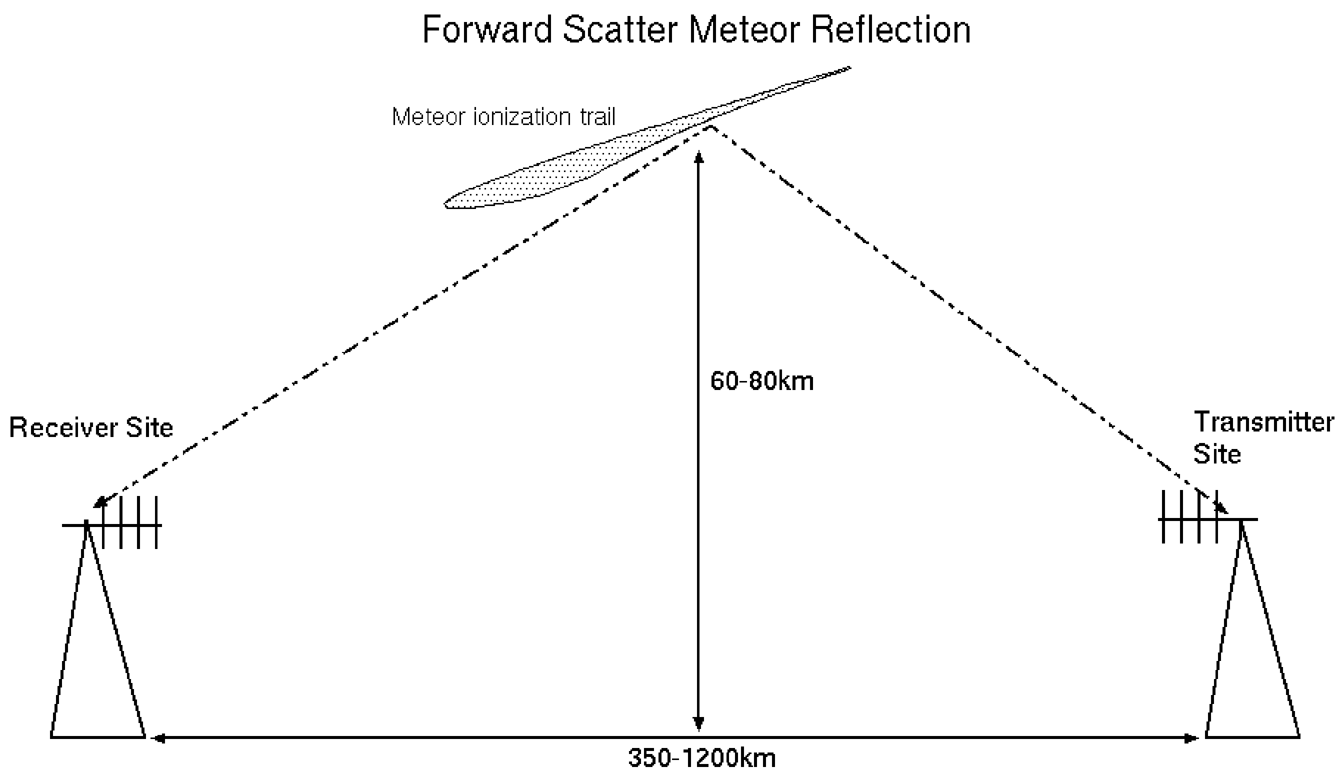
Forward-Scatter Meteor Detection using *Gnu Radio* + RTL-SDR devices

Marcus Leech, Science Radio Laboratories

Introduction

The technique of *forward-scatter* meteor detection has been well-known for several decades. The technique involves the use of a distant radio transmitter—a transmitter that is beyond the usual ground-wave propagation horizon, to detect meteor transits through the *common scattering volume*[1]. Amateur efforts in this area are plentiful. The International Meteor Organization has an active special-interest gorup dedicated to radio observations, for example[2].

The following diagram illustrates this concept:



Path lengths of 350-1200Km are typical. Below 350km, the direct, tropospheric, path can interfere with detections from the forward-scattered signals.

1 See: http://www.dxfm.com/Content/propagation.htm
2 See: http://www.imo.net/radio/intro

Traditional Observing Practice: Broadcast FM Radio

In a traditional amateur observing configuration usually involves the use of a lightly-modified FM broadcast receiver, and a simple directional antenna. In this mode, the *mute* function on the FM discriminator on the receiver is monitored and used to determine when the receiver is *unmuted*, due presumably to a meteor transit through the *common scattering volume* between the distant transmitter and the receiver.

With this technique, the observer is able to produce hourly counts of events in which the FM demodulator is *unmuted*. Given the protected nature of the FM broadcast band, most of these events will be due to meteor transits, although transient tropospheric propagation modes also exist at these frequency ranges, and can be long-lived.

While this technique provides information about meteor counts, it provides no information about reflected power levels—there's no way to distinguish between events that are just barely able to *unmute* the receiver and those that are one or two orders of magnitude stronger.

This technique has the desirable property that it's easy to achieve, even by an experimenter with little background in radio electronics.

Traditional Observing Practice: VHF Broadcast Analog Television

A second technique popularly employed by amateur observers is to use the video carrier from an analog television station at a suitable distance. This technique has traditionally been very popular, due to the relatively low-density of high-power VHF television stations—it's easy to find a channel where the distance to the nearest station is appropriately large.

Various equipment configurations are used to observe TV carriers, including modified TV front-ends and IF strips, providing a voltage proportional to detected power—either from a video detector circuit, or measuring the AGC voltage on the front-end of the TV electronics. Since there is now a voltage proportional to detected power, the observer can get some quantitative data on the magnitude of the peak scattered energy, or even how that scattered energy varies over relatively-short timescales (seconds).

SDR Techniques: Detection and FFT analysis

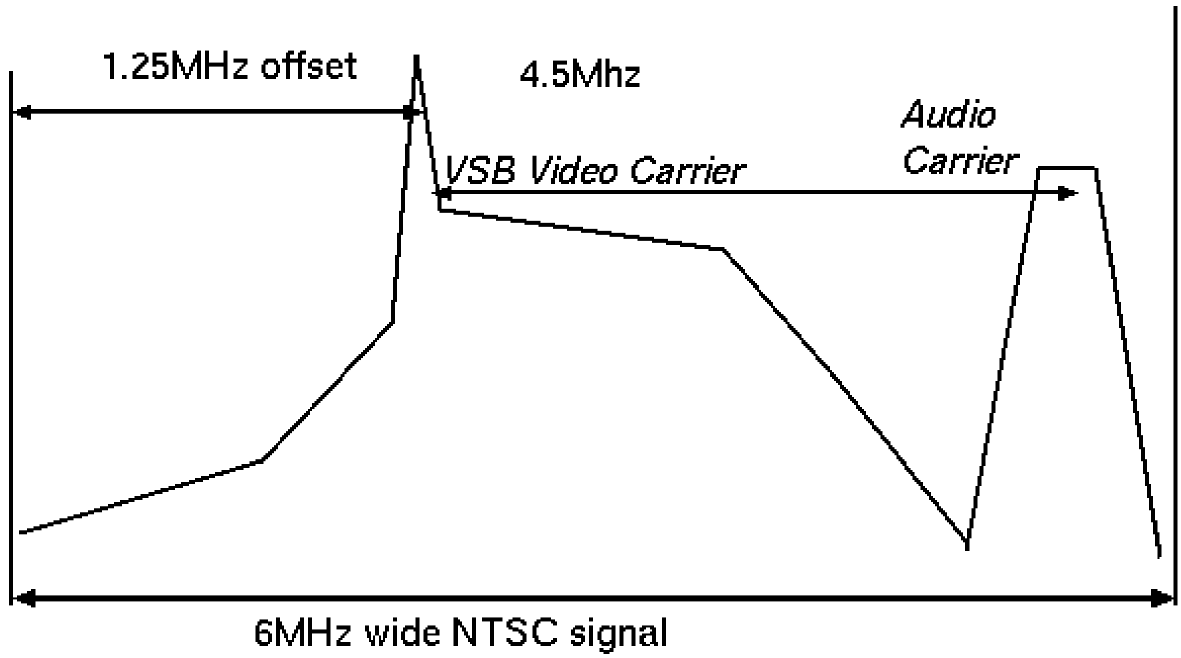
Modern, *Software Defined Radio* techniques move much of the signal processing functionality of a radio into a series of software functions intended to replace the functions of a typical analog radio. In a typical SDR-based receiver a *direct-conversion down-converter* converts the desired band around the desired center frequency to a *complex base-band* signal. This base-band signal is then sampled by two coherent Analog-to-Digital converters (ADCs). The resulting *digital base-band* signal can then be processed as a series of time-domain complex samples using many different techniques that provide filtering, detection, spectral analysis, etc.

Several different software frameworks exist to allow the construction of signal-processing work-flows in software. One such framework is *Gnu Radio*[3], and the work described here makes extensive use of the *Gnu Radio* framework.

3 See: http://www.gnuradio.org

A significant advantage to an approach that yields digital time-domain base-band samples is that FFT analysis becomes fairly straightforward. This allows analysis of the Doppler components of the received forward-scattered signal. Such components provide information about relative velocities of the meteor trail. This assumes a narrow-band source signal whose Doppler analysis is straightforward. Conventional analog television has a strong, narrow band, CW component at the video carrier frequency that is relatively stable over the time-scales of a meteor scattering event.

This is illustrated schematically below:

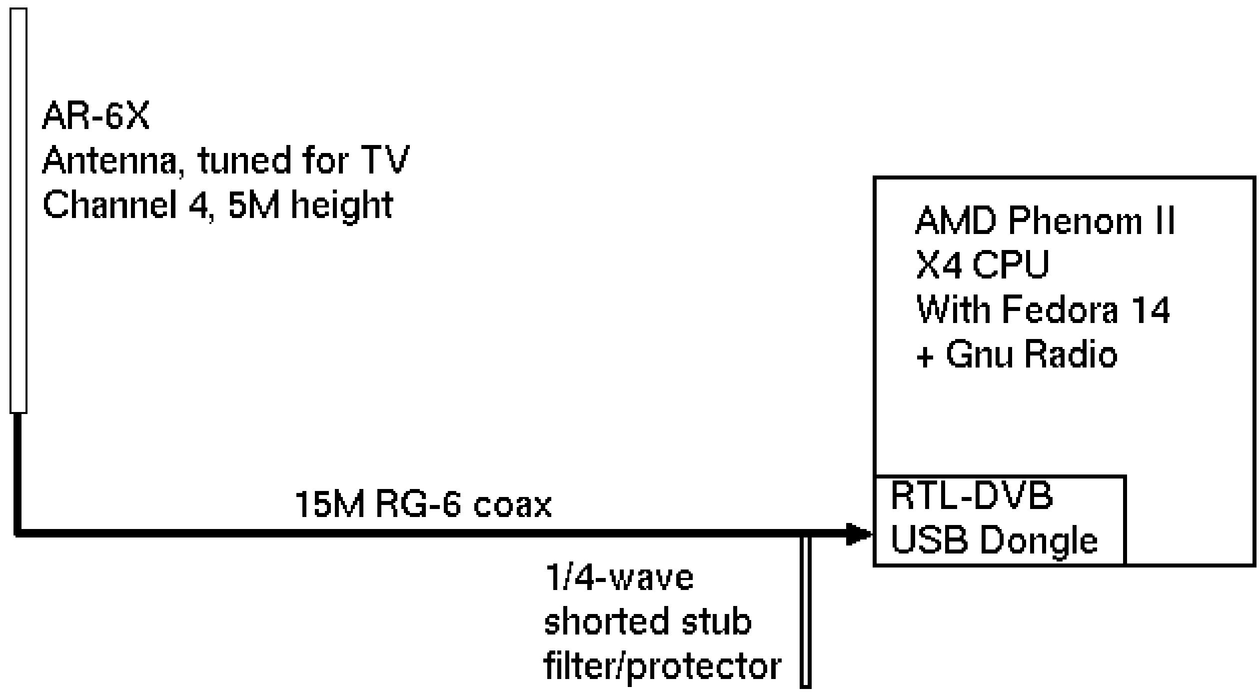


Note that the video carrier is VSB modulated, which is similar to AM, but with the lower sideband significantly attenuated to save bandwidth. The central spectral component in the VSB carrier tends to be stronger than the other components, and quite stable. So this component can easily be used to measure Doppler signatures of an analog TV signal that is scattered by a meteor event.

Unfortunately, in North American, NTSC video signals are rapidly disappearing from the landscape, being replaced rapidly with ATCS digital-video signals that have no convenient narrowband spectral feature that can be used in the same way as the NTSC video carrier can be.

A Gnu Radio Based 3 Channel Meteor Receiver

A Gnu Radio based receiver has been constructed, with 3 detector channels. Each detector channel can be selected from an input bandwidth of 2MHz. A system overview of the currently-deployed experiement is shown schematically below:



The signal flow is relatively straightforward. The un-amplified signal arrives from the antenna via a length of RG-6 coaxial cable, where it is filtered with a 1/4-wave stub filter, and presented to a *RTL-SDR*[4] DVB-T "dongle" which provides a 2Msps baseband sample stream to the *meteor_detector* application that was written using *Gnu Radio*. The RTL-SDR Dongles are extremely-cheap DVB-T sticks that can re-purposed as general-purpose SDR receivers, covering frequencies from 64Mhz to 1.7GHz.

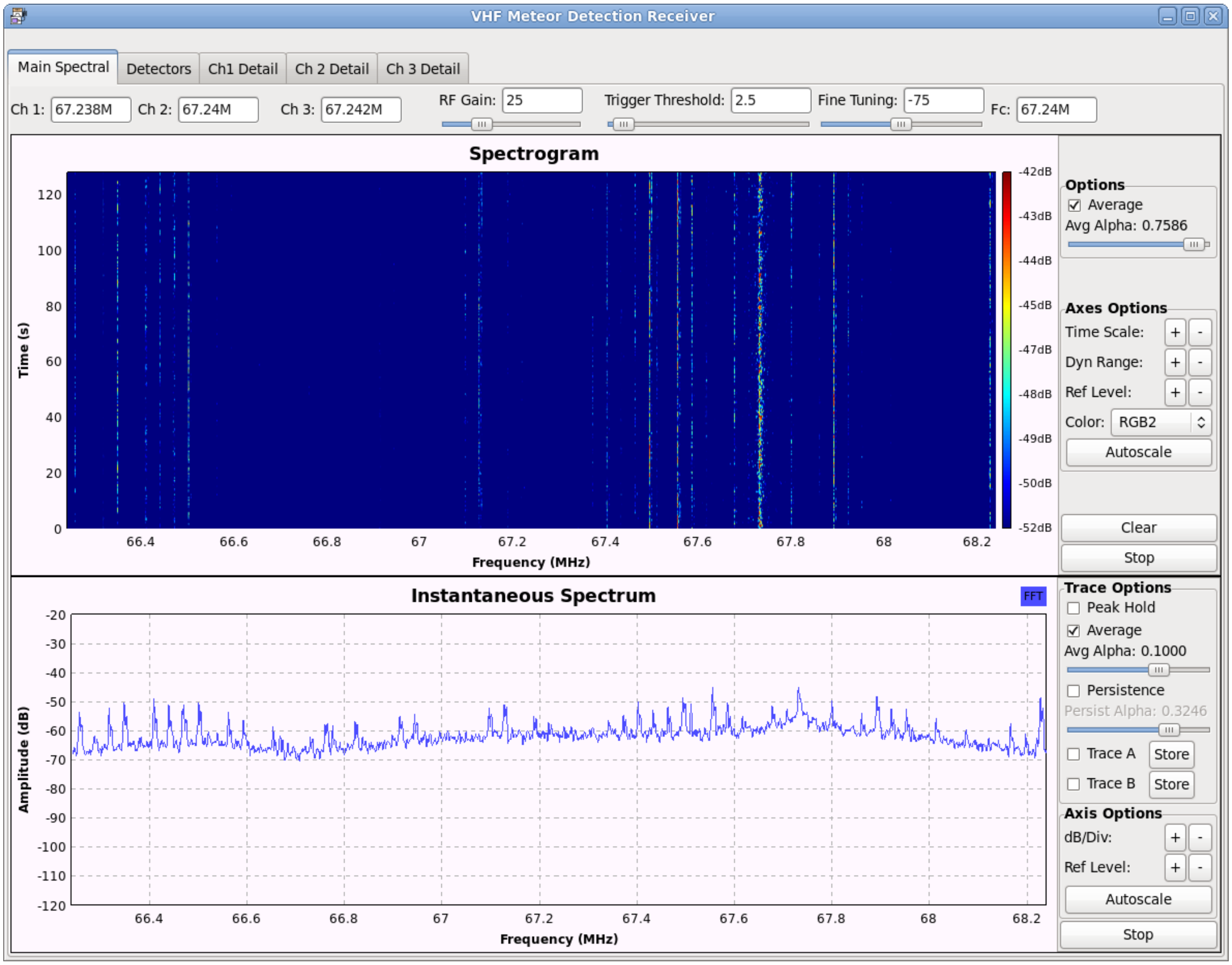
Discrete narrow-band channels are filtered from the input 2MHz bandwidth, and presented to thee *complex-to-mag**2* detectors and low-pass filters. The detectors are polled at 20Hz, and a threshold-based triggering algorithm is used to determine whether to record detector data or not. Similarly, the triggering decision also causes the complex baseband channel signals to be recorded simultaneously. Recording of the complex base-band allows post facto analysis of Doppler signatures and other post-facto analysis techniques.

A 2Mhz input bandwidth allows flexibility in the observing paradigm—either a single video carrier, or up to three other carriers, such as broadcast FM may be used. With broadcast FM, the 2Mhz input bandwidth spans 10 standard FM broadcast channels. In some locations, it's relatively easy to find 3 "empty" channels within a 10-channel span. For observing using TV video, the alternative channels can be used as a "sanity check" on the central video carrier channel. A detection is unlikely to "light up" anything but the central video-carrier channel, due to the spectral structure of an NTSC video signal.

Channel bandwidths for the 3 detectors are variable in 500Hz steps from 500Hz to 3KHz. With video carrier detection, narrow bandwidths tend to be more sensitive.

The "front panel" of the meteor_detector application is shown below:

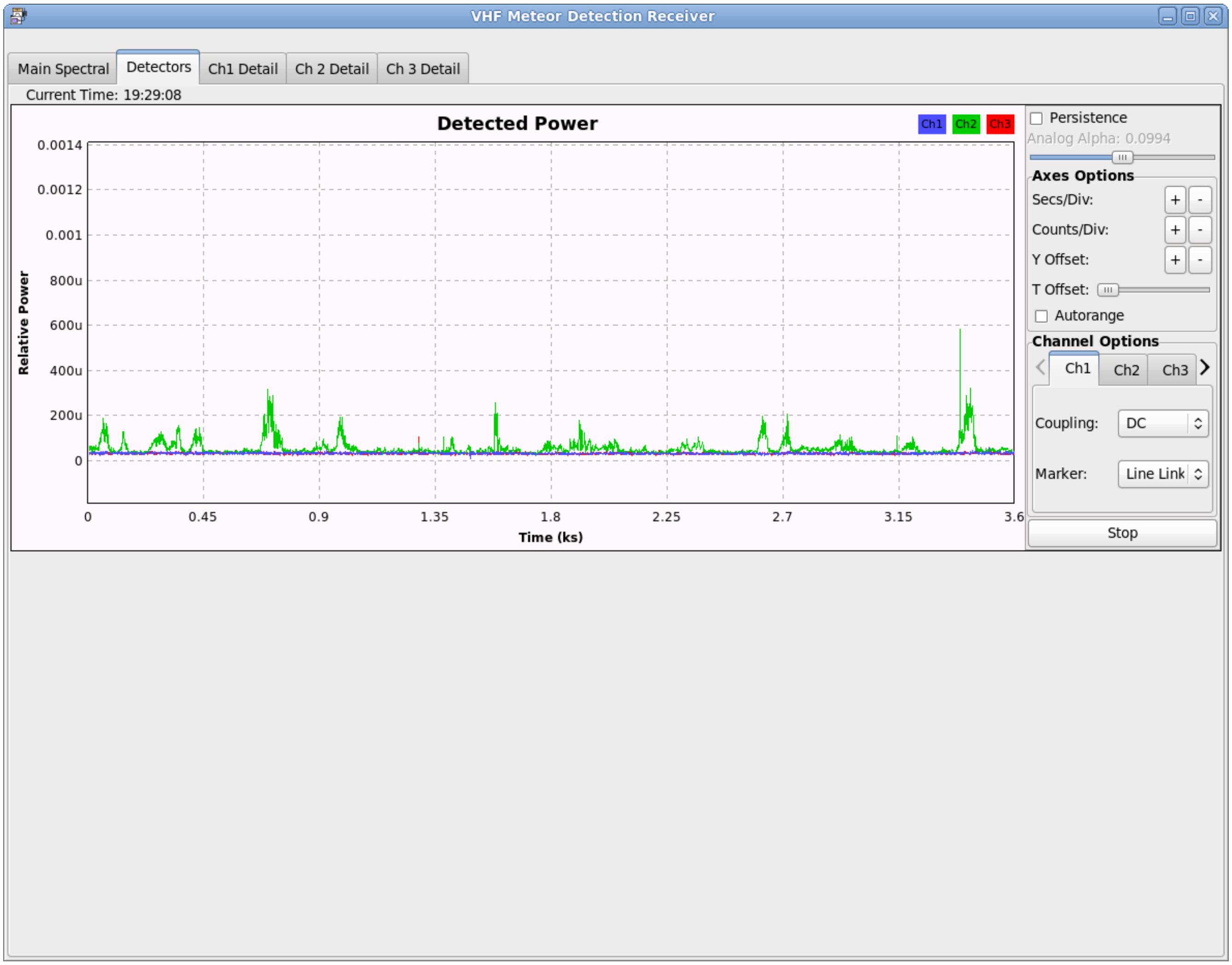
4 See: http://sdr.osmocom.org/trac/wiki/rtl-sdr



This shows the input 2MHz bandwidth, both as a conventional PSD spectrum, and as a colour-mapped spectrogram.

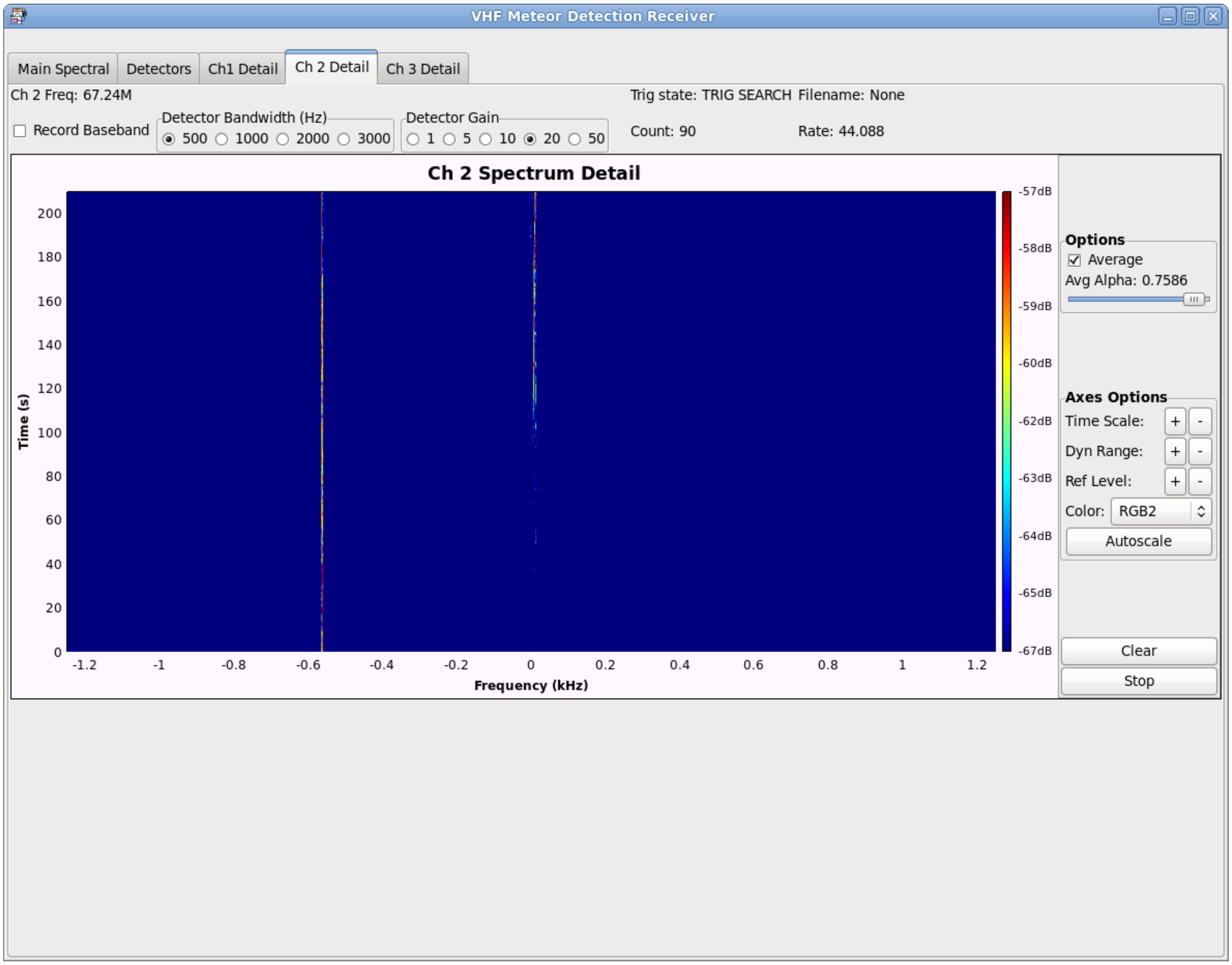
It also contains controls for selecting the tuner frequency, fine tuning, and the frequencies for the 3 input channels, as well as the RF gain, and detector threshold.

The instantaneous detector outputs are displayed in a strip-chart display, as below:



Shown above, we can see that the central channel, in this case tuned to the TV channel 4 video carrier at 67.240Mhz (shown in green above) contains several significant events, whereas the “check” channels either side of the central channel have no such events shown, which is precisely what is to be expected using a TV video carrier.

Spectral details for each channel are shown in a separate panel, shown below:



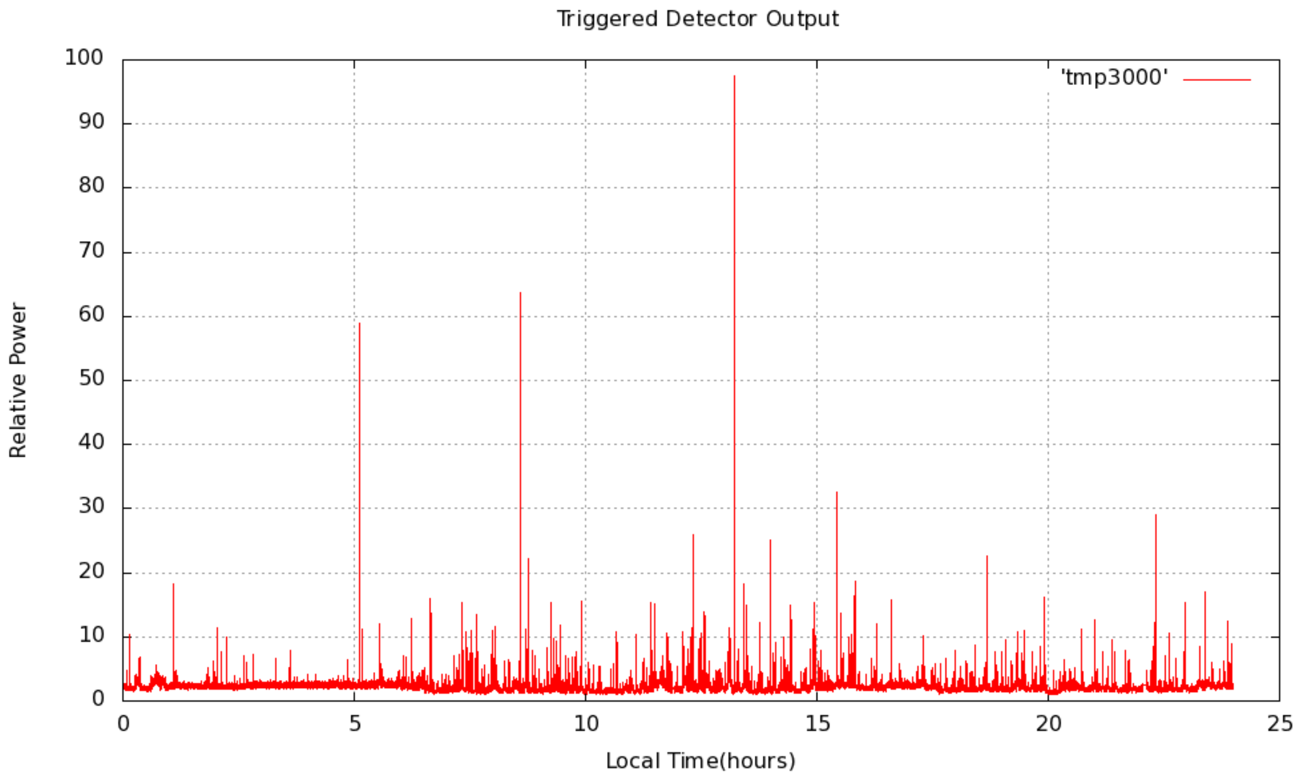
Above, we can see the tail end of an “event” near the middle, at 0Hz, and a local spur, offset almost -600Hz from the central carrier spectral component.

This panel also shows event counts, and rate estimates, and allows control over detector gains, and bandwidths.

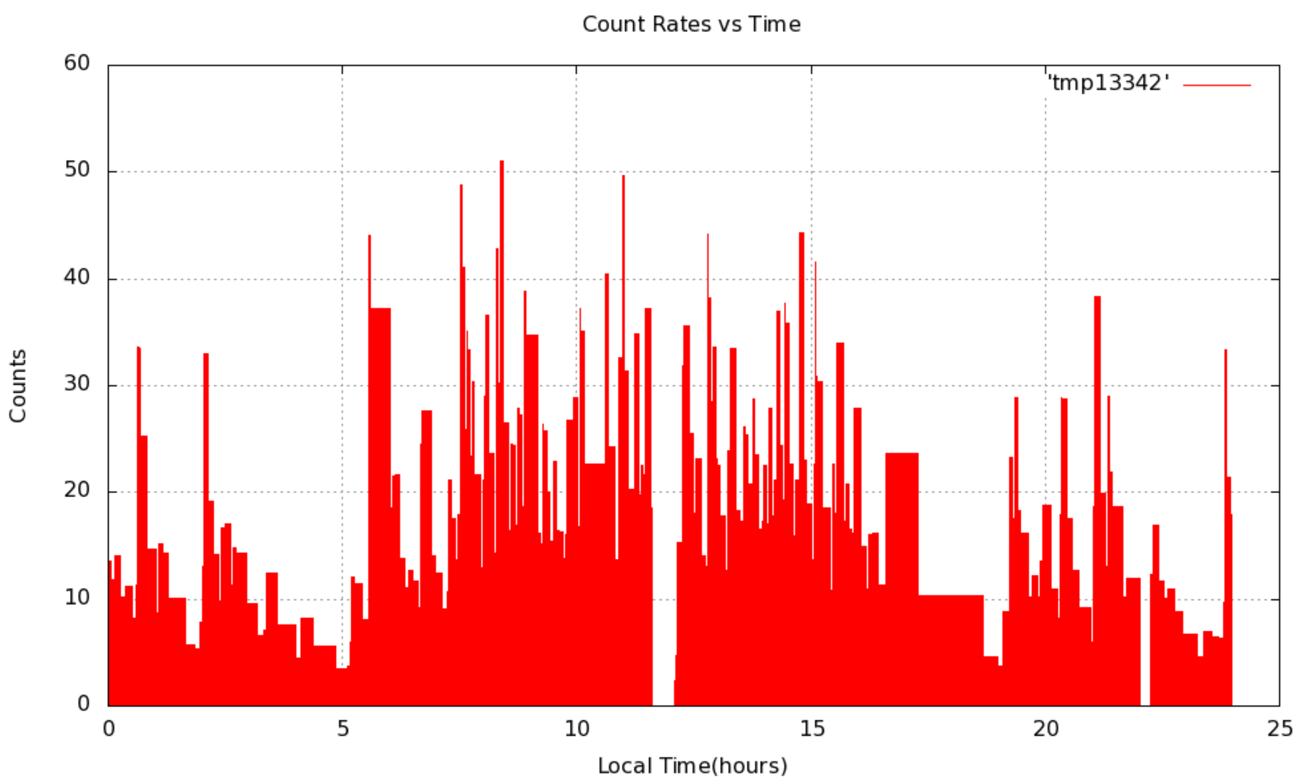
Post processing

The receiver application uses a triggered-recording approach to recording events, and the complex baseband data that accompanies the detector data.

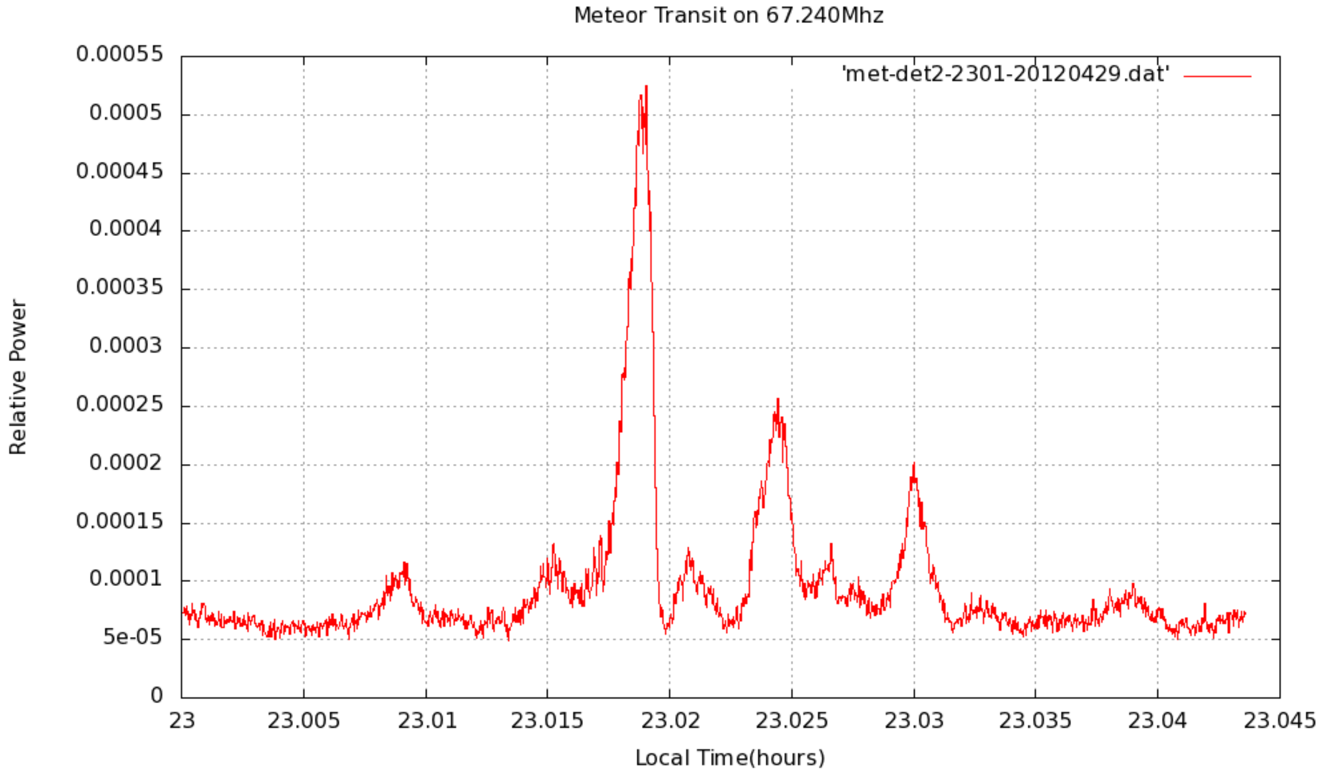
Along with triggered-event recording, detector data is also recorded in a so-called daily event record, with a 1Hz time-domain resolution. Such a daily record is shown below.



Also, a daily record of event rates (events/hour) is maintained, and is shown below

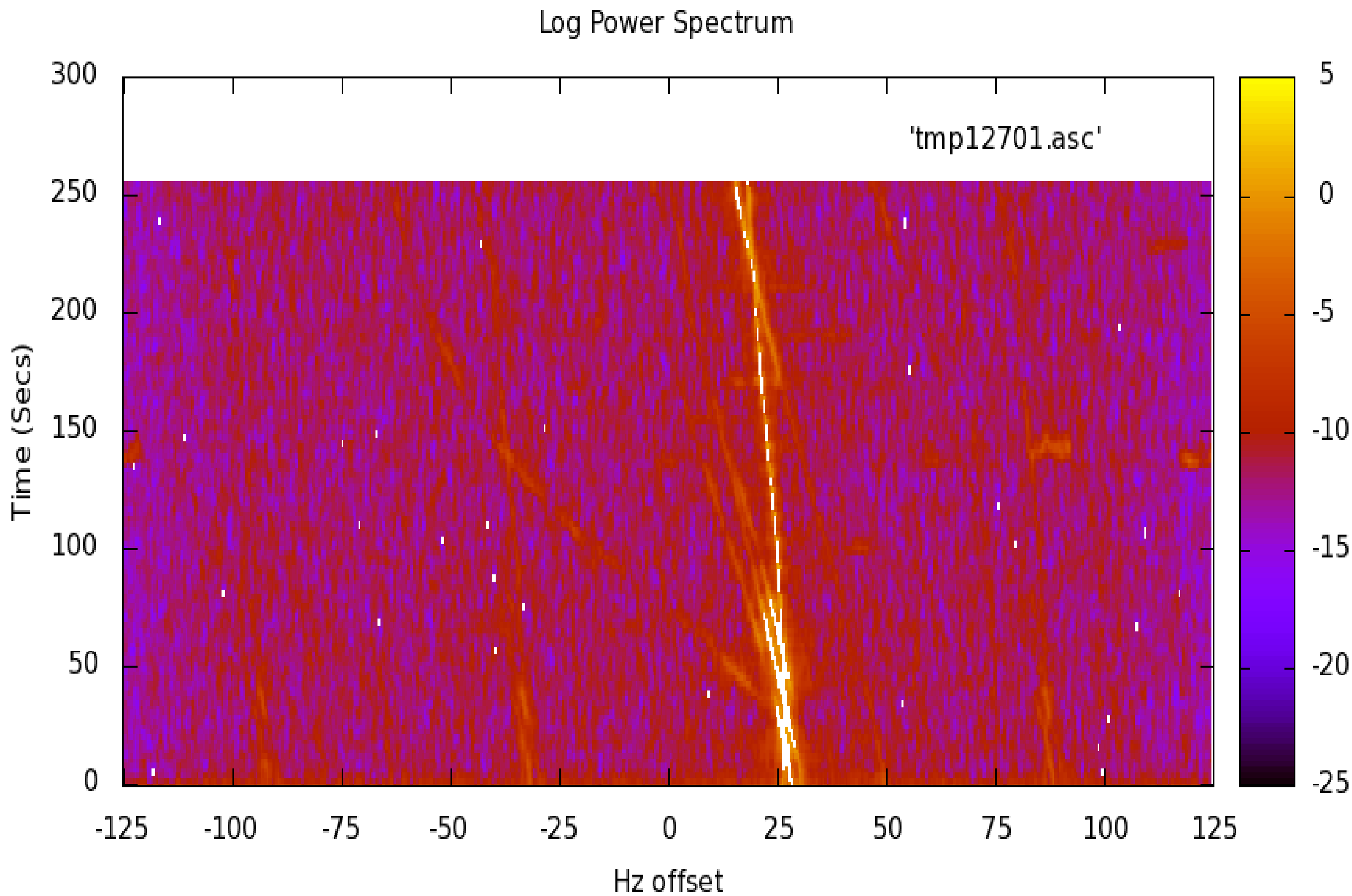


Individual detector events are recorded with high-resolution (20Hz currently). A typical event is shown below:



It's easy to see the large-timescale scintillation effects in the above event record, as the specular-reflective "surface" of the ionization trail causes changes in received power as the trail moves relative to the receiver.

Along with the detector data, the baseband data can also be analyzed post-facto. Shown below is a spectrogram of the central 250Hz of the baseband data during a detection event:



The above spectrogram shows several spectral features whose frequency changes over the course of the observation, and with further analysis can yield information about relative velocities. Weak 60Hz harmonic content is shown above for the first few 10s of seconds of the event, strongly suggestive of the video-carrier origins of this event. In fact, NTSC video signals have observable components at 60Hz and 15750Hz intervals (vertical refresh interval, and horizontal sync frequency respectively).

Conclusions

Simple, cheap, SDR-based platforms provide a suitable basis for a sophisticated amateur-scale system for radio-based meteor detection, allowing sophisticated analysis providing both received-power estimates, and the ability to perform doppler analysis of the baseband signals.

The work described above is available via the CGRAN website, via "SVN" at:

https://www.cgran.org/svn/projects/meteor_detector