

Using ADS-B Aircraft Tracking

ADS-B Aircraft Tracking receives and decodes signals from planes overhead

Background

Modern planes carry an Automatic Dependent Surveillance-Broadcast (ADS-B) Mode-S transponder. This transponder periodically broadcasts location and altitude information to air traffic controllers and other aircraft. The system replaced traditional RADAR systems which work by bouncing a radio signal off the plane and listening for the echo. ADS-B uses an accurate on-board GPS receiver and broadcasts the GPS location data to ground controllers and other aircraft via radio, thus providing more accurate and stable data. ADS-B is also used to help aircraft avoid collisions by sending a warning or taking automatic emergency action if the flight computer detects a possible collision from ADS-B data.

Currently, ADS-B data is not encrypted so an SDR can be used to decode these signals. The decoded data can then be used to create a live home aircraft radar system. ADS-B signals can be found at a frequency of 1090 MHz. ADS-B uses “Mode S” which provides the location data for ADS-B. Public websites including flightradar24.com and flightaware.com display ADS-B data through the internet as well. They receive ADS-B data through volunteers who have bought dedicated ADS-B receiver hardware or are using an RTL-SDR and feeder software.

Hardware Considerations

Antenna

With a good antenna an SDR could be capable of receiving aircraft ADS-B signals from over 250 nautical miles away, or about 460 km or 290 miles. Many people have found that in most cases the stock antenna that comes with the dongle can pick up ADS-B signals without modification. Its performance will depend on distance from the aircraft and local RF interference. ADS-B operates at 1090MHz with vertical polarization which just means that a vertically oriented antenna should be used. Frequencies in the gigahertz region are “line of sight” frequencies meaning there should be a clear unobstructed path between the antenna and the transmitter on the aircraft. Since ADS-B signals are generally quite strong and come from aircraft flying up high, reception is quite easy and even untuned antennas can work decently. The provided telescoping antenna at its shortest length on a suitable ground plane will likely provide adequate reception for most users. However, to increase ADS-B receiving range, place a properly tuned antenna at an elevation.

COAX Feed and Connectors

The coax feed line (the length of coaxial cable between the antenna and dongle) should be high quality, low loss and as short as possible. At gigahertz frequencies long runs of cheap coax tend to reduce signal strength significantly. Use coax cable intended for satellite TV installations such as RG-6 or RG-8 as these cables are designed to work well at gigahertz frequencies. Alternatively, use an active USB extension cable and place the dongle as close to the antenna instead of using coax cable. BNC, N or SMA connectors are recommended. Poor connectors at gigahertz frequencies could net up to 1-3 dB of loss per connector.



Low Noise Amplifiers (LNAs)

By simply placing an LNA in front of the SDR, ADS-B range can be significantly increased. This is because the noise figure (NF) of the RTL-SDR at 1090 MHz is approximately 5 dB. Using a high quality LNA can reduce the system noise figure down to 1 dB. Essentially this means that SNR will be about 5-6 dB's higher, resulting in significantly more ADS-B packets received. The additional benefit of using an LNA is that coax and connector losses can be overcome if the LNA is placed right by the antenna. To use ADS-B, the antenna should be placed on a roof or a mast for optimal performance. This means that many meters of coax cable will be needed. Even if high quality RG-6 coax is used, the loss at 1090 MHz for 10 meters (33ft) would be about 3.5 dB plus about 1 dB in connector losses. The LNA can be placed at the antenna and powered by a bias tee.

Filters

If there are strong interference broadcast stations nearby (e.g. FM, DAB, DVB-T, GSM) then these signals can cause the dongle to overload and desensitize ADS-B reception. Overloading becomes even more likely if an LNA is used. In these cases a filter should be. The FlightAware 1090 MHz filter can be used. This filter is found at rtl-sdr.com/store. In addition a ADS-B LNA + filter combination unit is available.

The filter or the LNA can be placed “first” or closest to the antenna. Place the LNA first, then the filter, if the LNA can handle strong signals (high linearity/OIP3) and there are not too many interfering signals. Most filters usually have an insertion loss of about 3 dB, and so placing the LNA first will nullify that insertion loss. On the other hand, If interfering signals are exceptionally strong, then they could overload the LNA. In this case, place the filter first. The easiest way to check is to view the spectrum in SDR#. If the signal quality decreases with the LNA in front, then put the filter first. If the signal quality looks similar with either the LNA or filter first, then put the LNA first.

Software Installation

Note that for the Windows based software the SDR drivers need to be installed via Zadig. The ADS-B decoder and a map display program must be downloaded. The best combination of decoder and display programs are RTL1090 and Virtual Radar Server.



RTL1090 can be downloaded from <https://rtl1090.com/>. Scroll down the page to find the IMU (Installer and Maintenance Utility). Selecting that option will automatically download all the required files (Figure 18)

Unzip the downloaded file, and run the resulting installation file. If Zadig has already been installed, that installation can be skipped. Windows security and/or antivirus software may suggest that the application not be run. Click “more info” and “run anyway”.



Figure 1 The download page for RTL1090. Select the circled option.

To run RTL1090 find the executable rtl1090 application in the folder it was installed to (Figure 19).

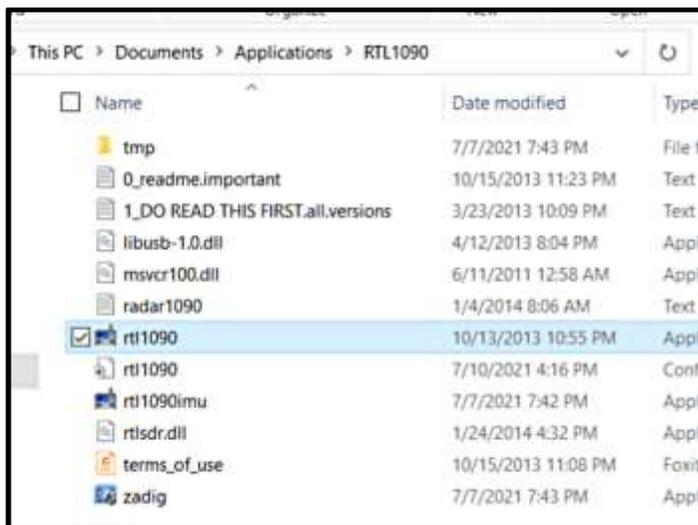


Figure 2 Double click on rtl 1090 to install

Upon opening a small square screen will appear. To start decoding press the start button (Figure 20)



Figure 3 Click Start to begin debugging

To visualize the decoded data on a map, the Virtual Radar Server is needed. VRS is Windows (and Linux compatible via Mono) based free software program which displays plane positions in a web browser using Google maps. The map can then be shared with other people over the internet if desired. Virtual Radar Server can be downloaded from <http://www.virtualradarserver.co.uk/Download.aspx>.

1. Download the VRS Windows installer from the website.
2. When installing selecting a port number for the web interface is required. Make sure that the chosen port does not conflict with another port that is being used by another web server. Then open VRS from the start menu. If by chance the VRS is installed with a port conflict, VRS won't run. If that happens, reinstall with a different port number.
3. It may be necessary to install an older version of the .NET application. This is necessary for VRS, accept and let the installer install the software.
4. VRS should install an icon in the Start menu. Click that icon to open the virtual radar server.
5. Go to Tools → Options.

- (Optional) Click on Receiver Locations and a box appears (Figure 21).

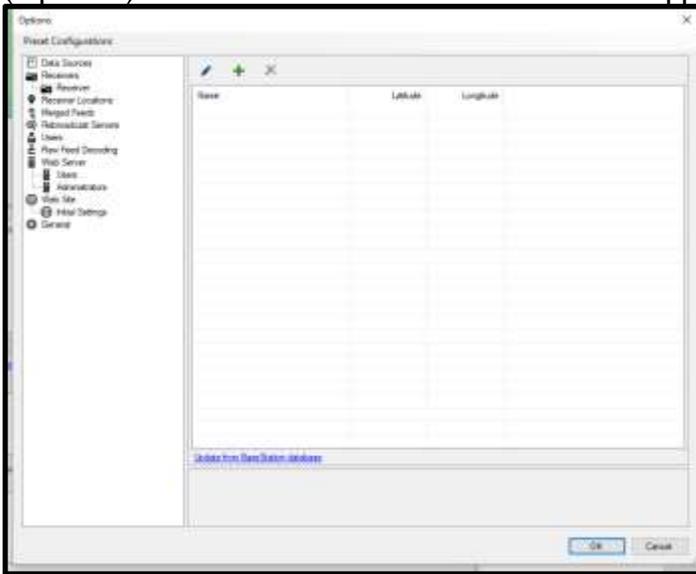


Figure 4 To add receiver location, click the "+" symbol

- Click the green + and add the name of location and coordinates of the receiver. Latitude and longitude can be determined by clicking on that location in a Google map.
- Remaining in the Options menu, in the left menu tree, click on Receivers, then click on the green plus icon to add a receiver.
- The properties of this receiver will show.
- Name the Receiver "RTL-SDR".
- Change Format to "AVR or Beast Raw Feed". Without this selectio the software will decode messages but won't track planes.
- Choose the appropriate location in the drop down box next to Location.
- Keep the IP Address at 127.0.0.1 and set the port as 31001. 31001 is the output port for RTL1090 (Figure 22).

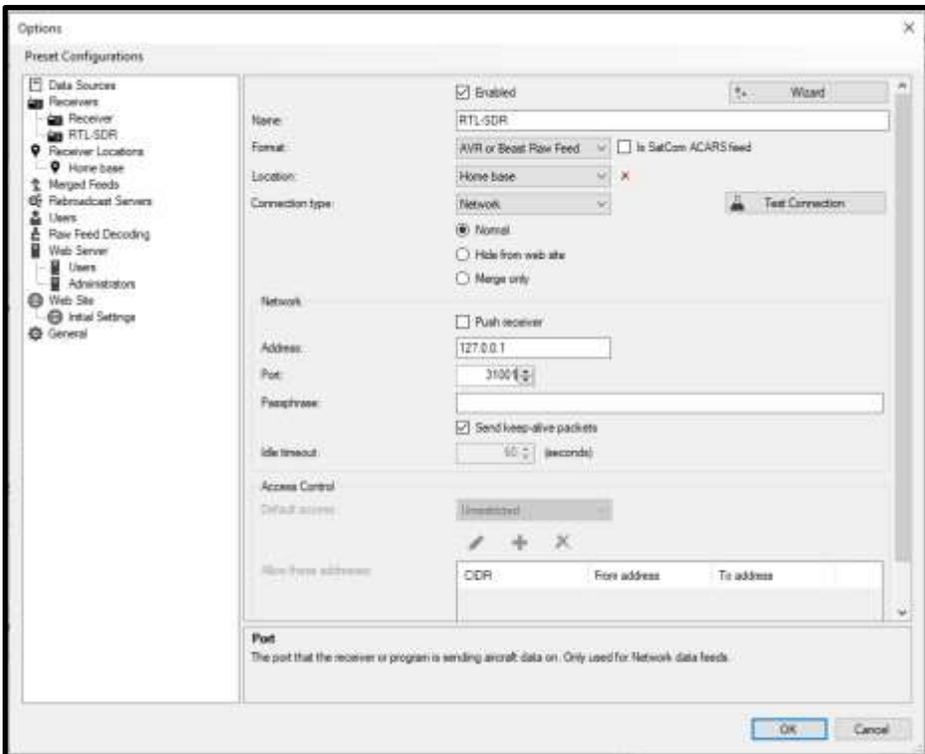


Figure 5 Correct settings for receiver location. Name and location are customizable. All other settings should match those displayed.

14. With RTL1090 running, click on Test Connection. A message showing that a connection can be made should appear
15. Click on Receivers again, and set the “Web site receiver”, “Closest aircraft receiver” and “Flight Simulator X receiver” to the RTL-SDR receiver just created (Figure 23). Press OK.

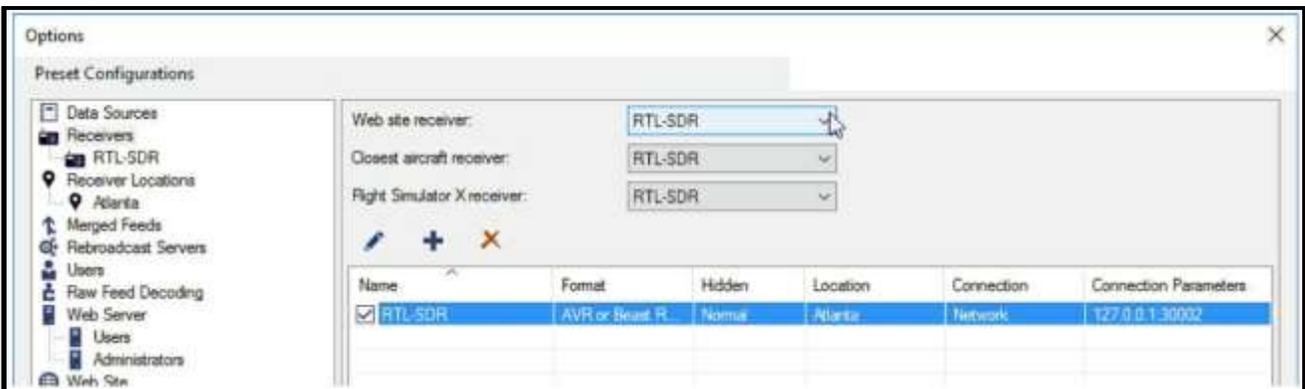


Figure 6 Setting the receivers to the local location.

Now click on the link to <http://127.0.0.1:8081/VirtualRadar> in the middle right of the VRS main window (Figure 24).

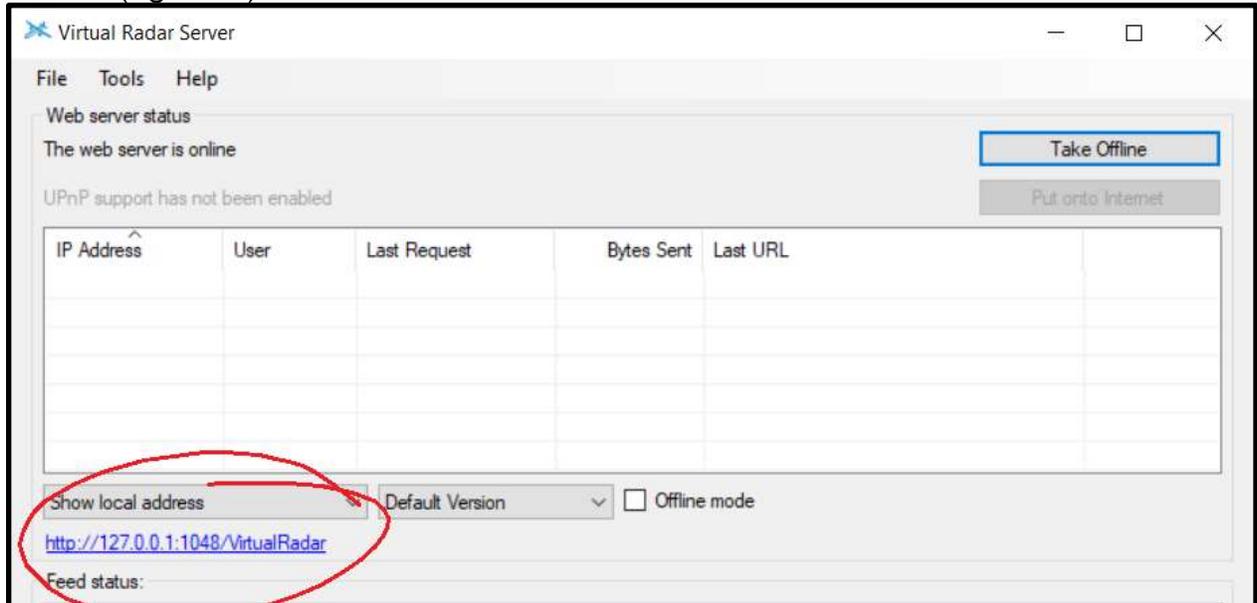


Figure 7 Click on the indicated link to connect to VRS Google Map

16. A web page with a special VRS Google map will load. Zoom out and scroll to your location on the map. Graphics of planes should appear as the ADS-B frame decodes from ADS-B decoder program.

To use Virtual Radar Server in the future simply start RTL1090 and then Virtual Radar Server.

Chapter 5 - Receiving Satellite Transmissions

Many satellite transmissions can be received by amateur radio enthusiasts. This section provides tips for modifying the basic set up to receive this data.

There are many satellites circling above the Earth that are communicating in frequencies all across the radio spectrum. There are a variety of satellite tracking applications available. Convenient web based trackers can be found at <https://www.n2yo.com> and <https://www.heavens-above.com>. These sites are a little different, but complementary. Some of the capabilities of these sites include:

- The ability to predict the times satellites will pass over your location, including identifying those passes that will be visible along with the relative brightness of the object.
- Detailed information about the orientation and altitude of the orbit of every satellite
- The ability to plot the ground tracks of satellite orbits. Heavens-above also has the ability to display orbits as viewed from above the orbital plane or from above the satellite.
- Downlink frequencies for transmissions from each satellite
- Historical information about each satellite
- Both websites include other interesting information, visualizations, and links to explore.

Many satellite transmissions can be received by amateur radio enthusiasts. Most of the signals from powerful commercial or governmental satellites require decoding to be understood. There are satellites such as amateur radio repeaters that don't require decoding, but these typically operate at lower powers and so generally require specialized antennas in order to receive an adequate signal. While both of these hurdles can be overcome by SDR users, they are beyond the scope of this introductory guide.

Nonetheless, there are a few types of satellite transmissions that may be receivable at your location with the hardware in the kit and/or some simple additional materials. Two such projects that we'll describe here are capturing NOAA weather satellite images and listening to "pirate" radio transmissions using US military communications satellites (MILSATCOM).

NOAA Weather Satellite Images

These satellites use a transmission protocol known as Automatic Picture Transmission (APT) which was developed specifically for use on weather satellites. It is an analogue transmission that is somewhat similar to the HF Fax mode used on the HF bands. APT is transmitted in grayscale, but software can be used to colorize the image.

The NOAA satellites only pass overhead at certain times of the day, broadcasting a signal. These signals appear at around ~137 MHz and only when a satellite is passing overhead. Each satellite uses a slightly different frequency. Their frequencies are shown below.

NOAA 15 - 137.6200 MHz



NOAA 18 - 137.9125 MHz
NOAA 19 - 137.1000 MHz

Satellite location can be tracked overhead using the tracking websites described above. With an appropriate antenna, transmissions can be received and identified using a dongle and SDR#. Processing the transmission to produce images requires the use of two more software applications. One to process the images and another to direct the output from SDR# to the image processing software. Installation and use of these applications will be discussed further below.

Hardware Setup

A specialized antenna is best for receiving satellite transmissions. Such antennas can be purchased, or home built with modest skills and supplies. Depending on location conditions, transmissions may be received with the supplied telescoping monopole antenna. Orient the antenna horizontally and adjust the length to $\frac{1}{4}$ wavelength long. At 137 MHz that is about 54 cm.

A likely improvement over the provided monopole can be obtained with a simple V-dipole antenna. NOAA satellites send signals with “right hand circular polarization” (RHCP), and thus a RHCP antenna is needed. A V-Dipole is the simplest antenna that can be made for receiving satellites. It is simply a dipole bent into the shape of a V, and mounted horizontally facing North-South. It is horizontally polarized, and not RHCP, but the difference is only 3dB. The wrong polarization can in fact be beneficial in this case, because a horizontally polarized antenna attenuates vertically polarized signals by 20 dB, and most terrestrial signals are vertically polarized. This can significantly reduce the effects of terrestrial interference.

A readily available V-dipole antenna is commonly known as “rabbit ears”. With a set of rabbit ears and a bit of coaxial cable, an antenna can be constructed that can receive the NOAA satellite transmissions. An example setup is shown below (Figure 25).



Figure 8 On the left is the complete rabbit ear set up. On the right is a close up of the connection.

Setups may vary depending on available hardware. Looping the coaxial cable into a balun as described in Chapter 1 will help improve the signal to noise ratio considerably. The coaxial connector shown is commonly provided with rabbit ear antennas and should be readily available in hardware stores.

The coaxial cable can then be connected to the SDR using one of the provided adaptors (Figure 26)



Figure 9 Connecting the antenna to the dongle. The picture above shows components before connection. The picture on the right shows three elements connected.

This setup introduces the potential for several impedance mismatches and consequently the received signal strength is likely to be attenuated significantly.

Rabbit Antenna Set up Instructions

1. Each arm should be $\frac{1}{4}$ wavelength long. At 137 MHz that is about 54 cm.
2. The V should be approximately 90 degrees
3. The antenna should be placed horizontally with the V opening towards the north.
4. At this point, it is possible to test the antenna and determine if it is receiving a satellite transmission. Attach the antenna and dongle to the computer and open SDR#.
5. Determine when one of the NOAA satellites is passing overhead and tune SDR# to the appropriate frequency and set the receive mode to WFM (Figure 27).

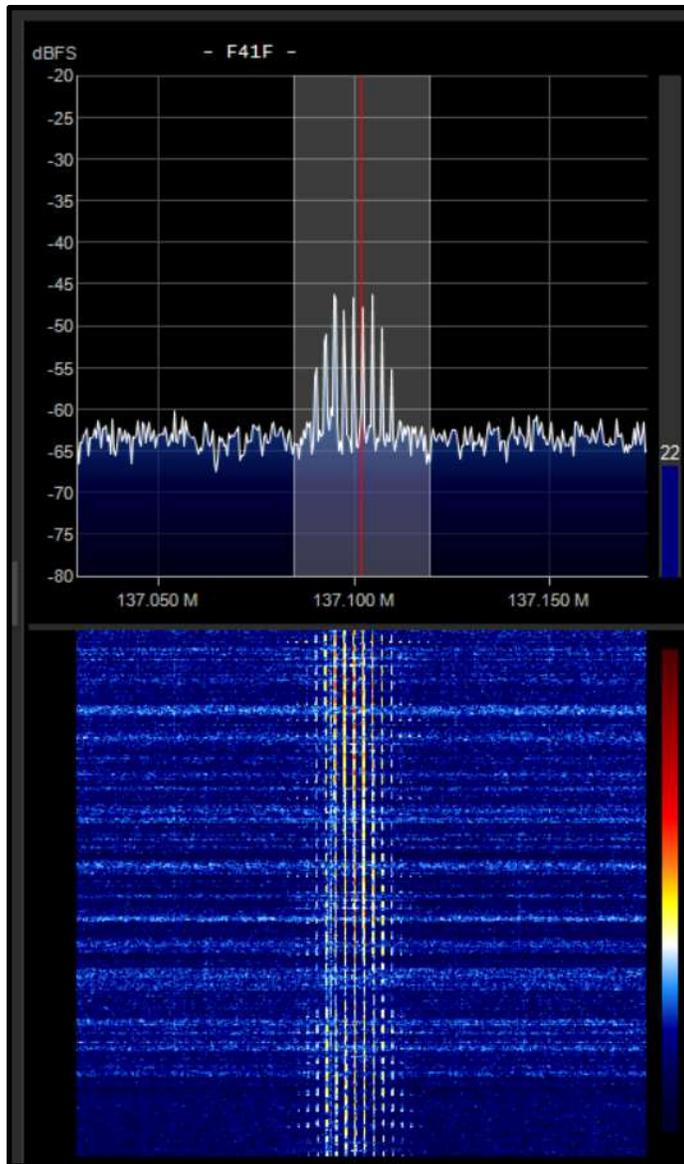


Figure 10 Example of SDR# waterfall image when receiving a satellite signal.

Software Setup

Before use image processing software can be used, audio pipe software to route the output from SDR# to the image processing application must be installed. We have used VB Cable audio pipe software successfully. To install VB Cable go to <https://vb-audio.com/Cable/index.htm>.

- I. Download the Windows version of VB Cable from the website (Figure 28).



Figure 11 Double click on the Download for windows icon

2. Extract all the files from the downloaded .zip file.
3. Right click on the VBCABLE_Setup or VBCABLE_Setup_x64 application and select “Run as administrator” (Figure 29).

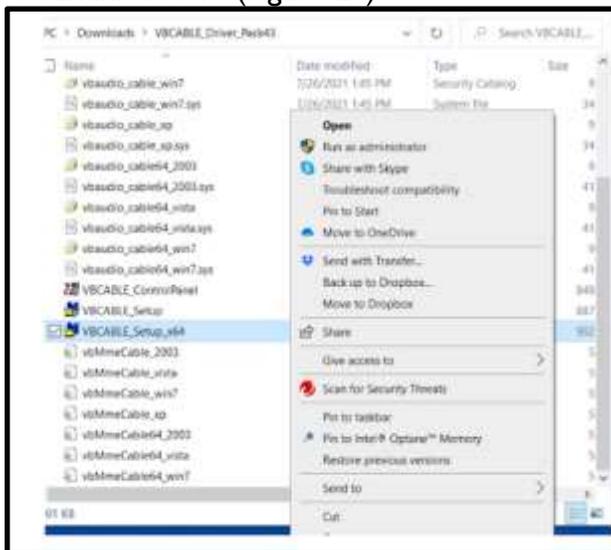


Figure 12 Right click on the VBCABLE_setup_x64 and select “Run as administrator”

4. Follow the prompts
5. **The computer must be rebooted before using VB Cable.**

After VB Cable the is installed, plug in the SDR and open SDR# and from the main menu open the “Audio” window and select “VB-Audio” as the output (Figure 30).

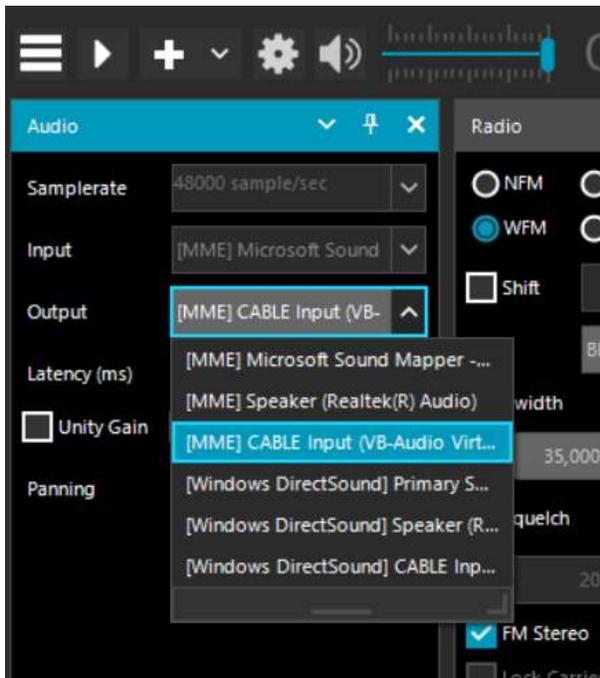


Figure 13 Select CABLE Input (VB-Audio Virt...)

Download the image processing software, WXtoImg.

1. Go to <https://www.wraase.de/wxtoimg/> and download the Windows preconfigured file.
2. Unzip the downloaded file and run the “install” batch file in the extracted folder.
3. Open WXtoImg and set Ground Station Location, by going to Options → Ground Station Location. Enter city and country, or latitude, longitude and altitude (Figure 31). The location information is used to determine when a satellite will pass over your sky.



Figure 14 Setting up the location of the ground station.

4. Go to Options → Recording Options and select CABLE Output (VB Audio Virtual) from the Soundcard menu. (Figure 32).

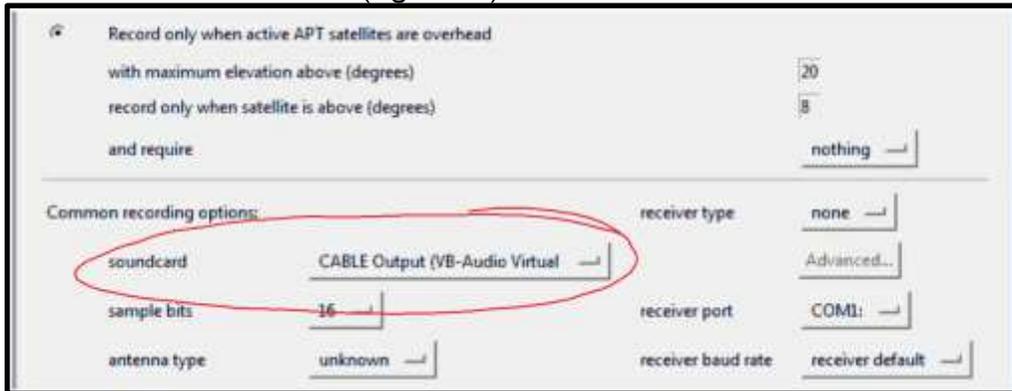


Figure 15 Setting the soundcard option. The sound card menu is circled.

5. There are options when it comes to receiving satellite transmission. The software can record continuously but that will run down the laptop battery. Alternatively, “Record only when active APT satellites are overhead” “with maximum elevation above (degrees)” and “record only when a selected satellite is above (degrees)” settings can be selected. The default values can be reduced if the antenna has a good view of the sky and WXtolmg stops recording or doesn’t start fast enough when the APT signal is present in SDR#. Because the satellite transmits directly downward, passes with higher maximum elevations will get better reception as they will pass directly overhead and there will also be less obstructions from trees/mountains etc. Elevation values should be set according to terrain.
6. The Kepler file contains the information about satellite locations which needs to be periodically updated because satellites drift in their orbit over time. Go to File → Update Keplers to do an update. An active internet connection is required for the update.
7. To view when a NOAA satellite is overhead, go to File → Satellite Pass List. Take note of the frequency of the pass as well.
8. When the time comes for the satellite to pass overhead, open WXtolmg and go to File→Record (Figure 33). Make sure that the radio button “Record only” is selected and then click on Auto Record. The recording and decoding will begin automatically when it is time for the satellite to appear on the horizon. It will automatically stop when it goes out of view according to the times in the satellite pass list. If for some reason the recording doesn’t start in time, click on the Manual Test button to immediately begin decoding.



Figure 16 The Wxtolmg record window. Select the radio button. Click Auto Record.

- Open SDR# and select audio from the menu which is represented by three lines in the upper left hand corner. Then select MME Cable Input from the Audio Output drop down box. (Figure 34).

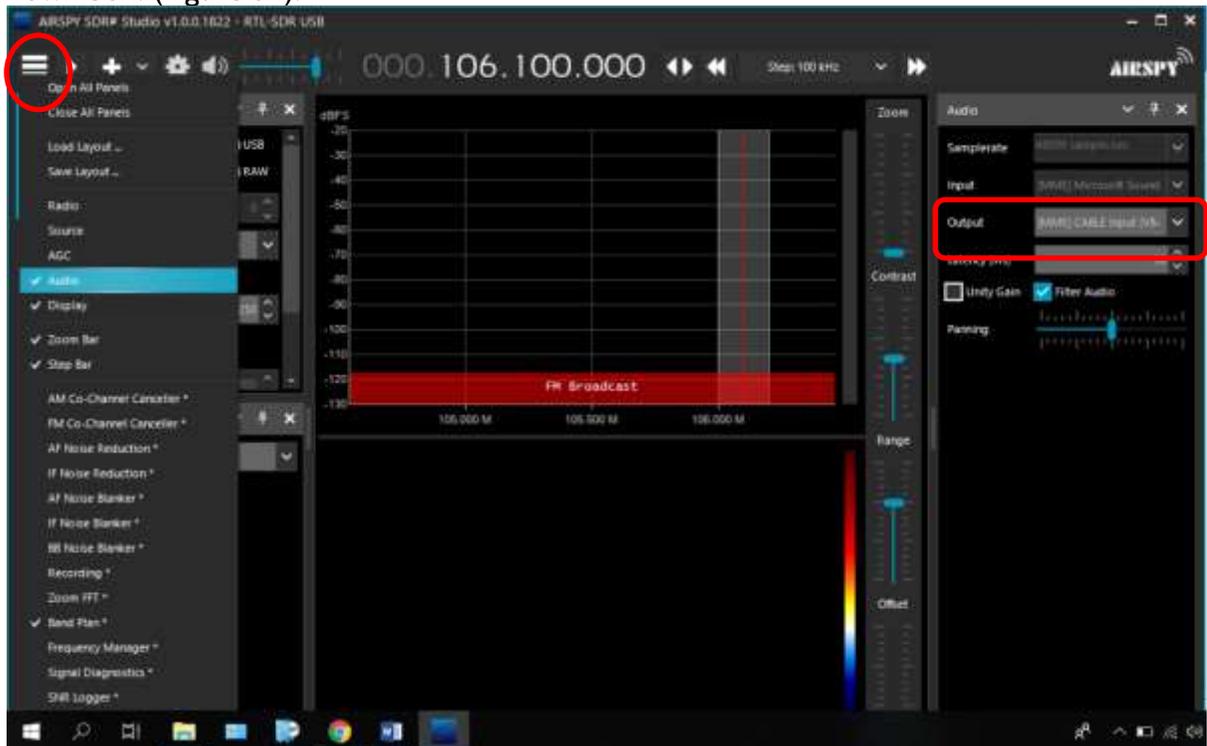


Figure 17 Audio has been selected from the menu on the left (highlighted). Then the output was selected from the drop down menu (in red).

10. Next tune to the frequency that the satellite will be broadcasting at. The frequency is found at the top of SDR# in the middle of the box. In figure 33 the frequency is listed as 106.100. To tune to a specific frequency just click above or below a number. For example, if we were to tune the frequency in figure 33 to 137 we would click above the 6 to get 7 and above the 0 in 106 to get 3.
11. Click on the configure button and adjust the gain settings to optimize the signal to noise (Figure 35). Recall that increasing the gain to approximately 40 will make the signal appear more clearly and will reduce the effects of interference.

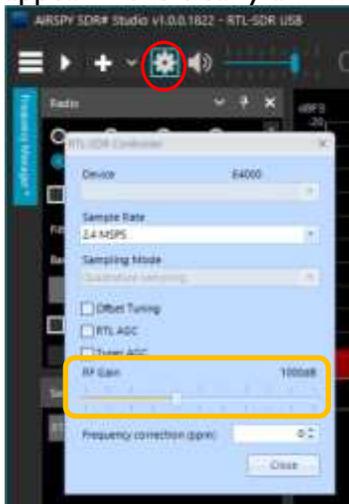


Figure 18 The Configure button is circled. In the pop-up box adjust the gain setting.

12. Adjust the volume in SDR# and/or Windows volume settings so that the volume bar in the bottom right hand corner of WXtoImg shows a green color.
13. WXtoImg should now be decoding and showing the weather satellite image as it is received. Set the filter bandwidth within the range of 36- 40 kHz so that the signal is received and is not affected by Doppler shift.
14. Once the image has been fully received, the options under the Enhancements and Projection menu can be adjusted in order to add false color and enhance the received image.

Military Satellite Communications (MILSATCOM)

From the late 1970s to the 1990's the US military launched "Fleet Satellite Communications System" (FLTSATCOM/FLTSAT or UFO) satellites into geosynchronous orbit (the satellites stay in the same spot in the sky at all times). The satellites were designed to allow for global communications between US Navy personnel at sea or on land. They operate in the frequency range of 243 – 270 MHz. Normally most military communications are encrypted, and nothing can be heard from them. However, these satellites are essentially unsecured repeaters in space, and they will sometimes unintentionally pick up and repeat signals from the earth. For example, in Russia and some parts of Asia long distance telephone calls in rural areas are made with UHF radio transmissions. These satellites can pick these signals up and repeat them back down to a wide area. Sometimes radio stations from various parts of the world can be heard.

The signals are quite strong and often a standard $\frac{1}{4}$ wave ground plane antenna tuned to 255 MHz can receive the signals. Since these frequencies are quite close to broadcast FM or DAB/DVB-T frequencies, filtering may be required.

The SDR along with the telescoping monopole antenna tuned to the vicinity of 255 MHz (29 cm long) can receive signals from these satellites. Unencrypted transmissions are occasional and sporadic.

