Aero: Monitoring and Analyzing HFDL Messages

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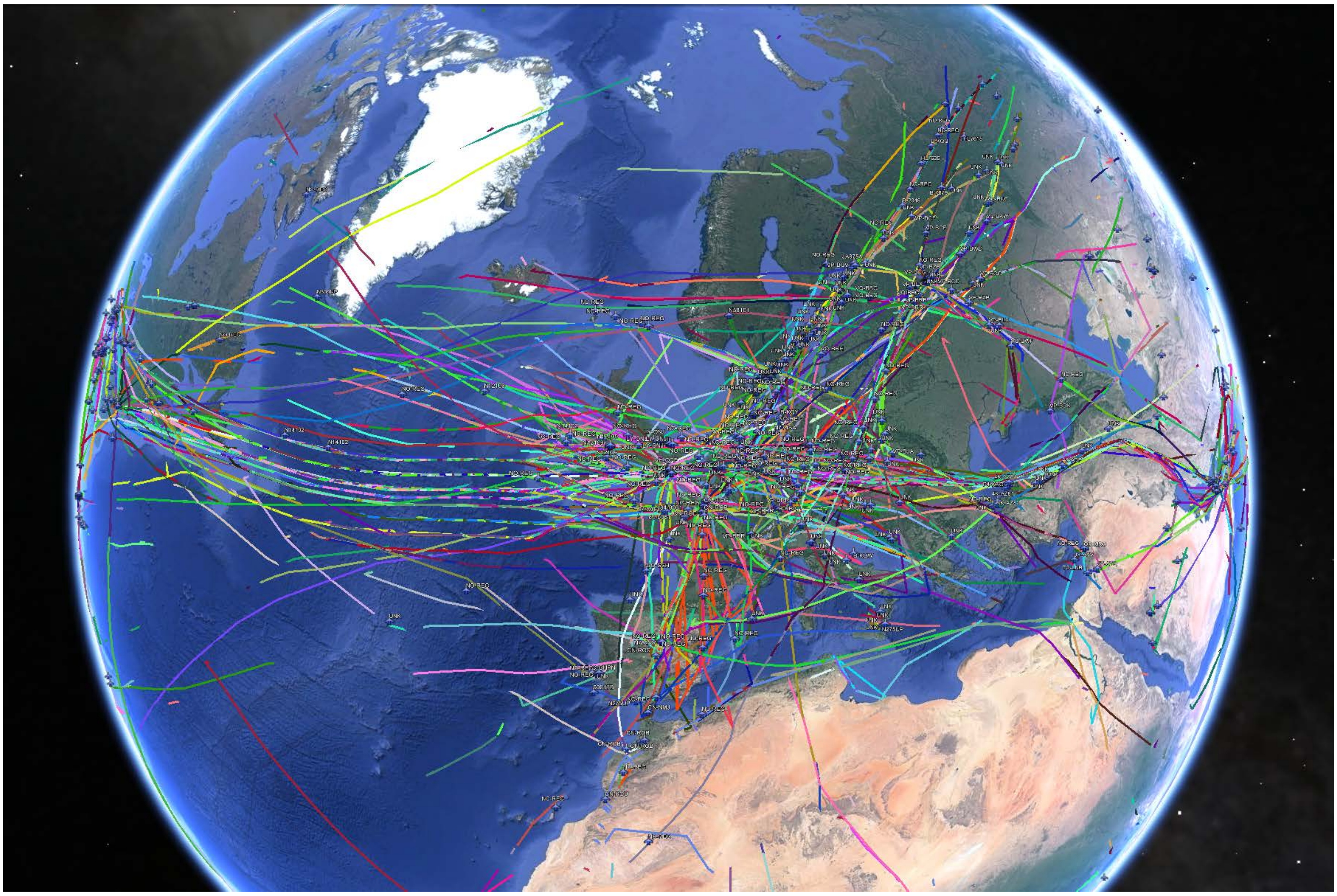

Figure 1: Here you see part of 29.000+ HFDL messages from August 15th, drawn onto Google Earth by Mike Simpson's software "Diplay Launcher". Please note also the dense coverage of the Atlantic routes, where there is no VHF communications. The only flight over the Ukraine was brave Royal Jordanian RJA 177 from Amman to Moscow. Data came from the HFDL net on shortwave, decoded by Charles Brain's software PC-HFDL.

This paper shows how to monitor HFDL transmission of aircraft. First, it gives some background about the HFDL system and, secondly, continues with a mere recipe about how to receive, visualize and analyze up to nine channels in parallel – live or from a recorded HF file. Sincere thanks to Mike Simpson and Dick van Noort (PA-2015, NL-13560) for their most valuable work and patience!

Communications between air and ground is mostly done on VHF. But if an aircraft is out of reach of a ground station, it has to maintain communications by either satellite or HF. This paper deals with the HF part, namely the ARINC net of 15 Ground Stations, scattered all over the world. It is the net with the most traffic on HF. Protocol used is HFDL or High Frequency Data Link.

The massive amount of received messages (I get 40.000+ within 24 hours) calls for parallel reception, parallel decoding and a very smart tools to navigate through all these information.

In autumn 2016, all this is at your hand for either free or just a small price. It is centered around Mike Simpson's Display Launcher – a free software, presenting the results of up to nine channels in a spreadsheet-like format and offering links to FlightRadar24 as well as Google Earth. Mike has developed this software, and recently gave it a major relaunch to work reliable and consistent even over days.

HFDL – some Notes on the System

The HFDL network was introduced in 1993 as a digitally network to strongly support HF voice communications. It is now owned and operated by Rockwell Collins. The combination of a robust PSK-mode (ARINC-635), strategically placed Ground Stations and an adaptive frequency management made it a highly reliable system under even adverse space weather: Over 2.600 equipped aircraft result in about 5 million messages a month.

The HF net is part of a much bigger system, the ARINC Global Network. It aggregates messages and information from all channels, e.g. VHF, SATCOM, and HF. See *Figure 2* on the next page on how HF integrates into this network. *Figure 3* shows the Ground Stations with their numbers.

Propagation & Frequency Management

The HFDL net works with an adaptive frequency management. This involves the use of so-called Active Frequency Tables, ATF. See *Figure 4* overleaf for an example received August 18th, 10:00 UTC.

The ATFs are based on space weather observables and are changed accordingly to provide the most reliable communication in respect to e.g. season and time of the day. All current ATFs of the whole net are transmitted via so-called "Squitters" by each Ground

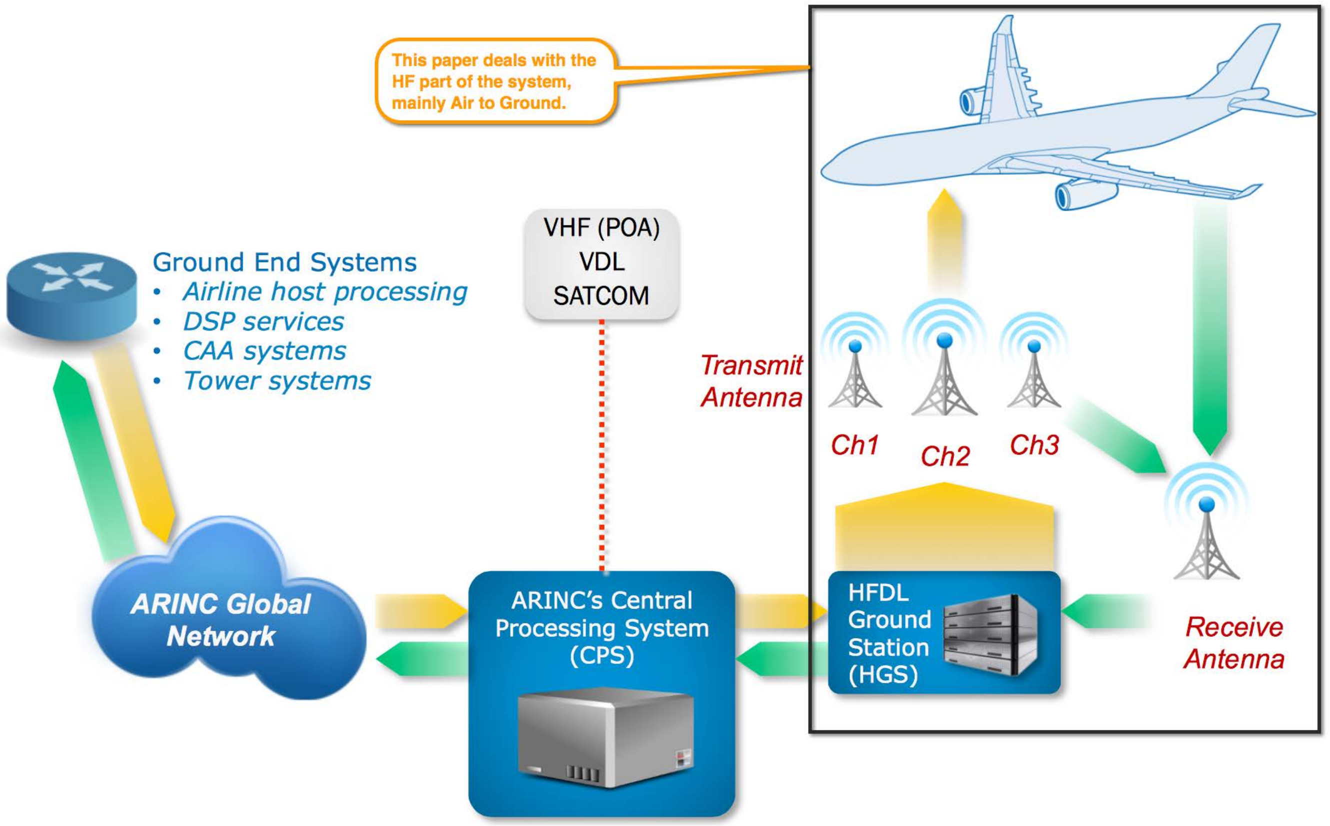

Figure 2: The HFDL system is part of the ARINC Global Network, combinig information from many sources to serve airlines. Source: Rockwell Collins

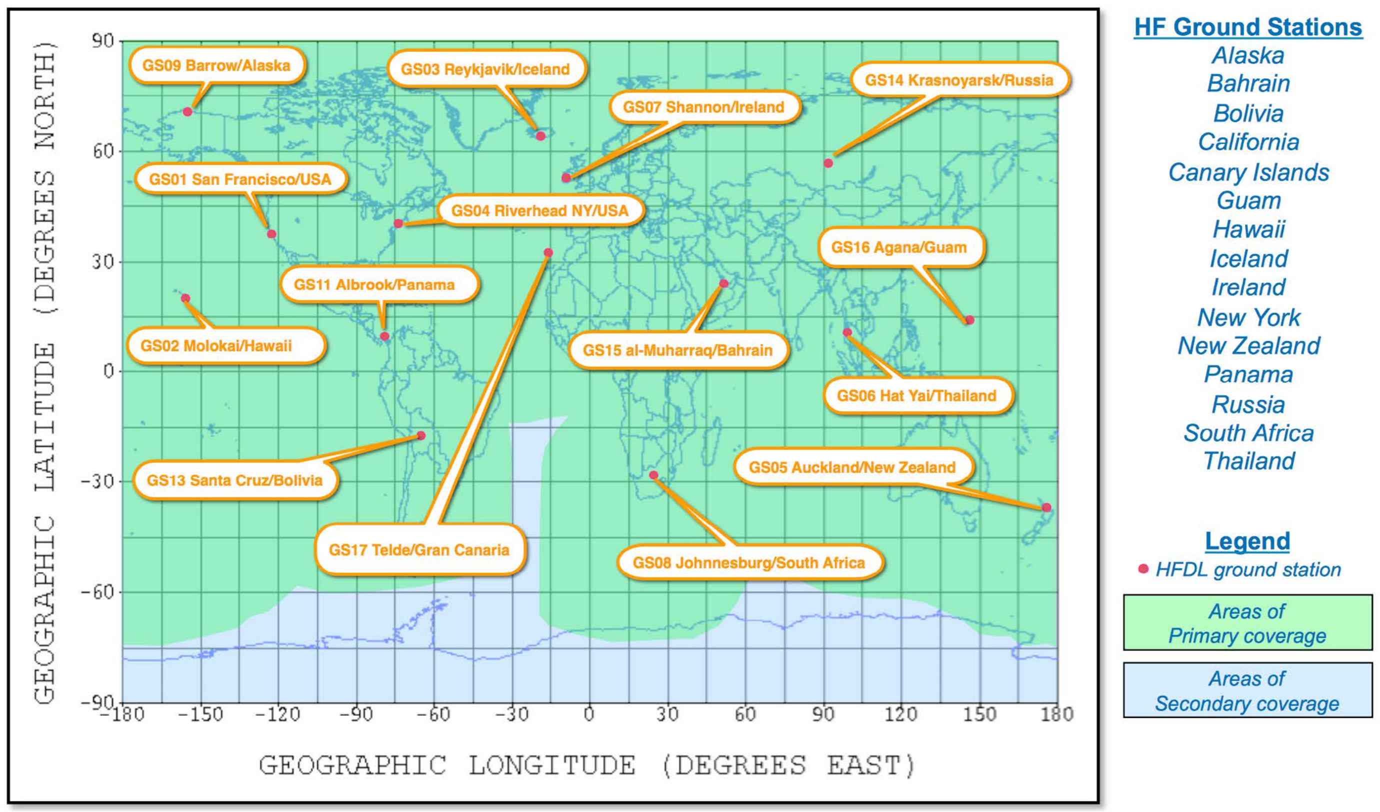

Figure 3: All 15 Ground Stations are strategically placed over the globe in respect to the most congested routes. Special attention has been paid to serve the "trans-polar" flights where SATCOM may face problems and reliable HF communications is always a challenge. This map by Rockwell Collins has been annotated with e.g. Ground Station numbers as they appear in a column of "HFDL Display Launcher" software. Source: Rockwell Collins, annotations by DK8OK.

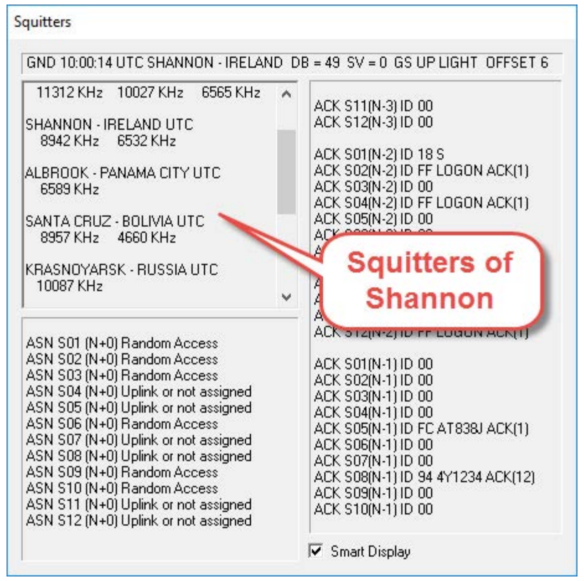

Figure 4: An example for (part of) the current Active Frequency Table AFT, as send by Shannon's Squitters, 8.942 kHz; August 18th at 10:00 UTC

Station. Before start af the aircraft, the current ATF is loaded to the HFDL transceiver of the aircraft. For initial contact to the net, the aircraft is scanning through this set of channels, and logs on to the strongest Ground Station. Once en route, the aircraft scans in the background e.g. 20 other channels. If communications with the Ground Station first logged on fails due to propagation, the aircraft automatically switches to the the next propagating channel.

Rule of thumb is that a path with one or two ionospheric hops working best. This means that the distance between aircraft and Ground Station generally should not exceed 6.000 km. So, if you are living in Europe, Ground Stations like Shannon and Reykjavik are just perfect. This doesn't exclude reception from Hawaii or New Zealand (Ground Stations as well as aircraft), but most probably you will get the highest amount of messages from transmitters inside a circle of about 6.000 km around your antenna. Most of the traffic originates from aircraft. Their transmitters have an HF power of about 125 watts, fed into a tuned antenna. Due to various factors, the resulting HF link is most effective near the highest usable frequency. So you generally should concentrate on frequencies over 5,7 MHz.

Setting up the Stage

Now we have a general idea on how the HFDL works. As it uses dynamically a couple of Ground Stations as well as frequencies, this is an ideal case for today's monitoring technology.

How monitoring them generally works

To tell it backwards: Display Launcher accepts up to nine input input streams of data massages from air and ground. They come from up to nine instances of PC-HFDL decoder. This software has been developed by Charles Brain.

Each decoder is fed by an audio signal from an SDR, tuned to each one channel of a Ground Station. Aircraft is using the same channel by time division multiplex, or designated time slots. Software SDR Console 3.0 by Simon Brown offers up to 24 demodulators within the HF bandwidth of the SDR. With an SDR like ELAD's FDM-S2, this band maybe of up to nearly 5 MHz width. There already are cheap SDRs around with even 20 MHz of bandwidth (e.g. HackRF), but they have to be used with an HF converter and offer just a limited dynamic range due to their only 8 bit resolution. See here on how you nevertheless can use this system for serious monitoring. LimeSDR is a promising project from the end of 2016.

Connection between receiver software and decoder has to be made by so-called virtual soundcards or Virtual Audio Cables. One example of this piece of software is VAC by Eugene Muzychenko, offering up to 256 virtual input/output "cables". *Figure 5* provides a general block diagram. We will go through it step by step.

SDR & Antenna

The *radio* should be a software-defined radio, or SDR. Preferably, it should provide 16 bit ADC resolution for a good dynamic range and a bandwidth of at least 5 MHz. Other resolutions are possible (the lower, the worse). Smaller bandwidths will reduce the choice of channels in different bands. In this case you will miss a great number of messages, even from the same aircraft on its route.

Antenna: First try what you already have. With very limited space, an active antenna maybe a good choice. My antenna is a quadloop of 20 m circumference in a birch in the garden. It is nearly invisible, not that sensitive to local noise, and not so easily overdriving an SDR with 16 bit analogue-digital converter (ADC).

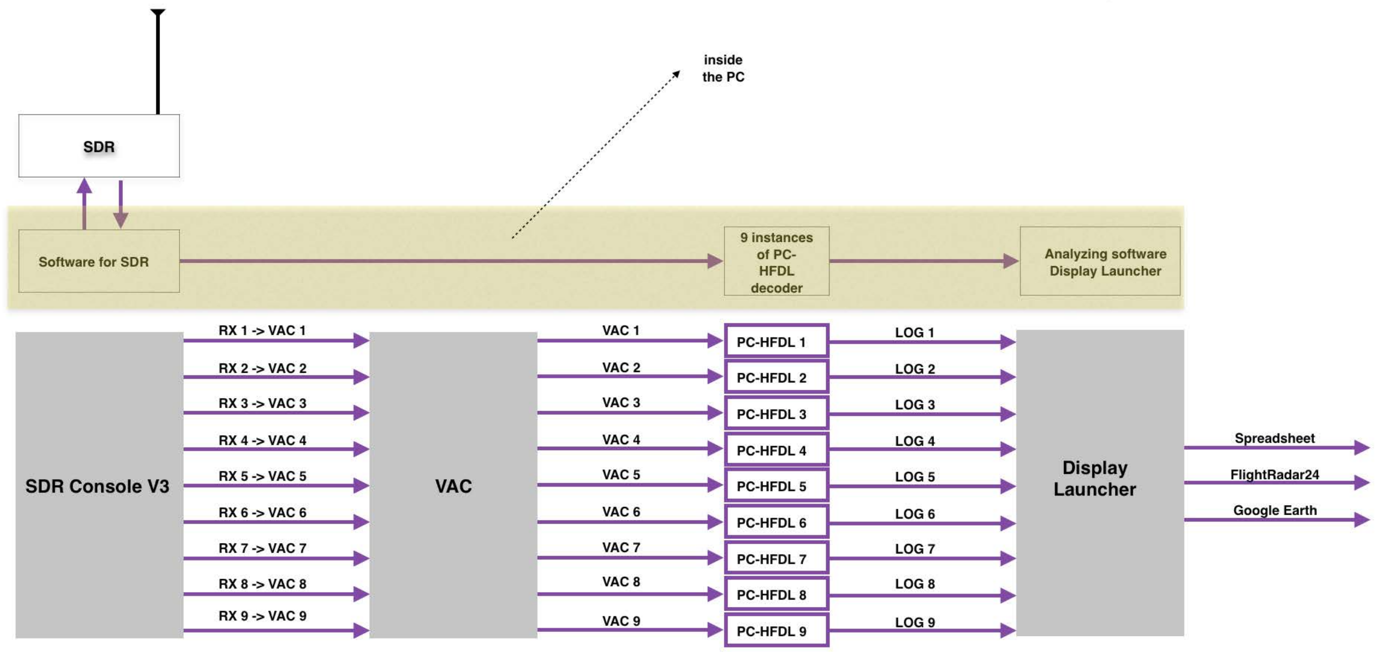

Figure 5: How to perform reception, demodulation, decoding and analyzing of up to nine HFDL channels in real time. See above ("inside the PC") for a general view, and below a more detailed one. Most of the operation is done within the PC by four pieces of software. They are virtually interconnected.

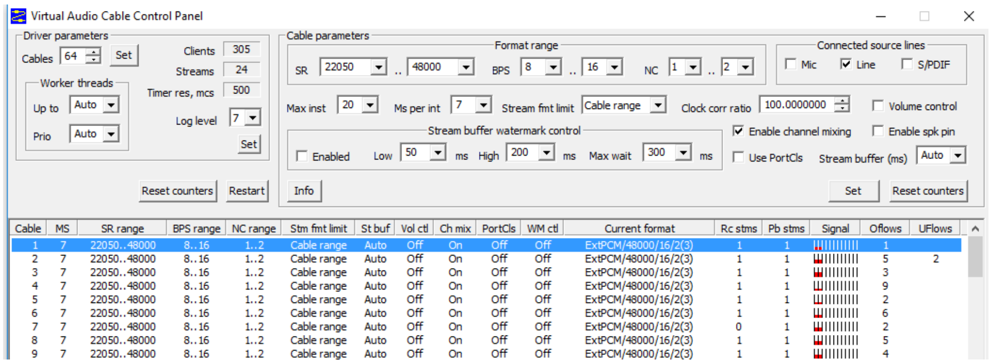

Figure 6: Virtual Audio Cables connect demodulators and decoders. They are a must for this kind of monitoring a multitude of channels.

Virtual Audio Cable VAC

Imagine the virtual audio cable just like a real cable with two ends, connecting a demodulator *output* of software SDR Console V3 and the *input* of a decoder.

With VAC software (see *Figure 6)*, you have to define the number of cables (up to 256, but recommended as low as needed for keeping your overview). Then they will show up in the menues of audio sources and sinks. You may now connect a demodulator output of software SDR Console V3 (source) with the input of an instance of PC-HFDL decoder (sink).

SDR Console V3

This is the perfect companion for nearly each and every SDR. With up to 24 demodulator outputs and monitoring each of these channels in a "Matrix", this software is nothing but tailored for your needs:

- Set the centre frequency so that the alias-free range of your SDR will cover all HFDL channels wanted.
- Tune each of the up to nine channels to the desired frequency with *AGC Fast* (so that after a strong signal gain will recover fast for a possibly weak one just following), USB and a bandwidth of about 3 kHz.
- Assign each channel to a different VAC output. It helps if you do this according to the pattern: RX1 - VAC1, RX2 - VAC2 … RX9 - VAC9.
- Save your work as "Favourite". See *Figures 7* to *9*.

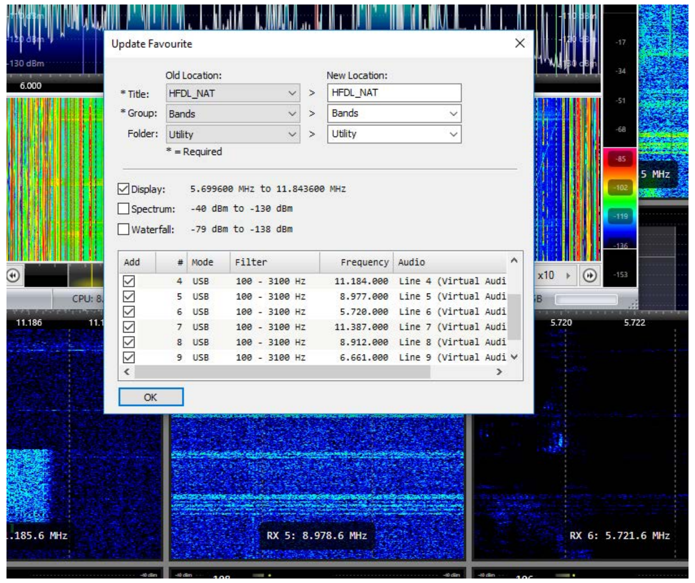

Figure 7: Here nine channels and their corresponding VACs have been set.

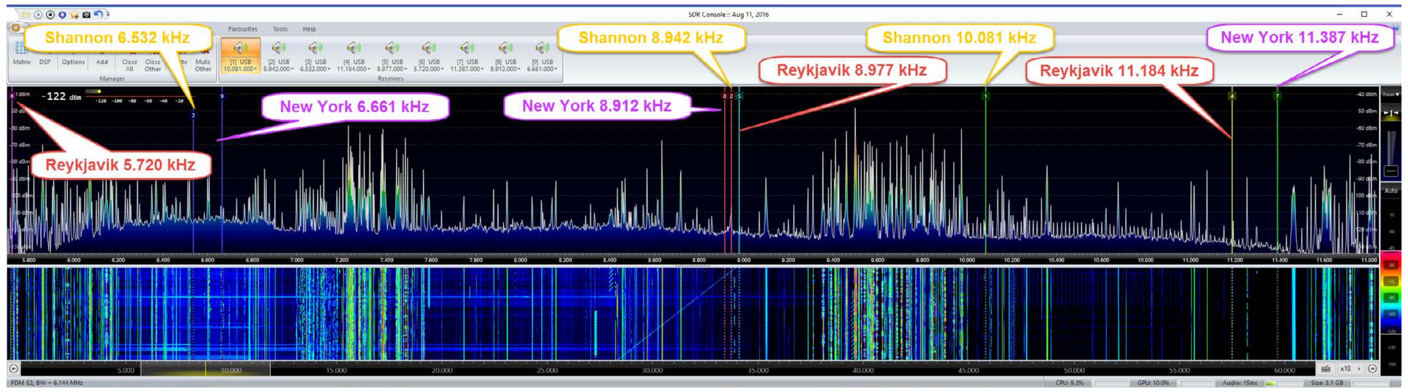

Figure 8: Nine channels have been programmed, with three different frequencies each for Shannon, Reykjavik and New York to monitor North Atlantic traffic. The 5 MHz bandwidth stretches a bit the power of the SDR as you see from the attenuation on both ends of the band. At the ribbon above the spectrum you see all nine demodulators (or receivers: RX) activated. Each RX guides its output to a different VAC, namely VAC1 … VAC9. Don't forget to un-mute each RX!

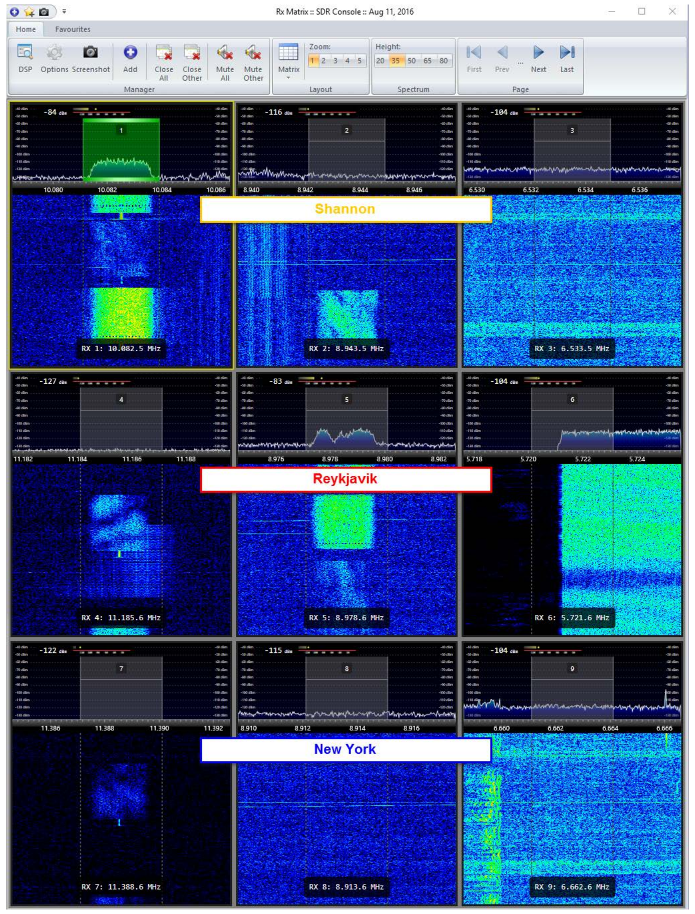

Figure 9: With the Matrix view you can check the activity on each of the channels with each their spectrum and sonagram. Here 2 x Shannon, 2 x Reykjavik and 1 x New York are active.

PC-HFDL decoder

For our example, we need nine decoders. Luckily enough, this is done with just one piece of software, namely PC-HFDL

You need nine so-called "instances" of it. These are nine installation in nine different folders – see *Figures 10* and *11*:

- Make up nine folders and name them PC-HFDL_1 … PC-HFDL_9.
- Download PC-HFDL.exe.
- Copy and paste one file each of PC-HFDL.exe into each of the nine folders.
- Double-click each of these exe-files in each folder to install the software nine times.
- Change the name of the icons to start the software from just PC-HFDL to PC-HFDL_1 … PC-HFDL-9.

Now you have properly installed nine instances of the decoder. In the next step, you have to define the different *input* of each of the nine instances:

- Open "PC-HFDL_1", click "Systems Options", choose "Sound Card Selection" and click onto "Line 1 (Virtual Audio Cable)". Repeat this up to "PC-HFDL_9", assigning to "Line 9 (Virtual Audio Cable)". See *Figure 12*.
- Open each instance, and under "Display Options" tick all boxes, but V-ACARS, H-ACARS and HEX. See also *Figure 9*. By this step you control the format and amount of information written into the log file. This log file will be read by software "HFDL Display Launcher". If you do not comply to this procedure, "HFDL Diplay Launcher" might get a hiccup under specific circumstances and may e.g. loop through.

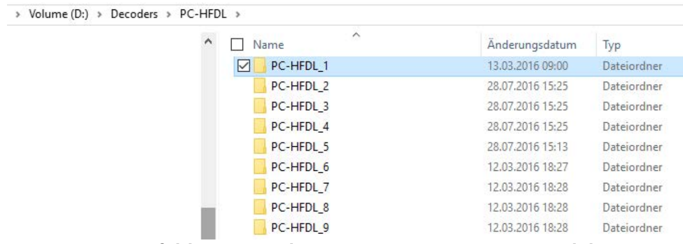

Figure 10: Nine folders, named PC-HFDL_1 … PC-HFDL_9 each keeps …

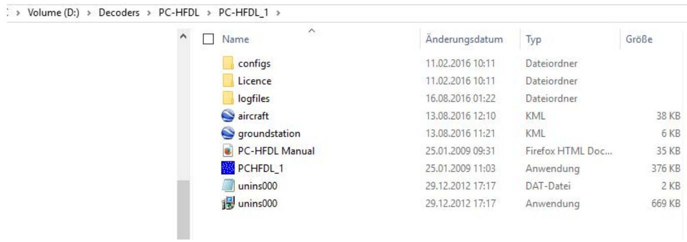

Figure 11: … an individual installation ("instance") of software PC-HFDL. Each of the nine programme icons had been named according to their folder PC-HFLD_1 … PC-HFDL_9.

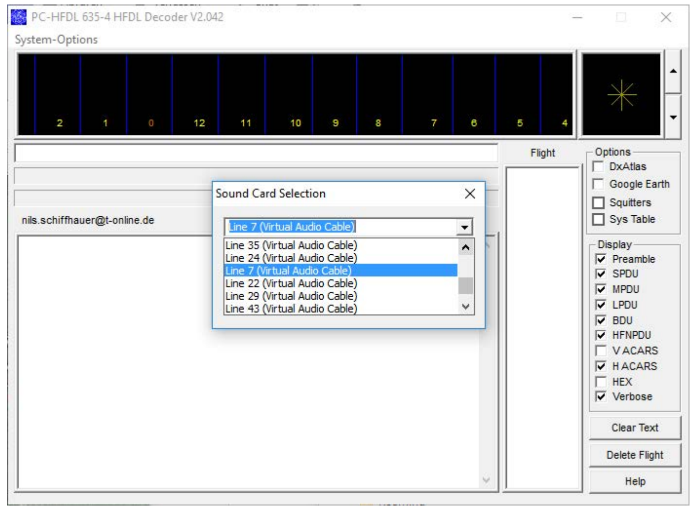

Figure 12: After having installed the nine instances of PC-HFDL in different folders, you have to assign each instance to a different VAC. Under "Display Options", V-ACARS and H-ACARS must be un-ticked.

To avoid a bug of PC-HFDL software with multi-CPUs systems you should set the *affinity* of each of the nine instances to only one CPU of your PC (thanks, Dick!). Unfortunately, you have to repeat this procedure each time after you had closed PC-HFDL and re-opened it again (see F*igures 13* to *15*, next page):

- Open all nine instances of PC-HFDL.
- Open the Task Manager of Windows (STRG+SHIFT+ESC, then click "Task Manager").
- Open menue "Details", scroll to your nine open instances of "PC-HFDL".
- Click onto "PC-HFDL_1", then open the context menue by clicking the right mouse key.
- Untick "All Processors", this empties all boxes.
- Tick just "CPU 1".
- Repeat the last three steps from PCF-HFDL-2 to PC-HFDL-9. You may tick another CPU than just "CPU 1"; but always only one CPU! Dick recommends to spread all PC-HFDL instances to some CPUs.

The *Figures* do refer to Windows 10, German version. They may differ from your system but should apply at least generally.

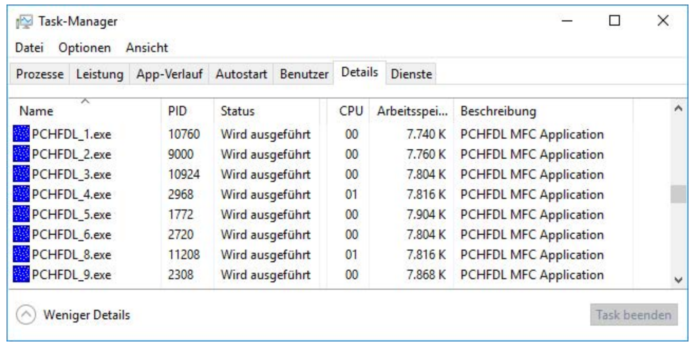

Figure 13: With "Task Manager" opened, click on menue "Details" and scroll to the active instances of PC-HFDL software.

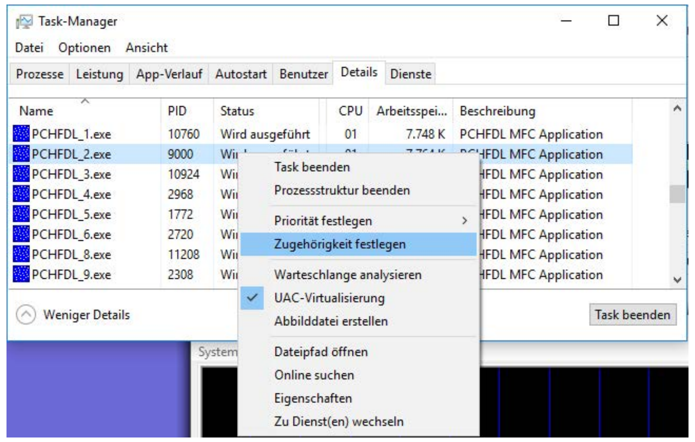

Figure 14: Point to one instance after another. Click right mouse key. In the context menue, click to "Set Affinity" and …

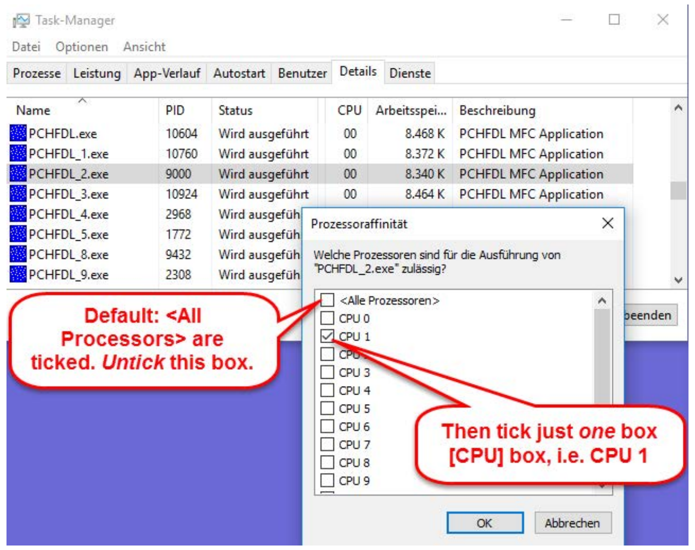

Figure 15: … first untick <All Processors> (default), then tick the box of just one processor. Click OK, and proceed to the next instance of PC-HFDL until you have changed CPU affinity of all nince instances. You have to repeat this each time after having an instance of PC-HFDL closed and re-open it again.

Display Launcher

Now all has been set for the "Display Launcher". It gets its information by the decoded HFDL messages of PC-HFDL instances 1 to 9. They are stored in their folder "logfile", automatically separated by days. So you have to prepare the paths for connecting both. Display Launcher will remeber these paths for the next time.

Set these paths via the Options' menue. See *Figures 16* and *17* on how to proceed and *Figure 18* to control that all has been done right.

As soon as you have did this and answered the question about what to do with the already saved logs of that day, the grid of Display Launcher should more or less rapidly fill with data, see *Figure 19*, next page.

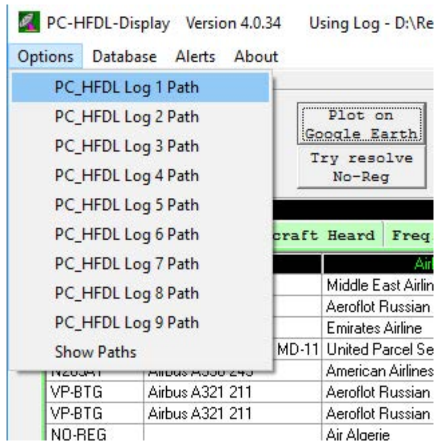

Figure 16: Set the Logpaths via the Options's menue. Click onto the wanted menue point ("PC_HFDL Log 1 Path" here) …

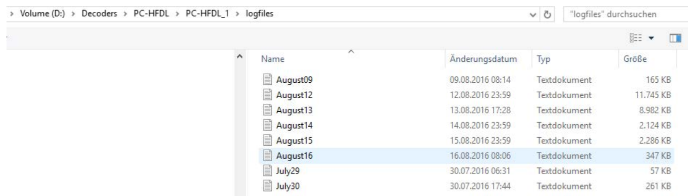

Figure 17: … choose it in the matching folder (PC-HFDL_1 --> Logfiles here) …

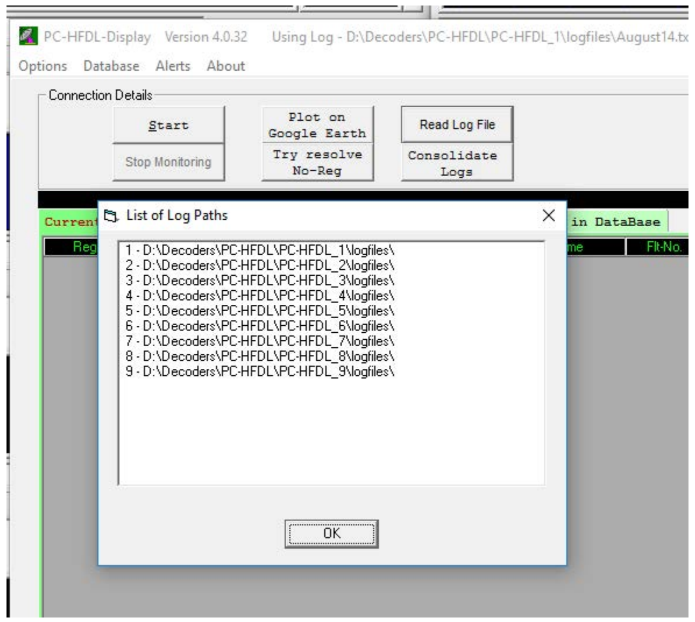

Figure 18: … and eventually check it by menue Options --> Show Paths.

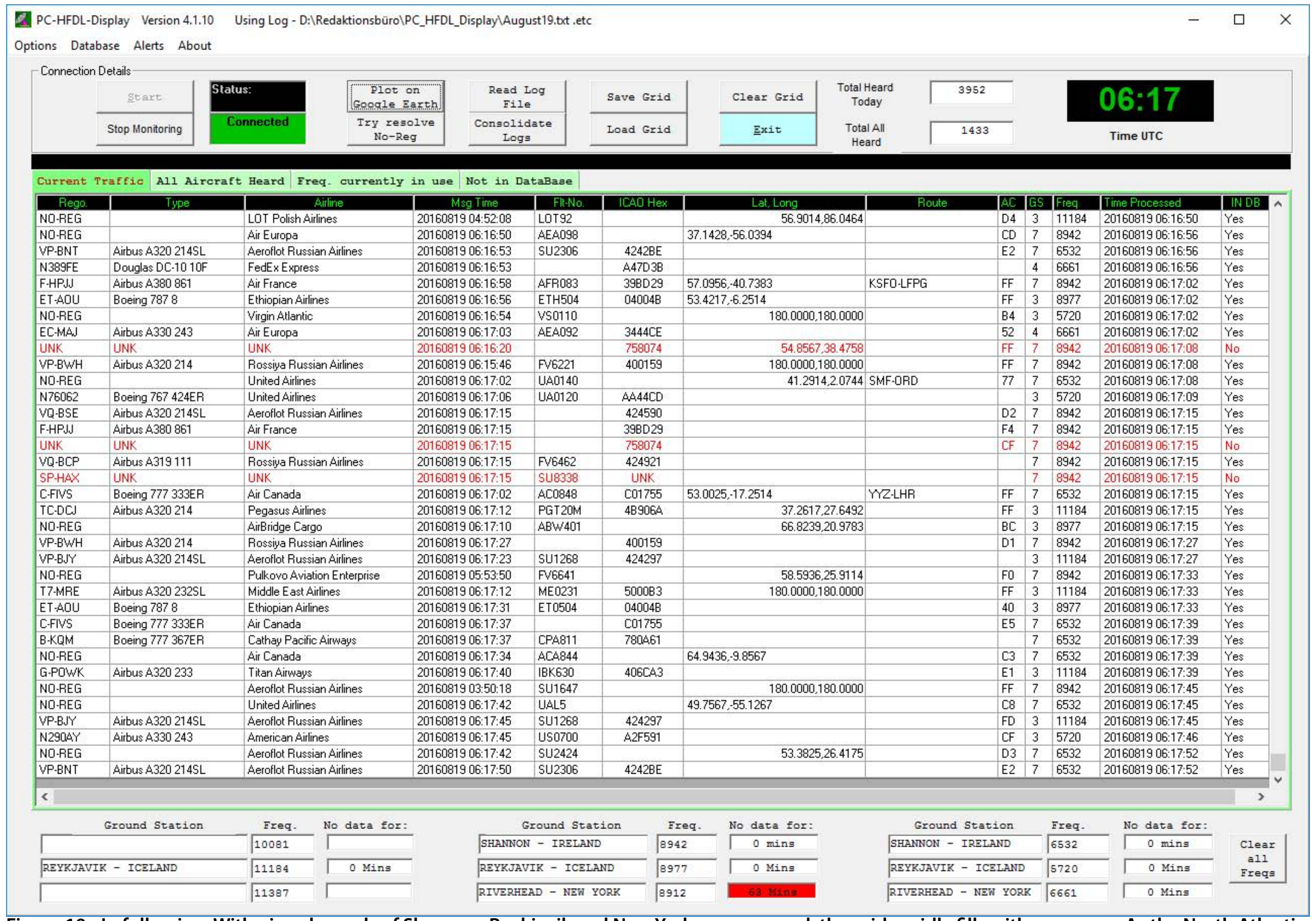

Figure 19: In full swing: With nine channels of Shannon, Reykjavik and New York programmed, the grid rapidly fills with messages. As the North Atlantic route is heavily used, 2.000 messages per hour are not a rare occasion. You see also here that I filled in the frequencies below the grid. They then are automatically inserted from the next available message in the grid, complementing the numer of the Ground Station (GS). As soon as the first Squitters had run in, menue "Freq. currently in use" will give you a list of all active frequencies of all active stations. The setup was running for about 70 minutes. In this time, nearly 4.000 messages were received ("Total Heard Today"). Nothing had been received so far on 10.081 kHz (Shannon) and 11.387 kHz (New York). Both were currently running on just the two frequencies – see next Figure. Due to propagation between New York and me, this signal had faded out at 05:14 UTC – current time 06:17 UTC minus 63 minutes, "no data for" on 8.912 kHz.

How to get these Frequencies?

The HFDL net works on about 145 frequencies, or: channels. As we had seen above, the Ground Stations do transmit a set of active frequencies as part of their so-called "Squitters". Moreover, Display Launcher keeps a record of station/frequencies over time.

In Europe, Shannon 8.942 kHz is a perfect starter almost 24 hours a day. Tune to this channel and let it run some hours to get a table of the other frequencies – see *Figure 20* and *21*. Generally speaking, you often see two or more frequencies at a time, changing; often one set for day, the other set one for night. There maybe a third short-living set of some channels at their local dawn.

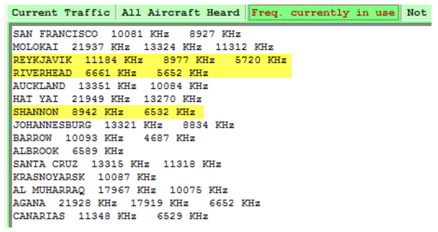

Figure 20: The current set of frequencies is available via the tab "Freq. currently in use" of Display Launcher. This reflects exactly the situation of the Figure above.

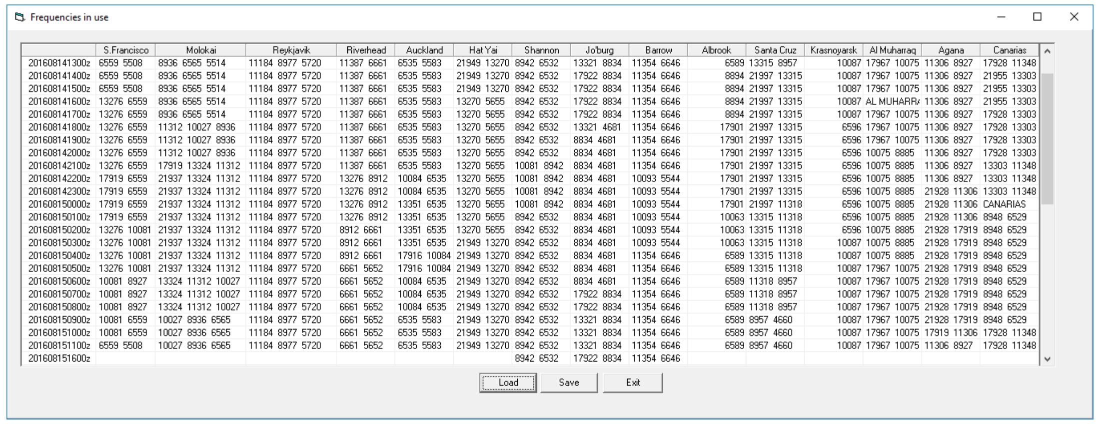

Figure 21: Software Display Launcher keeps a record of all stations/frequencies with the resolution of one hour. This very useful table is accessible via: Database --> Show Freqs Used. Then an empty table "Frequencies in use" pops up. Click "Load" and locate the file "FreqsInUse", per default located in C:->Radio Utilities->Display-Launcher->Reports

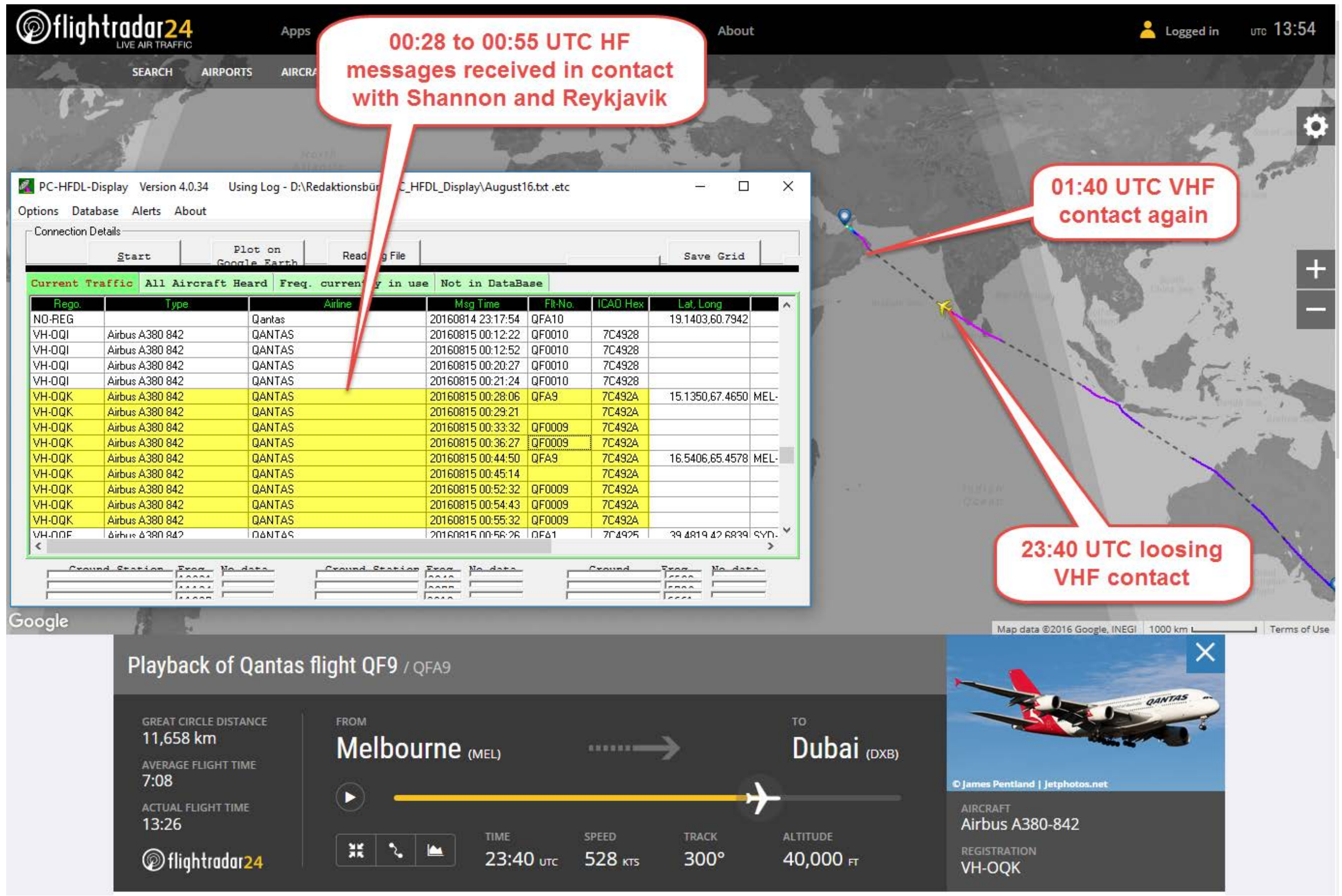

Figure 22: Here you see some advantages of HFDL monitoring in a nutshell: Qantas Flight QFA9/QFA0009 from Melbourne to Dubai has large portion of its route where there either is no VHF contact or no VHF receiver of the Flightradar24 monitoring network available, as the dotted part of the route shows in htis FlightRadar24 window. This dotted part maybe bridged by HF as it actually is done here during a leg across the Arabian Sea: HFDL takes over – see the marked part of Display Launcher's grid. This entry represents contacts with Shannon and Reykjaivk on three frequencies, although Bahrain Ground Station would be next to the aircraft. As I didn't monitored also Bahrain, some HFDL messages might have been missing.

Visualizing the Messages: FlightRadar24 and Google Earth

You can visulaize the messages via FlightRadar24 and via Google Earth.

FlightRadar24 is a Swedish internet service with hundreds of volunteers around the globe. They stream the results of their VHF/SHF receivers to this website. As matter of nature, there are region, where no VHF/SHF data gets through, and you have to rely on HF (or: satellite). This gap is filled by HFDL (*Figure 22*). On the other hand, this HFDL service is used in parallel to VHF. You may also make the discovery that FlightRadar24 intentionally suppresses some kind of aircraft, like nearly all military flights and many business jets.

To pick a flight in FlightRadar24, just double-click it's entry in the grid of Display Launcher – voilà, see again *Figure 22*.

To show all aircraft in the grid on Google Earth, just click to "Plot on Google Earth". If you are connected to the Internet, soon Google Earth will open, inserting all relevant data (ie. these aircraft messages with geographical data with "180.0000,180.0000" intentionally being omitted) as so called KML file at the sidebar of Google Earth. In the same moment, this file and all aircraft with these data are plotted on the scalable globe – see *Figure 1* on the first page. Moreover, position of the same Flight Number are connected by a line. You won't believe it first – its a simply stunning feature! Even military flights can be tracked, see *Figures 23* (below) and *24* (next page).

With many data (e.g. 10.000+ message), it may take a while until the KLM file is written and sent to Google Earth. Diplay Launcher automatically stores each KML file in its Google folder.

Rego.	Type	Airline	Msg Time	Flt-No.	ICAO Hex	Lat, Long	Route	AC	GS	Freq	Time Processed	IN DB
40061B	UNK	Air Mobility Command	20160814 21:26:10	MC0061		40.0203,-74.5831		FA	7	6532	20160816 07:43:14	Yes
NO-REG		Air Mobility Command	20160815 00:05:48	MC0025		40.7581,-79.2836		63	4	8912	20160816 00:06:01	Yes
60017B	UNK	Air Mobility Command	20160815 00:33:32	MC0017		37.4456,-9.7436			7	6532	20160816 00:33:43	Yes
85-0010	Lockheed C-5M Galaxy	Air Mobility Command	20160815 01:07:00	MC0010	AE0567	39.0639,57.9228		15	3	5720	20160816 01:07:14	Yes
85-0010	Lockheed C-5M Galaxy	Air Mobility Command	20160815 01:23:28	MC0010	AE0567	38.0975,60.6483		A0	7	6532	20160816 01:31:32	Yes
40061B	UNK	Air Mobility Command	20160815 07:31:50	MC0061		48.7133,0.6622			7	6532	20160816 07:43:14	Yes
40061B	UNK	Air Mobility Command	20160815 07:43:02	MC0061		48.6031,2.5014			7	6532	20160816 07:43:14	Yes
40061B	UNK	Air Mobility Command	20160815 07:52:38	MC0061		48.4708,4.0847		FA	7	6532	20160816 07:52:50	Yes
40061B	UNK	Air Mobility Command	20160815 08:02:54	MC0061		48.2608,5.6994		FA	7	6532	20160816 08:03:08	Yes
40061B	UNK	Air Mobility Command	20160815 08:19:40	MC0061		49.5961,6.7994		FA	7	6532	20160816 08:19:51	Yes
40061B	UNK	Air Mobility Command	20160815 08:32:02	MC0061		49.9675,6.7033		FA	7	6532	20160816 08:32:14	Yes
40061B	UNK	Air Mobility Command	20160815 08:41:42	MC0061		49.9656,6.7019		FA	7	6532	20160816 08:41:52	Yes
V5-ANP	Airbus A330 243	Air Namibia	20160815 00:03:56		20103C			72	3	8977	20160816 00:04:03	Yes

Figure 23: Most military aircraft are intentionally suppressed by FlightRadar24 for political and/or security reasons. This is also true for the aircraft of the Air Mobility Command of US Air Force. s long as they also transmit HFDL messages, you may receive them (marked) and plot their positions on Google Earth …

Figure 24: … as seen here for 40061B, a Lockheed C5-B Galaxy of the Air Mobility Command of US Air Force.

Offline 1: Saving and open the Grid

As said, the grid of Diplay Launcher can be populated by up to nine demodulator outputs. They combine from textfiles of each of these decoders in different folders vom PC-HFDL_1 … PC-HFDL-9.

If you want to save this whole session to scrutinize the data later (e.g. you can sort each column by just clicking the headline of it, as in a spreadsheet), you simply click to "Save Grid". It then is save as a comma separate file (CSV) which can be important also to other software, e.g. Excel. You can also recall it again in Diplays Launcher: just click "Load Grid" and double-click onto the wanted CSV file.

Offline 2: Decoding from a recording

There are several reasons to decode not live, but from a recording. One maybe to decode stations with just a short opening, as Hawaii has it in Europe: Keep up to nine decoders active under live repcetion on channels which will be received for many hours. And decode these other channels offline from the recording.

This is also possible with SDR Console V3: You may take a 5 MHz wide recording, set the demodulators, and let it play like live. Each message contains the original date and time when being transmitted. So you get the correct data and may also perform the double-click to FlightRadar24 and Google Earth from this data. With the free version of FlightRadar24, you may look back seven days; with Silver, Gold and Business subscription this time will be prolonged to 60, 180 and 365 days.

Inside the Data

Above, we have handled an HFDL message like a black box. To give at least a general idea, how data proceeds from decoder PC-HFDL to the various forms of their presentation in the Display Launcher, just a rough overview:

- PC-HFDL is decoding the messages and is saving these data in an automatically written text file, day by day
- Additionally, PC-HFDL-Display saves all active frequencies every hour in a file called "FreqsInUse.csv" in the \Display-Launcher\Reports folder.
- These Freq used are taken from teh squitters in which a GS advertises its own active freq's and those of two other GS's.
- It is writing that type of data which had been ticked at the boxes of "Display Options", see *Figure 12*, above.

These textfiles indeed contain all information, but look a bit relcutant to be read by an unarmed eye. Here Mike's Display Launcher steps in:

- It reads the textfiles (so you have had set the correct paths), and is stripping and converting the data to represent it in the tidy form of a spreadsheet.

Sounds easy, but it isn't. One thing is, that you have to re-engineer part of the HFDL system. The other thing is that there always seem to be some exceptions and inconsistencies of the structure we see. We also don't want to see the 24 bit ICAO identifiers of the aircraft, but we want to know the call of the aircraft, the airline, the route etc. in plain language. This is the task of some software module inside Display Launcher (e.g. "ExtractAircraft") which in turn refers to massive data stored in the "Template" folder, e.g. "Aircraft2", a table with alone 150.000+ entries!

So there is room for some glitches. It should be emphasized that also some data as being transmitted doesn't comply to the rules, e.g. transmitting default or wrong or no position coordinates. Some unpredicted behavior of Google Earth doesn't make things easier.

All in all the described system works fine and unattended over days. This truly admirable effort of Mike is a major breakthrough in making the vast majority of this massive data digestable. Without his work, we would look at the textfiles as mere raw data. Thanks, Mike!

Some links & literature on HFDL

- HFDL website of Rockwell Collins
- Fundamentals of HF Data Link [an introductory presentation by Rockwell Collins, 2014/2015]
- Manual of the Implementation of HF Data Link (HFDL), ICAO
- Practical measures for combating communications systems impairments caused by large mangentic storms [a detailed paper on the propagation side of HFDL]