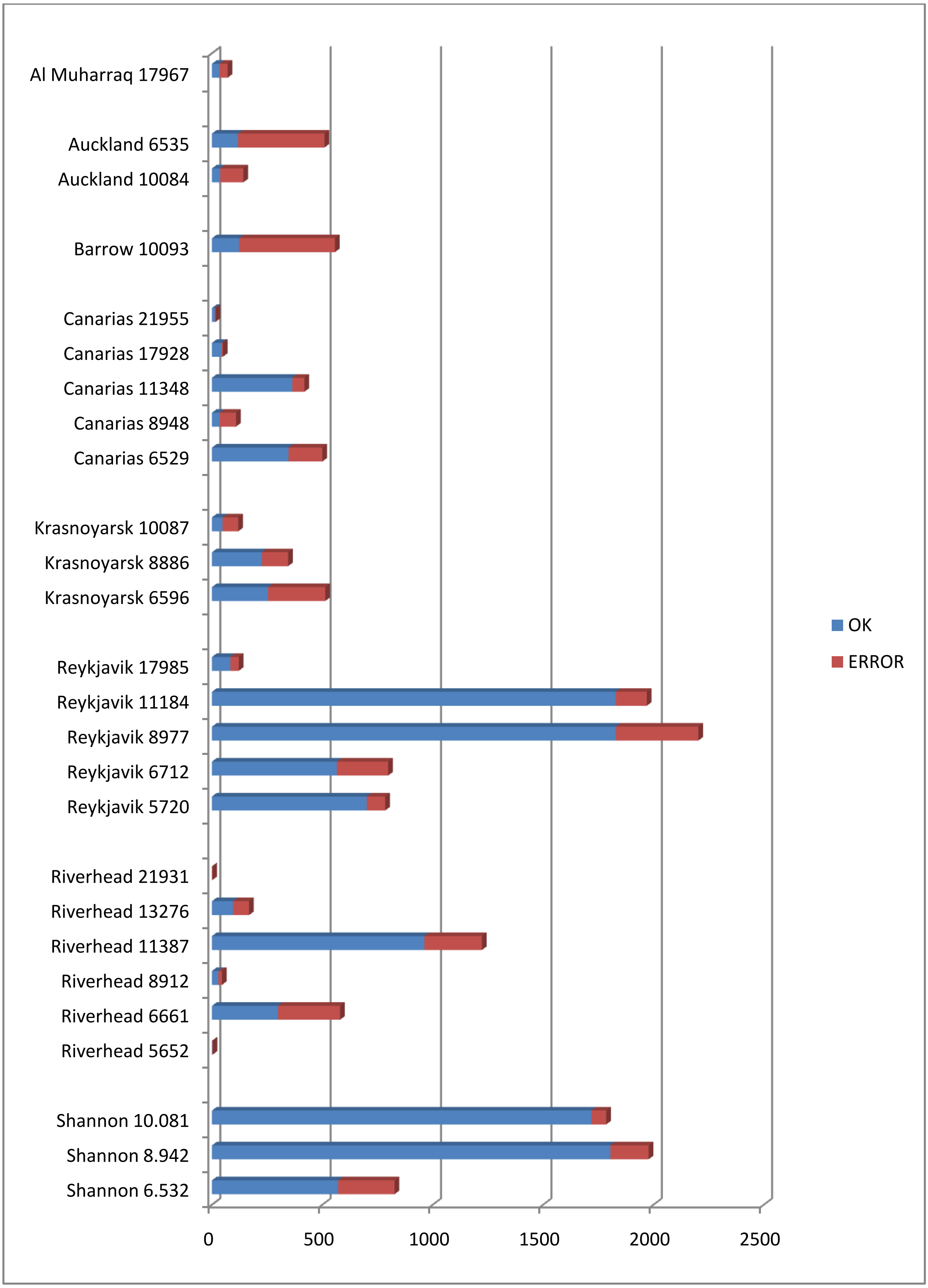


If you want to judge on the *reliability of a given path vs. frequency*, you have refer to the so-called Squitters as only they originate from the Ground Stations.

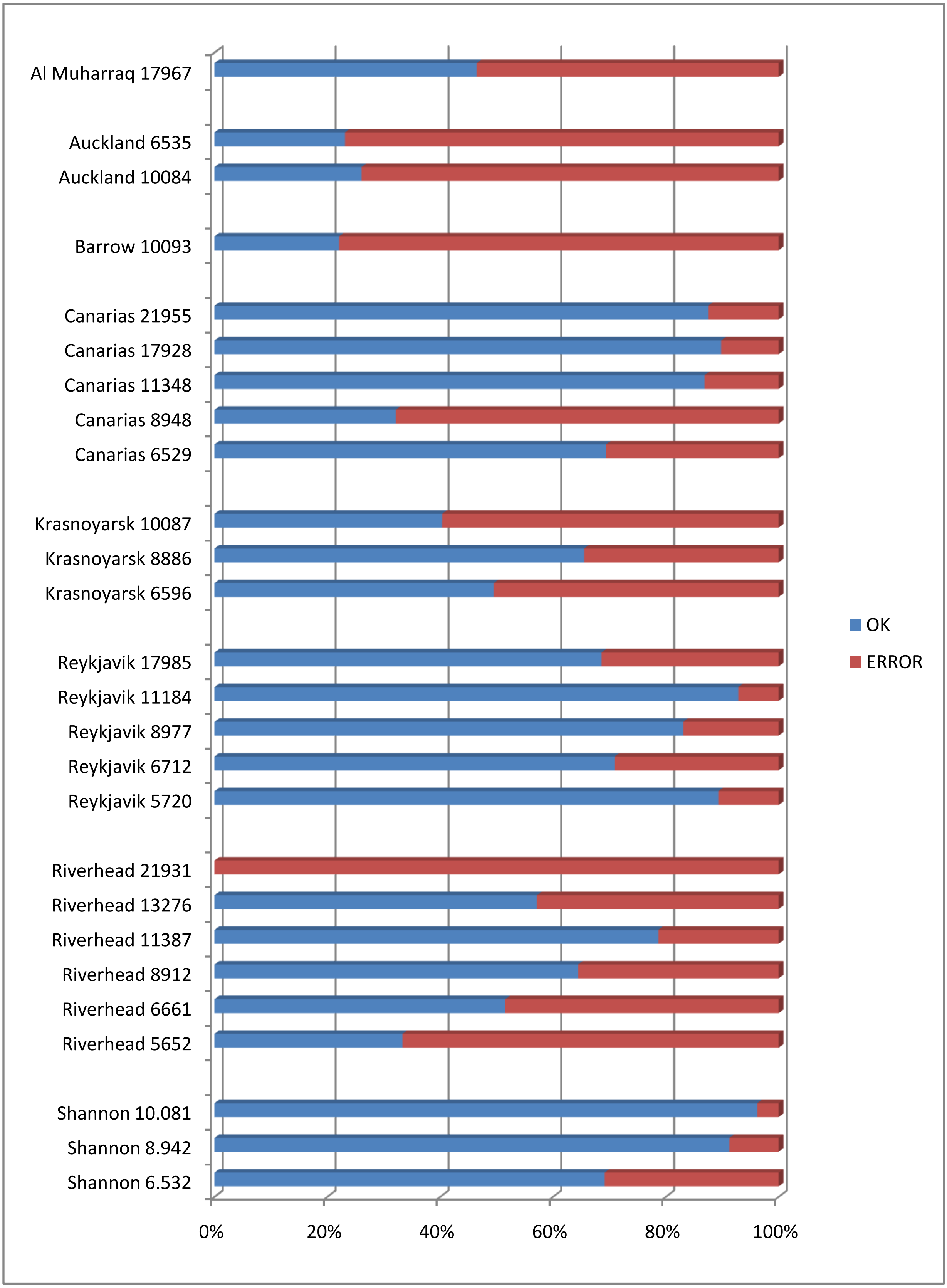
This has been done in two consecutive diagrams: first in absolute figures, second in percent.

These figures reflect ionospheres' conditions as well as operating time/frequency of the Ground Stations from just a DX perspective at the path Ground Station → My Location, but not from the perspective of a plane.

The overall reliability of this system itself is nearly 100%. But the reception of e.g. Ground Station Barrow/Alaska on 10.093 kHz was marginal in Germany at this day and with my equipment.

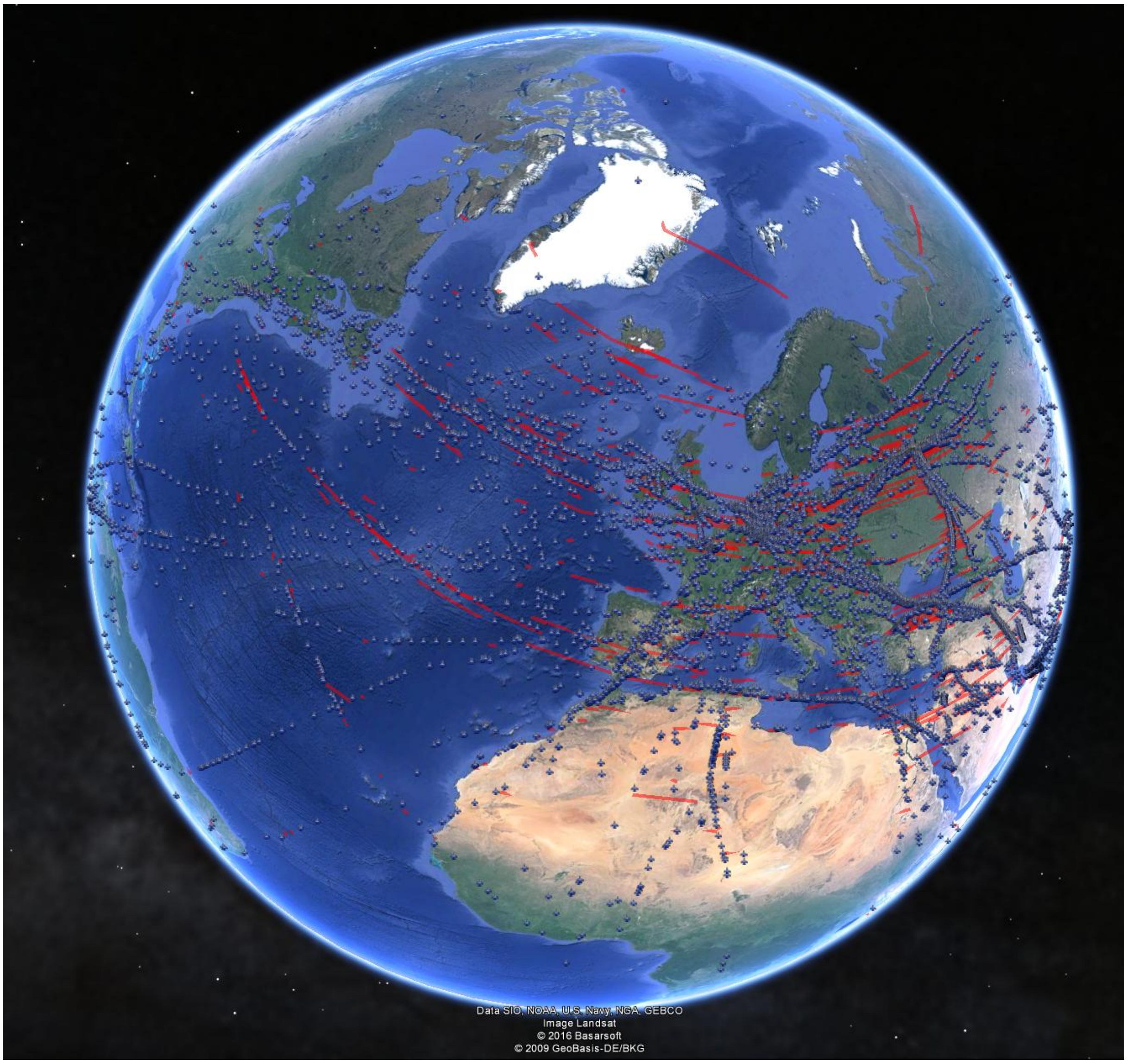


Squitters, absolute figures …

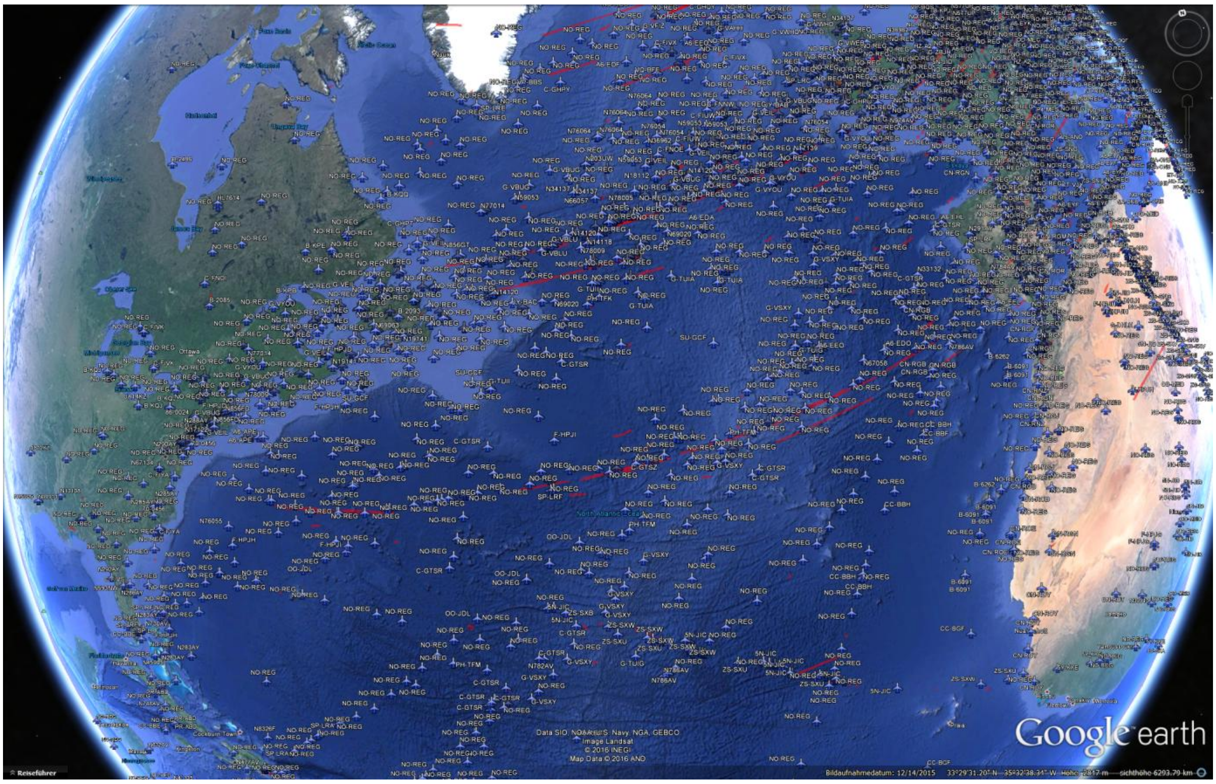


Squitters, relative figures. From comparing both figures, you easily see e.g. that “Shannon 10.081 kHz” provides the best reliability, plus a considerable number (1.700+) of Squitters

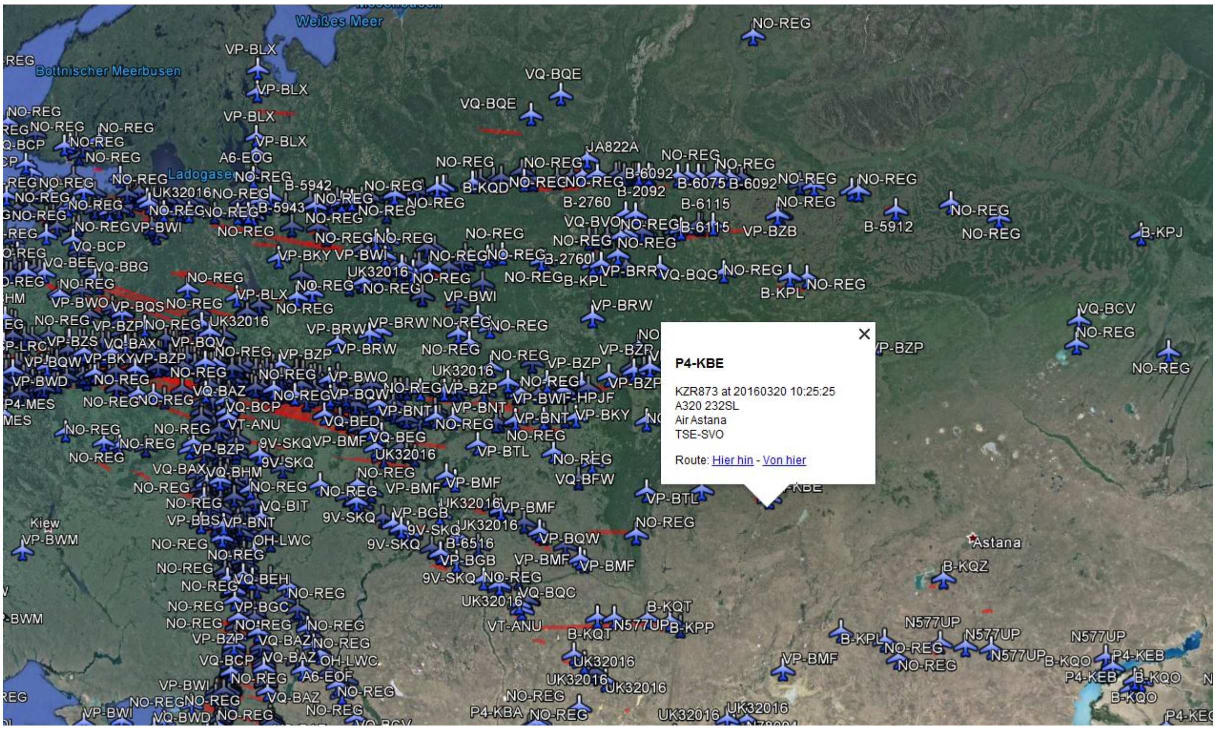
The three screenshots following are using a stunning feature of PC-HF-Display: projecting all planes which had given their geographical coordinates onto Google Earth:



This screenshot shows Europe, plus part of the North Atlantic and Africa. You clearly see the routes like streets in the air.



This screenshot focuses on the airways across North and South Atlantic.



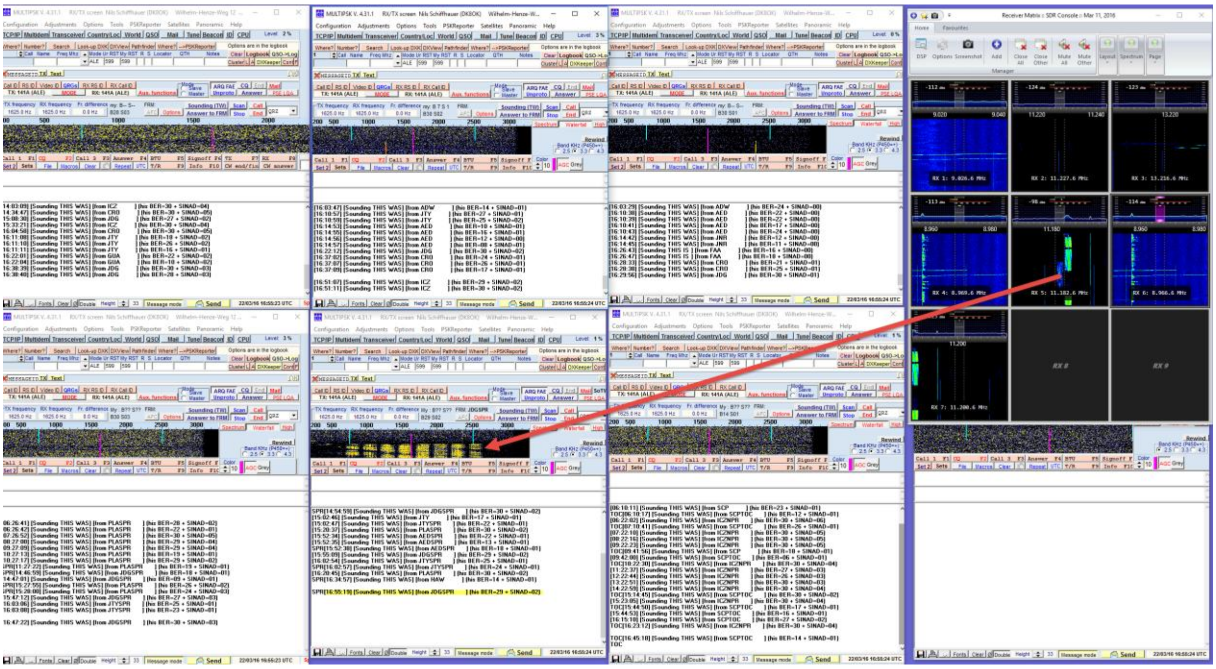
You may click onto each icon to reveal the data behind. Here I clicked onto a flight from Astana Airport/Kazakhstan to Moscow Sheremetyevo Airport (SVO).

Some other Examples

The same technique of multi-channel monitoring, as it has been shown on the preceding pages, may be also applied to other scenarios. Just some examples:

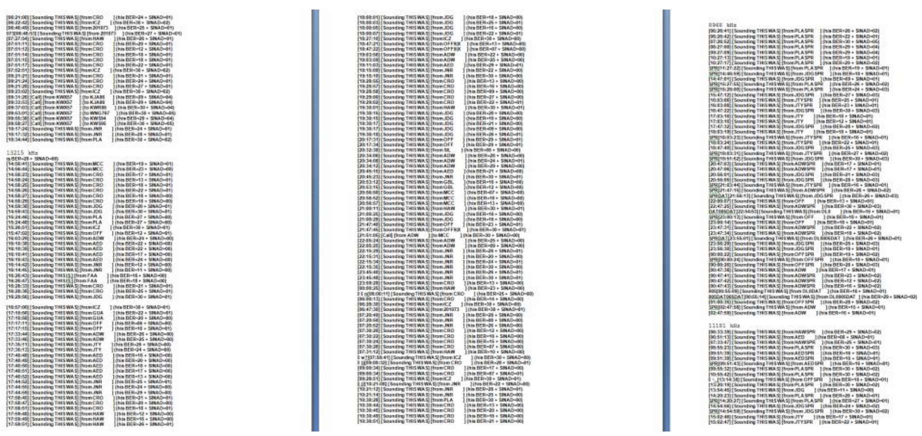
MIL-STD 188-144A [ALE]

Also this mode is an excellent candidate for monitoring: There are many channels with regular activity, e.g. all 30 minutes or all 6 hours … Please find below an example of some seven channels of the USAF net. I used MultiPSK as decoder as this software is very good on even weak signal and measure SINAD as well as BER for further analyzing. This software may be also opened many times (multi-instance). Each instance has to be assigned to a different VAC input.



Seven channels in action: In the "Matrix" (upper right) of software SDR COM 3.0, the channels had been arranged to correspond with the positions of the decoder windows – multi-instances of MultiPSK. In this screenshot, I just received a signal von 11.181 kHz from USAF Diego Garcia/Chagos Island, British Indian Ocean Territory. Other stations received from Guam (GUA), Yokota/Japan (JTY), Elmendorf/Alaska (AED), Ascension Island (HAW), Andrews/USA (ADW), Lajes/Acores (PLA), Puerto Rico (JNR), Croughton/UK (CRO), Sigonella/Italy (ICZ) and Camp Bondsteel/Kosovo (SCPTOC).

Having collected all logs for e.g. a period of 24 hours, you may also apply some statistics on these as demonstrated with ARINC – see below a part of the combined log:

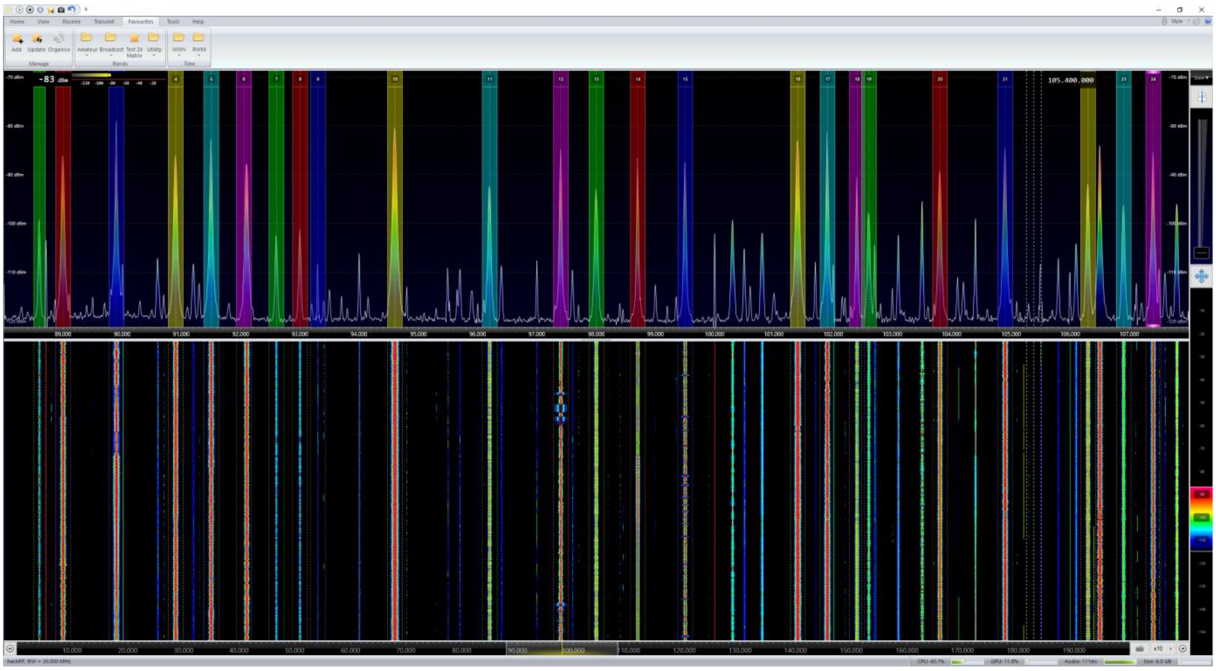


FM-Broadcast: 24 Radio Stations within 20 MHz

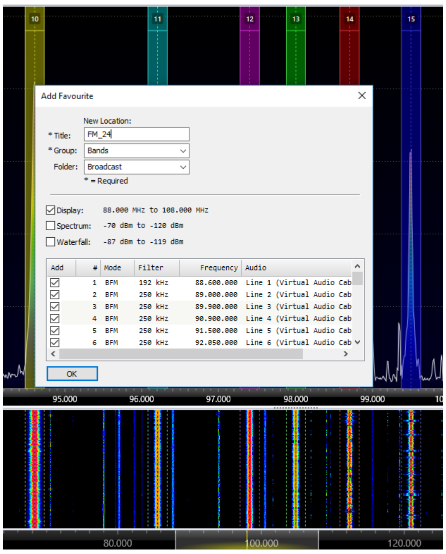
You want to monitor 24 different FM radio stations at once? It's also easy with this budget setup:

- HackRF ONE provides you with 20 MHz width (at 8 bit resolution, giving a nice quality even in congested Western Europe)
- MCRS for recording up to 32 channels/audio. Each recording retains the original recording time (meta data): When playing record for record with their integrated player, you see the running recording time!
- Audacity as an alternative player.

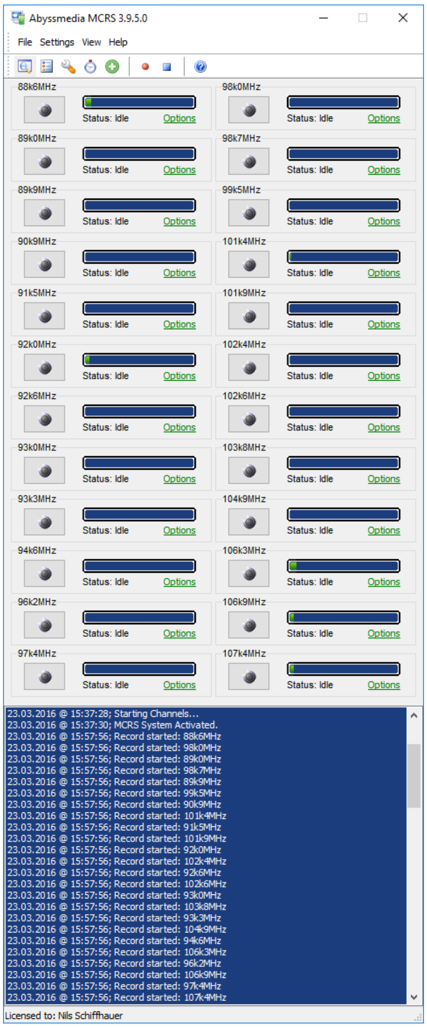
First tune into the FM band at 20 MHz bandwidth, centre frequency 98 MHz. Then place your virtual receivers VRX1 … VRX24 with their output to VAC1 …VAC24, respectively; see illustrations below.



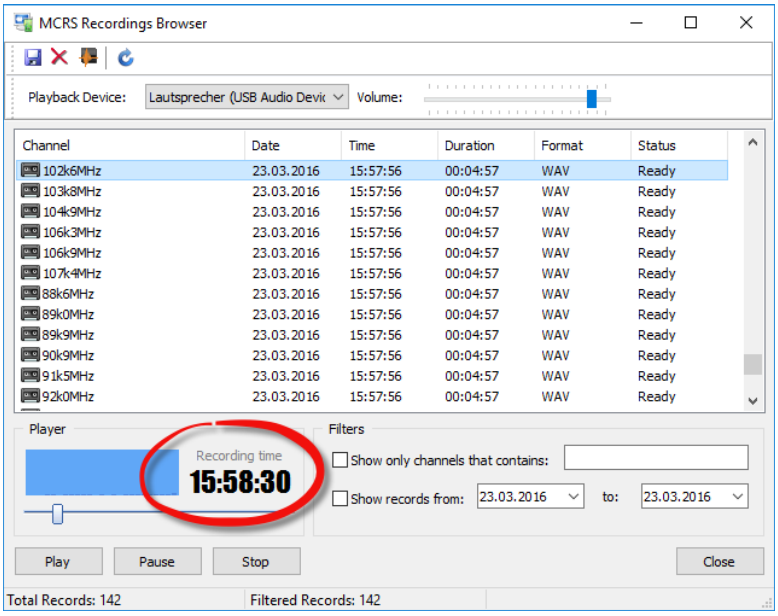
This is the complete broadcast FM band, as seen in the vicinity of Hanover/Northern Germany. Here all 24 available virtual receivers VRX1 … VRX24 had been set.



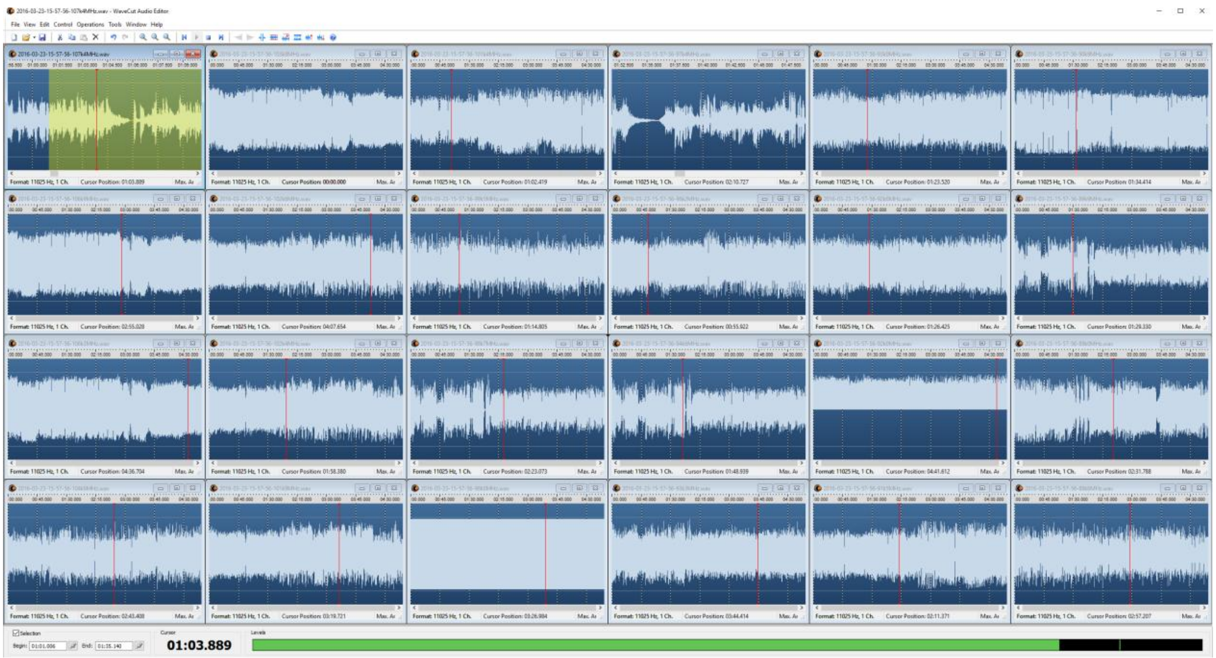
This screenshot shows how VAC1 … VAC24 are designated to VRX1 … VRX24.



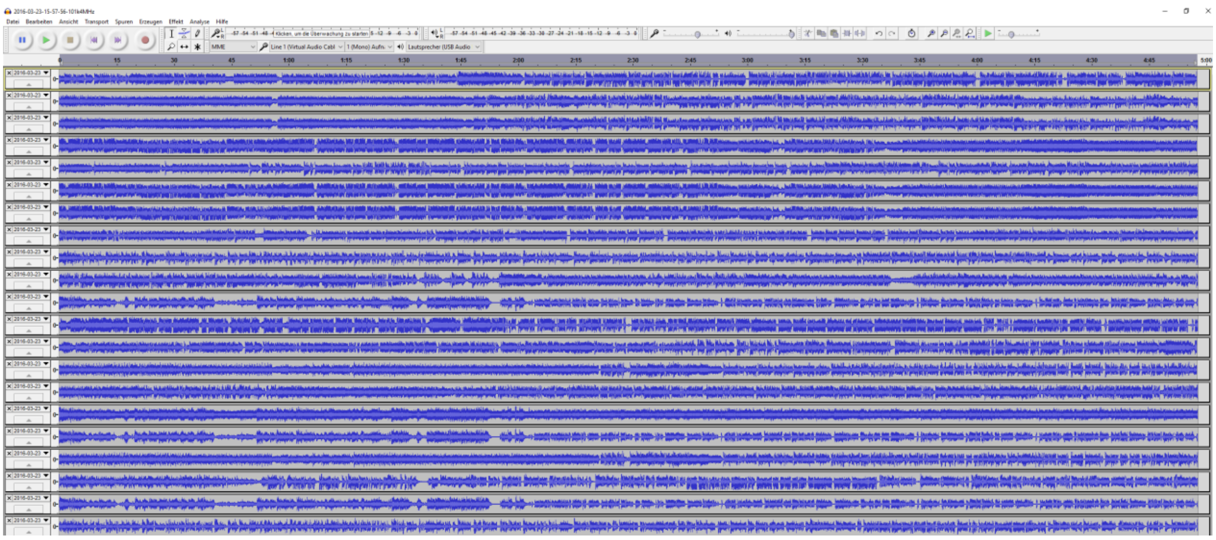
Multi-channel recorder MCRS system has been prepared to record VRX1 … VRX24 via VAC1 … VAC24.



After recording each of the 24 audio clips show their original recording time when played with MCRS Recordings Browser.



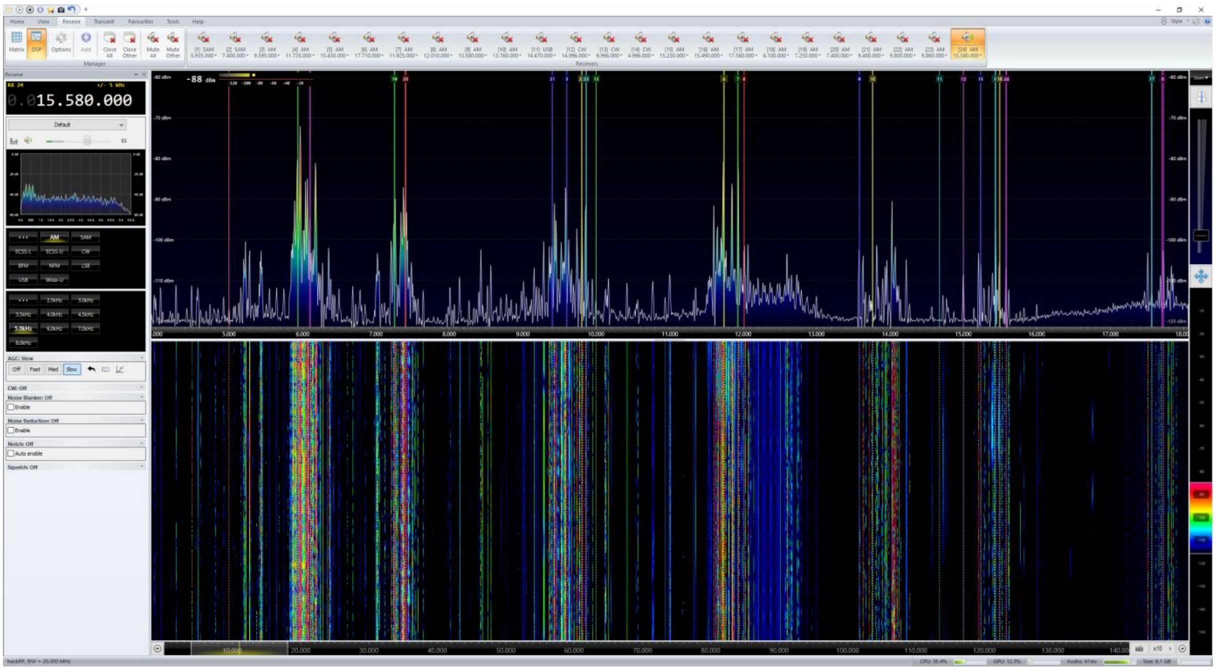
MCRS option Wave Cut Audio Editor then provides you with these 24 windows.



This is a view of some recordings in Audacity.

Some hints:

- If you have identified the stations on each channel, you may re-name part of the file name before the next recording (e.g. instead of “96k2MHz” this part should be named “NDRII_Hannover”).
- Professional radio monitoring should make use of the scheduler of MCRS software.
- To receive and demodulate 24 FM channels of 250 kHz bandwidth each calls for an able PC.
- With the 125 MHz Up converter for the HackRF One SDR, you get also access to HF, see next page for an example.



This is a view onto HF shortwave with RFHack One plus its Up converter. You clearly see the strong signals from the various international broadcasters from 49 meter (left) to 16 meter (right). I was just listening to Voice of America on 15.580 kHz in AM. 23 other virtual radios had been activated throughout the band, some in different modes (e.g. Russian Time Signal station RWM on 4.996 kHz, 9.996 kHz and 14.996 kHz in CW) and bandwidth.
Please keep in mind that you may also record each channel. That gives you the opportunity to check e.g. each broadcast channel in each international broadcast band in parallel. It's great for serious monitoring of news, programs or just doing some investigation into channel occupation over an incredibly wide range.

Amateur Radio – just some ideas

You may also use SDR COM V3's 24 channels for amateur radio. It's ideal for data reception/decoding on fixed channels, e.g. monitoring the NCDXF Beacon Network with FAROS software on 14.100 kHz plus monitoring WSJT around 10.138 kHz. You may monitor the amateur ALE network; park some VRX on SSTV channels or on channels for digital voice – all in parallel.

I tested much more innovative ideas in this field. Up to now my impression is that hams are not that much interested in state-of-the-art technology. If I have sound indicators for a change of this pitiful situation, I am pleased to come back to this topic in more detail.