Detecting meteor radio echoes using the RTL/SDR USB dongle

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Abstract: The Software Defined Radio (SDR) has become a popular concept for radio astronomers and radio amateurs. Inexpensive implementations allow hobbyists to dedicate SDR devices for various experiments such as monitoring radio echoes originating from meteors, as they enter the atmosphere. In particular, the "RTL-SDR USB receiver" is a very affordable SDR that uses a DVB-T TV tuner dongle based on the RTL2832U chipset. Priced of $15 per unit (approximately), this entry level SDR, when connected to a standard computer, represents an interesting option for monitoring meteor scatter activity 24 hours a day. This paper describes a practical method to receive meteor radio echoes and explains how the web site livemeteors.com works.

Introduction of RTL-SDR dongle

The "RTL-SDR dongle" is an inexpensive SDR receiver widely available today on the market that has become very popular with hobbyists, including those interested in radio astronomy. The dongle is based on the Realtek RTL2832U chip that was initially utilized for DVB-T demodulation only, for Windows systems. Eric Fry gets the credit of discovering that the original USB dongle, sold as DVB-T receiver, is capable of providing raw I/Q samples to the host and he coded Linux software to demodulate FM from this receiver (March 2010). The software development effort around RTL2832U has been transferred to Osmocom, who were making their own E4000-based SDR at that time.

The RTL2832U outputs 8-bit I/Q-samples, and the highest theoretically possible sample-rate is 3.2 MS/s, however, the highest sample-rate without lost samples that has been tested so far is 2.8 MS/s. The frequency range is highly dependent of the tuner utilized inside the dongle.

Fig. 1

The most popular tuners available with RTL-SDR dongles are Rafael Micro R820T (24 - 1766 MHz), Elonics E4000 (52 - 2200 MHz with a gap from 1100 MHz to 1250 MHz), and R820T2 (same as R820T, but better sensitivity and lower noise, utilized in NooElec products), see Figure 1.

Typical applications require a PC running Windows or Linux with a decent CPU speed, but nothing really above the standard configuration any home based computer would have today. In fact a Raspberry Pi computer would have enough resources for most of the applications. A popular application based on Raspberry Pi is to run a server on the board that would communicate with the RTL/SDR dongle connected on the USB port, then clients would have access to the I/Q stream over the network (local or internet).

Considering the decent performances and the low price, one would expect to find many applications for this mini SDR receiver. That is exactly the case. There is a large community of hobbyists, both programmers and users sharing their software which is usually open source and free. Literally, there are hundreds, if not thousands of different applications based on RTL/SDR. One good source to learn more is http://www.rtl-sdr.com

The device utilizes a generic crystal oscillator that has no thermal control, so it is very susceptible to environmental effects. In addition, the component has an internal bias present due to the manufacturing process among other factors. Also, the R820T tuner tend to oscillate at high frequencies above 1.5 GHz. The R820T2 behaves much better, but still there appears to be a tendency for instabilities and oscillations at about 1.7 GHz, close to the upper useful frequency. Although the performances as receiver are modest, the RTL/SDR dongle can be used for radio astronomy projects as well. Using the RTL-SDR one could measure the spectra of several well-known regions of neutral hydrogen emissions, and measure the galactic rotation. For HF work, which includes NASA's JOVE project, an up converter is recommended, as the frequency range does now allow the dongle to work well below 24 MHz. It's been reported that RTL/SDR is doing a good job for VLF projects, including SID monitoring. Of course, an up converter is required.

Introduction of meteor scatter reflected signals

When a meteor enters the Earth's upper atmosphere it excites the air molecules, producing a streak of light and leaving a trail of ionization (an elongated paraboloid) behind it tens of kilometers long. This ionized trail may persist for less than 1 second up to several minutes, occasionally. Occurring at heights of about 85 to 105 km (50-65 miles), this trail is capable of reflecting radio waves from transmitters located on the ground, similar to light reflecting from a mirrored surface. Meteor radio wave reflections are also called meteor echoes, or pings.

If the radio waves from the transmitter reach the meteor trail at a perpendicular angle, then the reflected signal will be directed back towards the original transmitter. This is called back-scatter. In forward-scatter, the transmitter and receiver are separated often by hundreds of kilometers or more, so the broadcast signal is reflected forward to the receiver from a meteor's ionization trail, which must lie somewhere between the two places. This paper refers to forward scatter only.

If we consider a transmitter with power P_T and antenna of gain G_T and a receiver with an antenna of gain G_R pointed in the direction of the reflection point, and R_T and R_R are the distances of the transmitter and the receiver to the reflection point, λ the radio wavelength used, r_e the electron radius, q the line density of the meteor trail at the reflection point, γ the angle between the incident electric field vector and the direction of the receiver (as seen from the reflection point), φ the half forward scatter angle, i.e., the half of the angle between transmitter and receiver, also as seen from the reflection point, and β the angle between the trail and the propagation plane, then the maximal received power P(0) is approximately given by:

$$P(0) = \frac{P_T G_T G_R \lambda^3 r_e^2 q^2 \sin^2\gamma}{32\pi^2 R_T R_R (R_T + R_R)(1 - \sin^2\phi \cos^2\beta)} \exp\frac{-8\pi^2 r_0^2}{\lambda^2 \sec^2\phi},$$ [1]

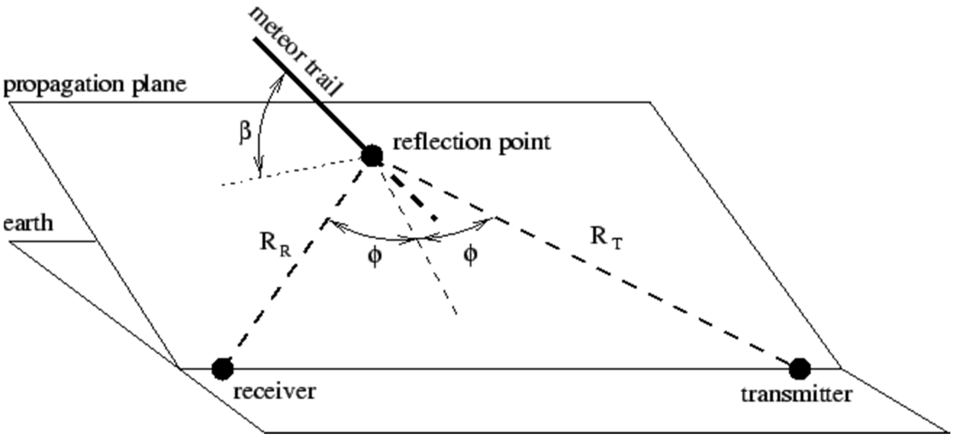


Fig. 2

An approximate expression for the duration of an is given by:

$T_{echo} = (\lambda^2 \sec^2(\varphi)) / (16\pi^2 D)$ [2]

D is the electron diffusion coefficient (m^2/sec), with an empirical value at an altitude between 80 and 100 km given by (h in km, D in m^2/sec):

$\log_{10}(D) = (0.067\ h) - 5.6$ [3]

From equations [1] and [2] we can derive the fact that the echo power is proportional to λ^3 and the echo duration is proportional to λ^2. This is important, as it may determine the optimal frequency used for forward meteor scatter observations.

For meteor echo observations, lower frequencies (approximately below 30 MHz) are not usable, because more often than not there is reception of the broadcast through ionosphere propagation, masking the meteoric reflections. Higher frequencies (around 150 MHz or higher) are not suited either, as theory shows the maximal height of observable meteors decreases with increasing frequency, and so do the duration and power of the received signal. The ideal frequency range for continuous meteor detection using forward scatter is between 40 and 70 MHz.

The ideal source of radio signals in that band should be continuous and powerful. For many years the video carrier of analog TV transmitters has been the best choice for forward meteor scatter monitors, especially channels 2 – 5 (see Table 1). The loss in signal strength at higher frequencies is caused by [1], and it can be on channel 5 4.3 dB below channel 1 for the same meteor echo

TV channel	Video carrier (MHz)	Ratio ref ch2	Loss dB
Ch. 2	55.25	1	0
Ch. 3	61.25	0.73	-1.3
Ch. 4	67.25	0.55	-2.5
Ch. 5	77.25	0.36	-4.3

Table 1

The problem is that analog TV has been discontinued in United States and it has been replaced with digital TV (DTV) on June 12, 2009. DTV does not utilize a powerful video carrier and digital television modulation systems are about 30% more efficient than analogue modulation systems overall so one expects that the transmitted power for DTV to be smaller. For forward meteor scatter detection receivers can take advantage of the ATSC pilot signal specific for each DTV channel, slightly lower in frequency than the analog video carrier. Unfortunately ATSC pilot signals are difficult to use because they do not carry too much RF power.

The good news is that some Canadian TV analog transmitters are still broadcasting powerful signals that can be utilized in wide areas of continental US. One good example is CHBX-TV in Sault Ste. Marie, Ontario transmitting on channel 2 analog TV 100 kW of power. To estimate the maximum range of a signal reflected by a meteor trail, one could resolve a simple geometry problem. The maximum distance would be:

$D_{max} = 2\ R\ \mathrm{acos}(R/(R+H))$ [4]

R: Earth radius (6371 km)
H: Altitude of reflexion point (85…105 km)

The maximum theoretical distance to utilize a continuous transmitting tower for meteor scatter detection ranges between 2070 and 2300 km. If we consider a conservative distance of 2000 km around the CHBX-TV tower located in Sault Ste. Marie, Ontario, the area coverage could be plotted (Fig. 3). More than half of US states could benefit from this Canadian transmitter for meteor detection projects.

Fig. 3

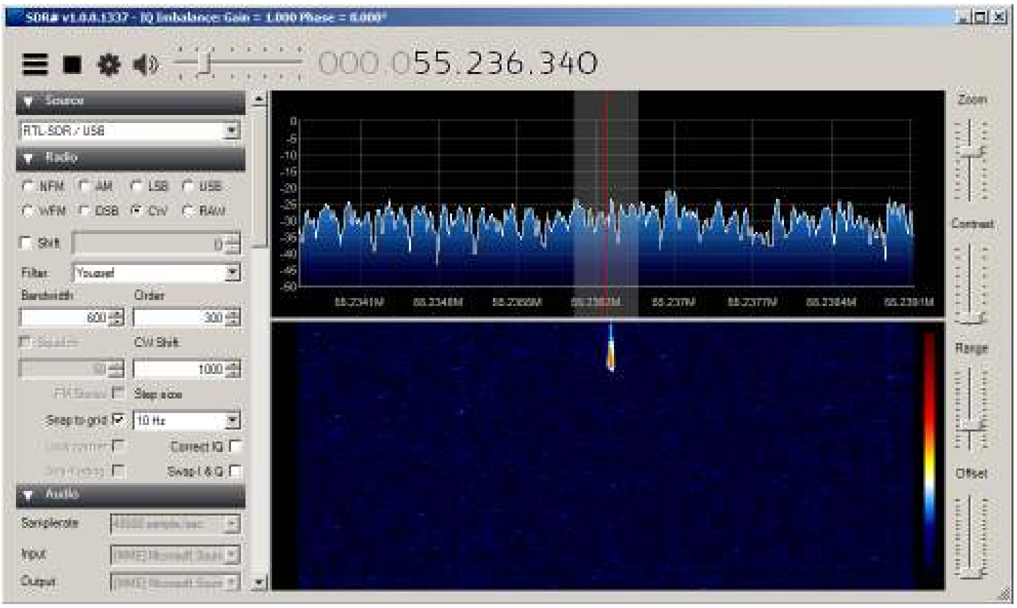
System diagram and configuration

The receiver located in Chantilly, Virginia, consists of a RTL/SDR dongle that has internally a R820T tuner, connected to a computer running Windows 7 Professional. The computer is built around an old AMD Athlon II at 3.10 GHz, with 4 GB RAM.

Antenna is a 5-element Yagi designed as TV antenna for low-VHF channels (Fig. 4). A TV rotator allows 360 degrees azimuth orientation. Currently the antenna is pointing to CHBX-TV in Canada. The reception chain utilizes now a CM-7777 Titan 2 Antenna Preamplifier (LNA) that provides, as per specifications, a 30 dB gain. The LNA is located on the mast.

Fig. 4

The software running on computer consists of SDR# (Fig. 5) and ARGO (Fig. 6). The audio signal demodulated by SDR# is routed internally to ARGO through Window's stereo mixer.



SDR# v1.0.0.1337 - IQ Imbalance: Gain = 1.000 Phase = 0.000°

000.055.236.340

Source: RTL-SDR / USB

Radio: ○ NFM ○ AM ○ LSB ○ USB ○ WFM ○ DSB ● CW ○ RAW

☐ Shift 0

Filter: Youssef

Bandwidth 600

Order 300

CW Shift 1000

Snap to grid ☑ Step size 10 Hz

Correct IQ ☐

Swap I & Q ☐

Fig. 5

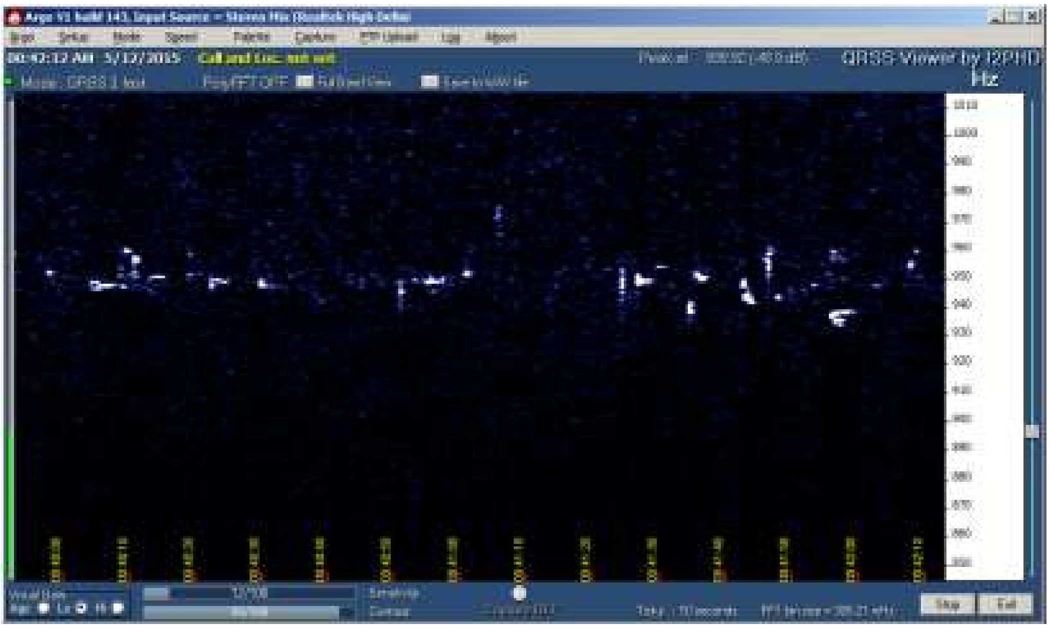
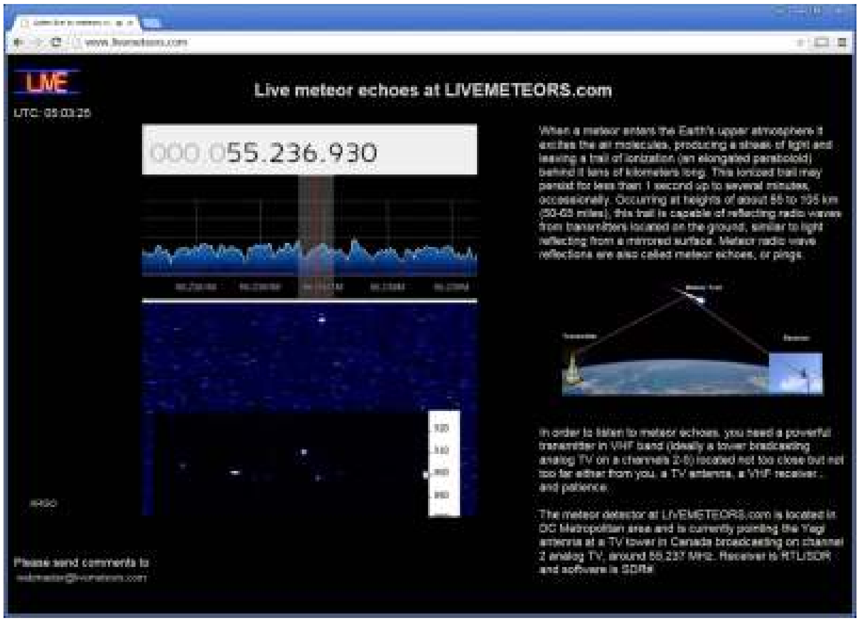


Fig. 6

LiveMeteors.com

The system is available 24/7 for users to enjoy at the address http://www.livemeteors.com



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In order to listen to meteor echoes, you need a powerful transmitter in VHF band (ideally a tower broadcasting analog TV on a channels 2-6) located not too close but not too far either from you, a TV antenna, a VHF receiver, and patience.

The meteor detector at LIVEMETEORS.com is located in DC Metropolitan area and is currently pointing the Yagi antenna at a TV tower in Canada broadcasting on channel 2 analog TV, around 55.237 MHz. Receiver is RTL-SDR and software is SDRsharp.

Fig. 7

In order to provide live audio and video streaming, additional software was installed on the local computer, while a dedicated media server dispatches the streaming in a web page.

On the local computer Open Broadcaster Software (OBS) has been installed to capture relevant areas of the screen covered by SDR# and ARGO. The live images are combined with the system sound and routed to the media server.

The media server is based on a http server (nginx) and a specialized RTMP plugin. Because it is recommended the live stream to be available on port 80, rather than other non-standard port, the server had to run on a separate machine, not to conflict with the Apache's port 80 supporting the web site. A VPS (virtual private server) was the best choice to run nginx.

The web site runs on a standard dedicated server and at this time it has only one single page. The clients connecting to this page must have Adobe Flash Player in order to display live streaming in the web page.

To summarize, the LiveMeteors.com system utilizes a dedicated server, a virtual private server, and a desktop computer, all running continuously to deliver the live service.

Conclusion

Forward scatter meteor detection is these days a project that can be completed by anyone in a weekend on a very low budget. A TV antenna, some 30ft coax 75 ohms cable, a $15 RTL/SDR receiver and a desktop or a laptop is all what one needs to get started. Software is free. Once the system works and the meteor echoes are detected, this project could go further: counting the meteors, listening on multiple frequencies the same echoes to compare amplitude and spectrum (with more than one USB dongle connected at the same computer), analyzing the spectrum features for Doppler shift effects, analyzing the amplitude to distinguish between underdense meteors and overdense meteors, plotting a curve of annual meteor shower activities, and so much more.

References

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