~ Sweepers ~

by Dave Typinski

While observing Jovian and solar emissions at 20.1 MHz, interference in the form of signals that sweep from low to high in frequency are often observed. Presented here is a brief description of one kind of "sweeper" that is found in the HF spectrum: over the horizon radar (OTHR). These appear as diagonal lines in HF spectrograph plots and as spikes in strip charts. I found that the sweepers I observe at 20.1 MHz are radar signals; I also found that the ionospheric sounders that I can detect do not transmit above 20 MHz.

The Observation

I use two RadioJove (RJ) direct conversion receivers tuned 100 kHz apart, one at 20.05 MHz and the other at 20.15 MHz.[1] The audio outputs of these receivers are sent to Radio-SkyPipe (RSP), a strip chart program that uses a PC's sound card as an analog to digital converter.[2] I also use an SDR-14 that feeds a spectrograph application, either Spectrograph or Spectravue.[3,4,5] The RJ receivers and the SDR-14 are fed simultaneously through power splitters by an RJ dual-dipole array phased to look directly south with an elevation angle of ~50°.[6] Figure 1 is a block diagram of my observatory equipment configuration.

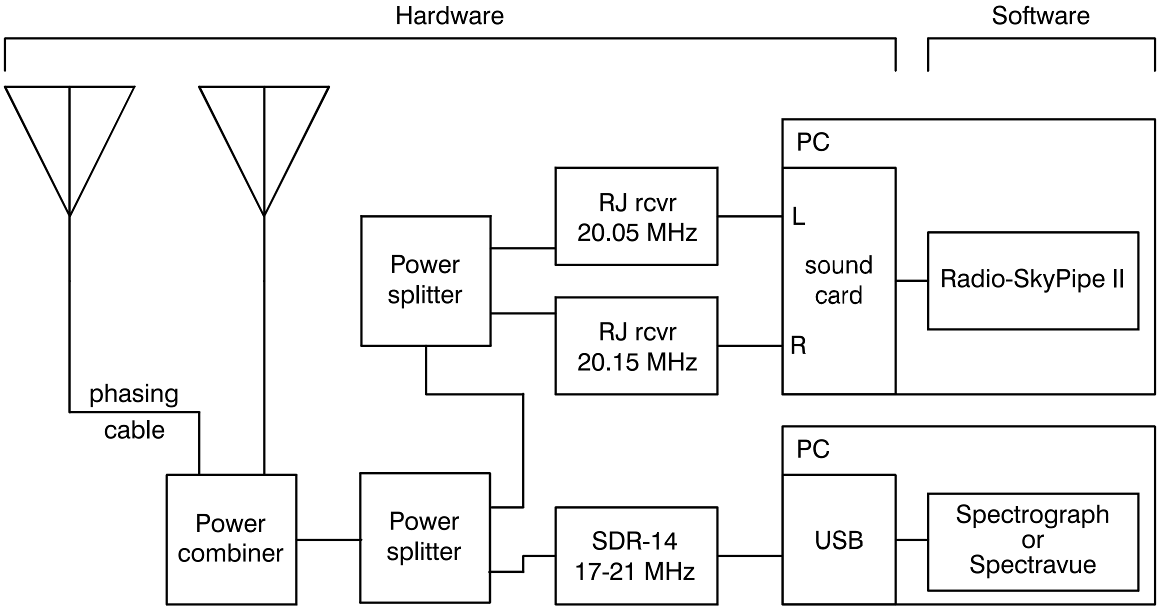

Figure 1 – AJ4CO Observatory station architecture.

In this arrangement, a portion of the local oscillator signals from the two RJ receivers leaks back through the power splitters into the SDR-14. This is advantageous. The RJ receivers do not have frequency displays and tend to drift in frequency from day to day by a few kHz; however, I can use the SDR-14 and Spectravue to obtain a measurement of the receivers' frequencies at any given time.

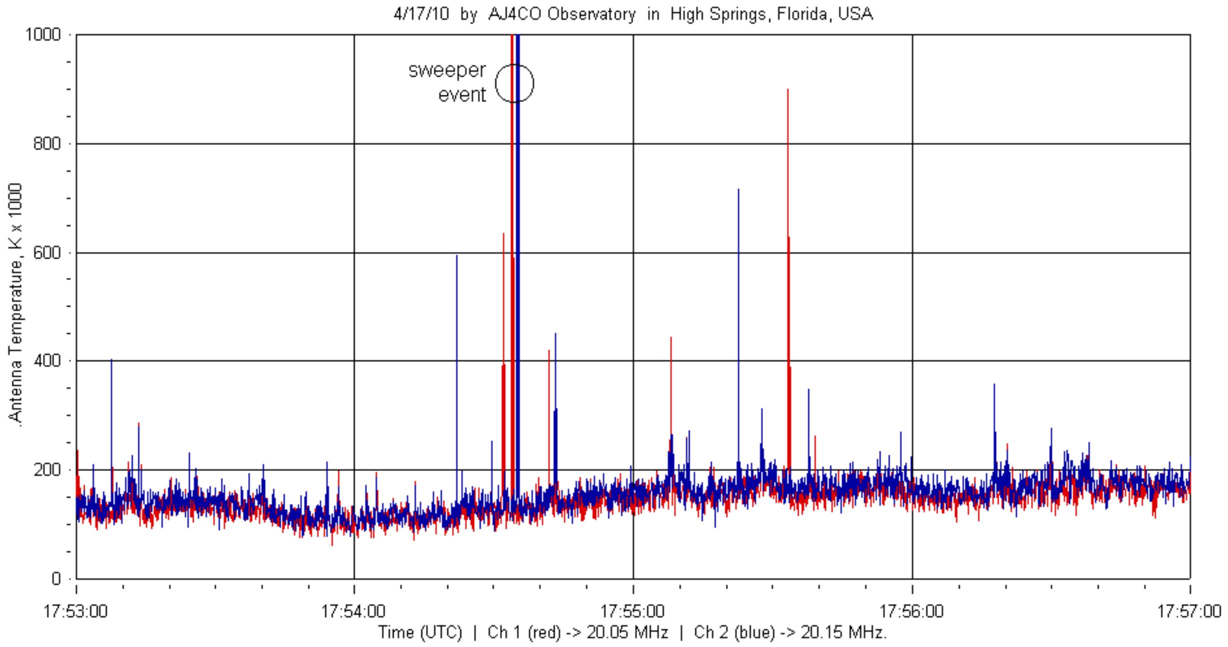

Figure 2 – Strip chart showing a sweeper event (circled).

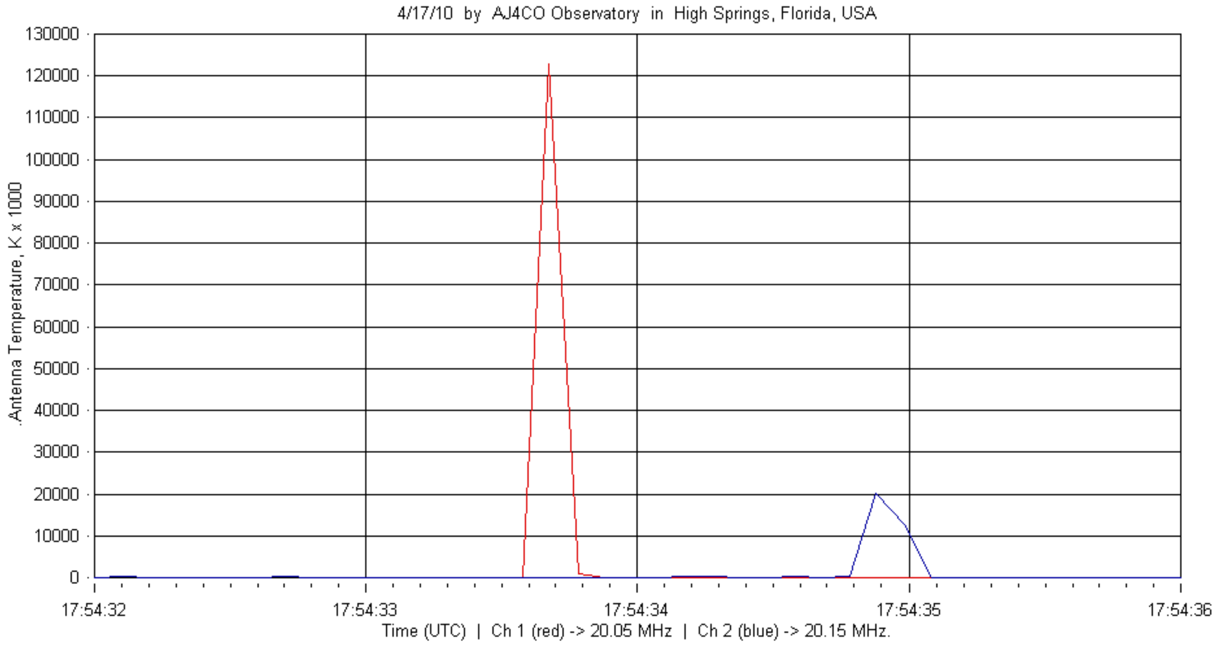

Figure 3 – Zoomed in view of the sweeper event shown in Figure 2.

While watching or reviewing the RSP strip chart, I often see a spike on the lower channel followed by a spike on the upper channel. The spectrograph plot of the same time period shows a diagonal line crossing 20.1 MHz at roughly the same time as the spikes appear in the strip chart. I conclude that these pulses are from a source that sweeps from low to high frequency, hence the name “sweeper.”

Figure 2 represents one such event I observed on 4/17/2010. This represents a four minute segment of the day’s drift scan I recorded using Radio-SkyPipe II. Figure 3 shows a zoomed-in view of the same event.

I measured the time between the pulses using Figure 3. Knowing the frequencies of the two RJ receivers, I calculated the sweep rate necessary to produce the observed pulses. With a 10 Hz RSP sample rate, the uncertainty in the time of each pulse is 50 ms. The receiver local oscillator frequencies were measured with Spectravue to the nearest 100 Hz.

$$\text{Sweep rate} = \frac{\left(20.1463\ \text{MHz} \pm 50\,\text{Hz}\right) - \left(20.0459\ \text{MHz} \pm 50\,\text{Hz}\right)}{\left(34.89\,\text{s} \pm 50\,\text{ms}\right) - \left(33.69\,\text{s} \pm 50\,\text{ms}\right)} = 84 \pm 5\ \text{kHz/s}. \qquad (1)$$

Figure 4 shows a four second vertical waterfall spectrograph plot of the sweeper. This plot was made with Spectravue and subsequently edited using Paint Shop Pro, an image editing application. The contrast and colors were enhanced to make the sweeper trace more visible; also, text and graphic indicators were added.

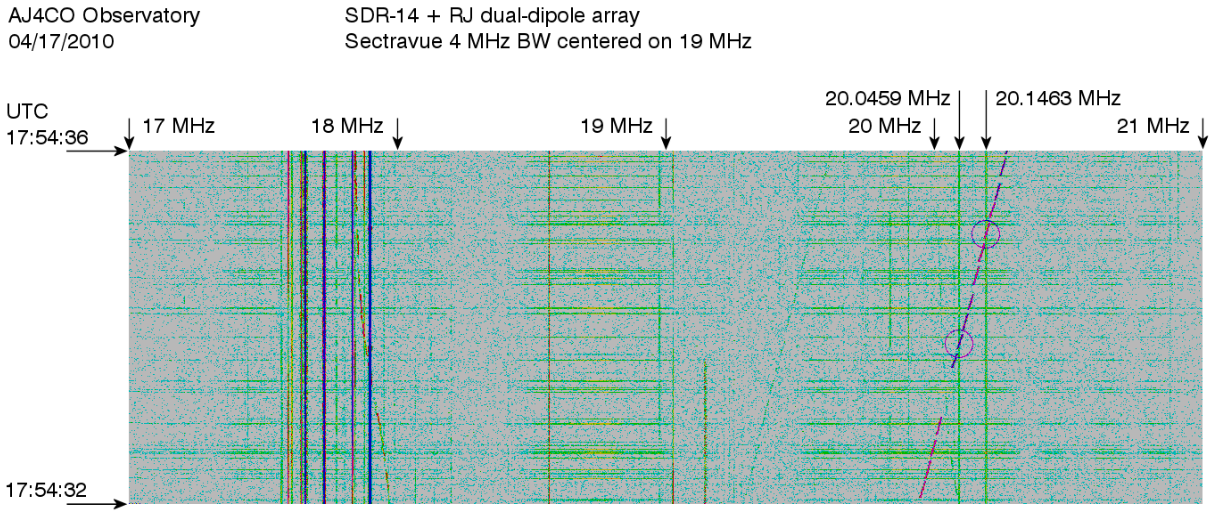

Figure 4 – Spectrograph plot of the sweeper. The two circles highlight the sweeper crossing each RJ local oscillator signal. Note the pulsed nature of the swept signal. Note also the gap in the swept emission at 20 MHz; I suspect this is to avoid interfering with WWV.

Using the amplitude triggered wav recorder function in RSP, I captured a 12 kHz sample rate audio file of this event. RSP channel 1 is stereo left, channel 2 is stereo right. I examined this file using Sony Vegas to obtain a more accurate timing of each pulse.[7] I made no effort to align the wav file with UTC; I was concerned only with the duration between the pulses. Figure 5 shows three screen captures from the Vegas waveform display. Note the double-hump appearance; the center is the zero beat as the sweeper's frequency matches the local oscillator frequency. Note also the 8.3 ms periodic signal courtesy of the local power company.

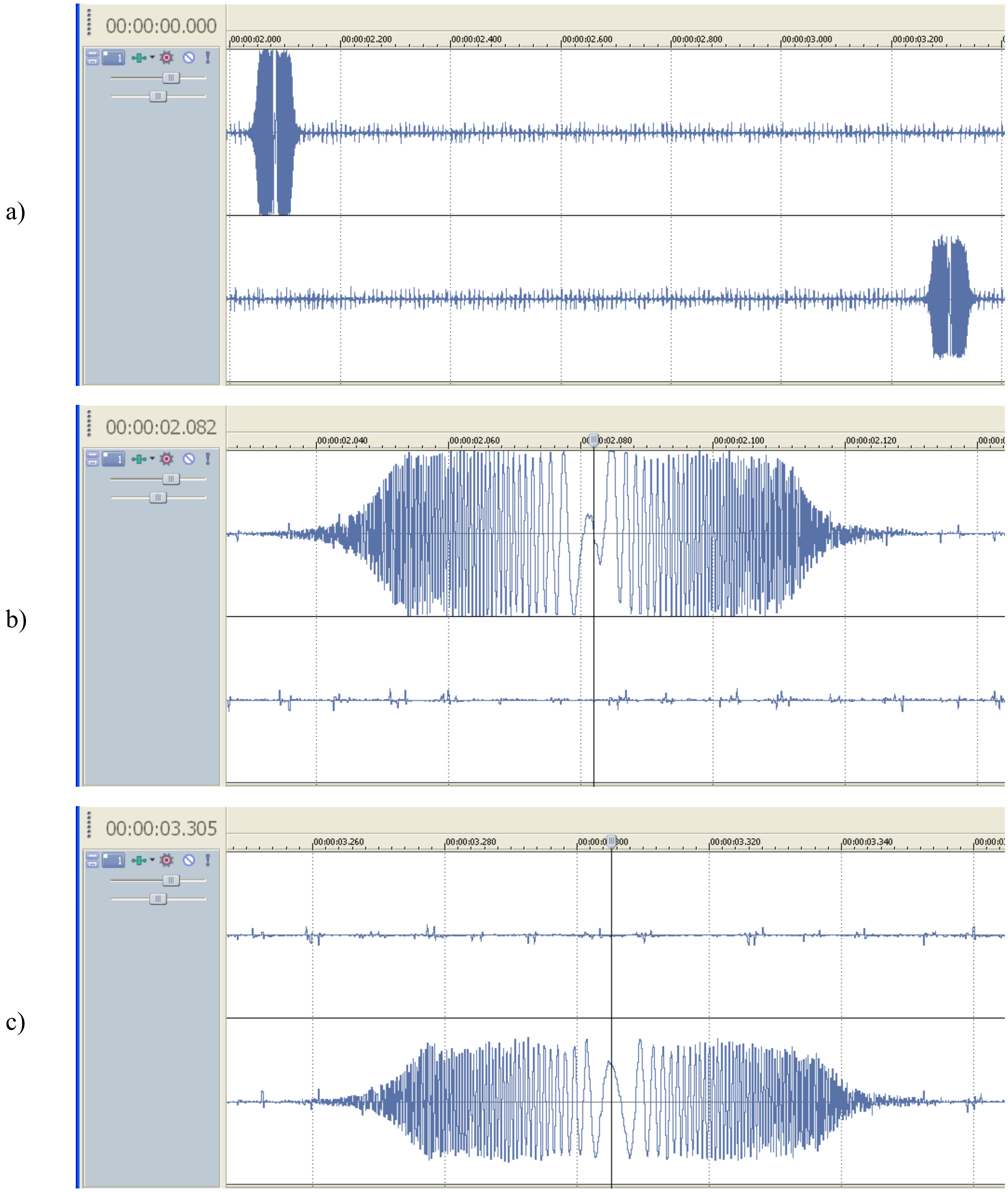

Figure 5 – a) both pulses, b) channel 1 relative time at 2.082 s, c) channel 2 relative time at 3.305 s.

The timing precision of Vegas is 500 µs. The pulse zero beat centerline was determined by eye using the waveform's profile, however, so a more reasonable uncertainty is 2 ms. I make the assumption that the sound card's sample rate drift over 1 second is less than 1 part in 10^3. The receiver local oscillator frequencies are the same as that shown in equation (1).

$$\text{Sweep rate} = \frac{(20.1463\ \text{MHz} \pm 50\,\text{Hz}) - (20.0459\ \text{MHz} \pm 50\,\text{Hz})}{(3.305\,\text{s} \pm 2\,\text{ms}) - (2.082\,\text{s} \pm 2\,\text{ms})} = 82.1 \pm 0.2\ \text{kHz/s}. \tag{2}$$

Source Characteristics

The ~80 kHz/s sweep rate and the pulsed nature of the signal shown in Figures 2, 3, and 4 indicates that this was most likely an observation of a Relocatable Over the Horizon Radar (ROTHR) emission.

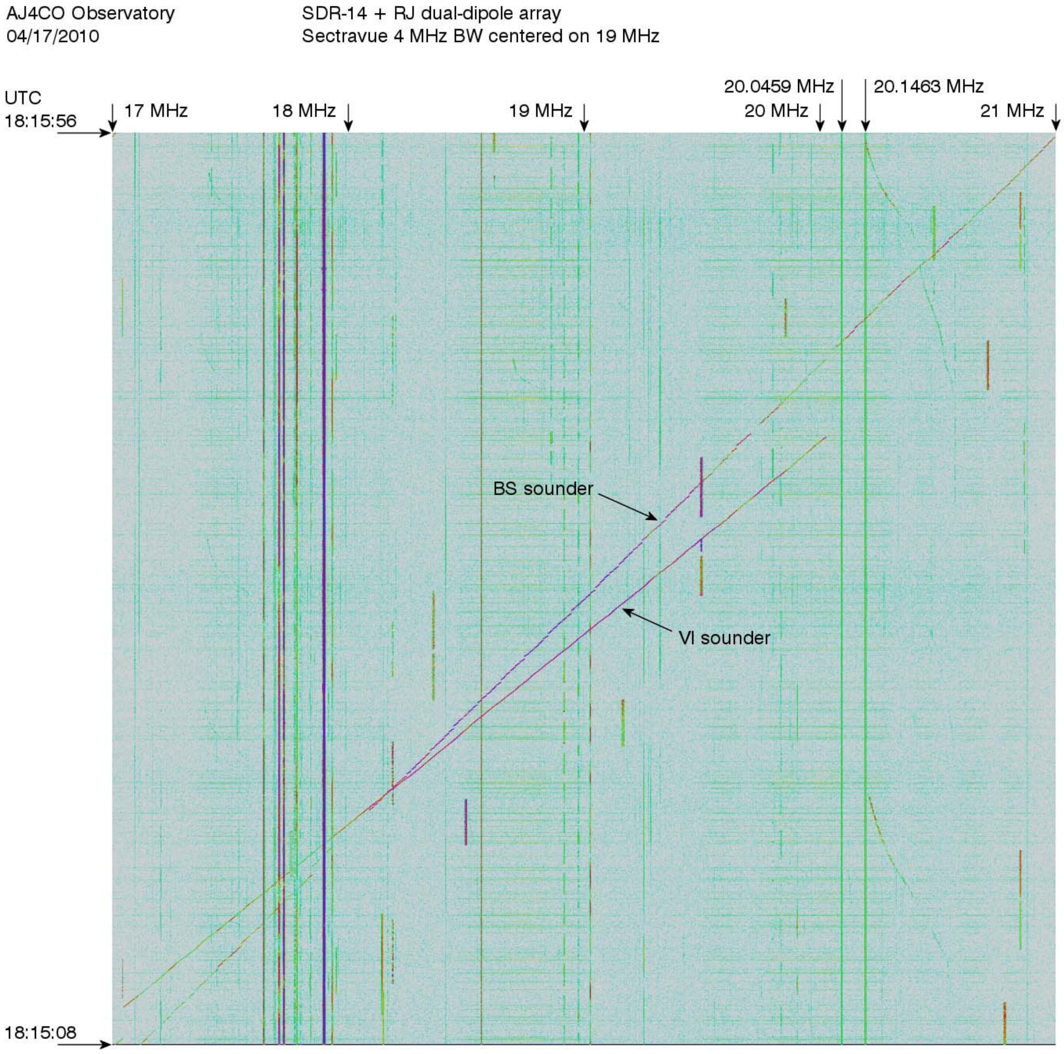

Figure 6 – Typical ROTHR emission plot. Note BS and VI sounder signals crossing at ~18 MHz.

The US Navy operates three known AN/TPS-71 ROTHR installations.[8] They are located in Virginia, Texas, and Puerto Rico. Each ROTHR installation has two transmitters that sweep from low to high frequency (see Figure 6).

1) A backscatter (BS) sounder; i.e., an over the horizon radar. The beam has a very low elevation angle and is aimed in a generally southward azimuth. This transmitter starts at 5 MHz and sweeps to ~30 MHz with short pauses every 20 kHz. The overall sweep rate is ~80 kHz/s.

2) A vertical incidence (VI) sounder; i.e., an ionosonde. The beam is aimed straight up at 90° elevation. This transmitter starts at 2 MHz and sweeps continuously to 20 MHz at 100 kHz/s. Note that the VI sounder stops transmitting before it can be observed at 20.1 MHz.

Emissions from BS and VI sounders are often observed at the same time. As such, I suspect the VI sounder provides information about the current state of the ionosphere to the BS sounder (the over the horizon radar). When the signals from both sounders are received simultaneously, I observe that the VI sounder overtakes the BS sounder at ~18 MHz. At my location in North Central Florida, the VI signal is often much weaker than the BS signal.

Source Identification

The characteristics of the BS sounder's timing remain poorly characterized by the amateur community. Fortunately, a BS sweep is often seen to be associated with a VI sweep, the timing of which is very well understood. Thus, I determine which ROTHR BS sounder was likely to be transmitting at ~20.1 MHz at 17:54:34 UTC by analyzing the timing of the associated VI signal. I make the assumption that there is a VI sweep associated with every observed BS sweep, regardless of whether I can observe the VI sweep.

The VI sounder start times are very precisely controlled, occurring on the edge of a UTC second of time. Each ROTHR station repeats a sweep every 12 minutes. While the schedules of which station is emitting when in each 12 minute block are not published, each station usually stays with the same schedule for days to weeks at a time.

One can determine the current timing of each ROTHR schedule if one can precisely time the arrival of a VI pulse at a known frequency. Knowing the distance of the ROTHR transmitters relative to the receiving antenna, one can account for the light-time delay. For example, if a receiver is precisely tuned to 13 MHz, the VI sounder will take exactly 110 seconds to sweep from 2 MHz to 13 MHz. If an observer in England has a receiver tuned to 13 MHz and sees a VI pulse occur 20 ms past the boundary of a UTC second, then that VI pulse must have come from the Virginia ROTHR since England is 0.020 light seconds from Virginia. One can also determine that the VI sweep must have started 110.020 seconds prior to the observed time. Using that information and the sweep rates of the VI sounder, one can calculate the time at which the signals from the VI sounders should appear at any frequency at any location.

Peter Martinez, G3PLX, has an ongoing project to passively monitor the emissions from ROTHR VI sounders and similar swept frequency transmitters.[9] Peter provided me with the signal timing—called the “chirptime”—of the three ROTHR VI sounders as he observed them on the morning of April 17th, 2010.

Puerto Rico	720:20
Texas	720:189
Virginia	720:197

In this notation, the “720” represents the signal’s repetition rate in seconds—which works out to, in this case, 12 minutes. The 12-minute blocks are defined as starting at exactly 0, 12, 24, 36, and 48 minutes past the UTC hour.

The “:nnn” represents the time in seconds past the start of each 12-minute block that the VI sounder signal starts sweeping from 0 MHz. Note that the VI sounder doesn’t actually start transmitting at 0 MHz, however, extrapolating the sweep back to 0 MHz is a convenient and unambiguous way to state the timing. For example, the Puerto Rico ROTHR VI sounder starts its sweep (at 0 MHz) 20 seconds into the 12-minute block.

While the chirptime indicates the timing of the VI sounder, the start timing of the BS sounder is not known with precision. I observed a BS sounder crossing 20.0459 MHz at 17:54:33.7 UTC ± 0.4 seconds. Note that I drop the uncertainty in frequency from here out because it is swamped by the uncertainty in the timing.

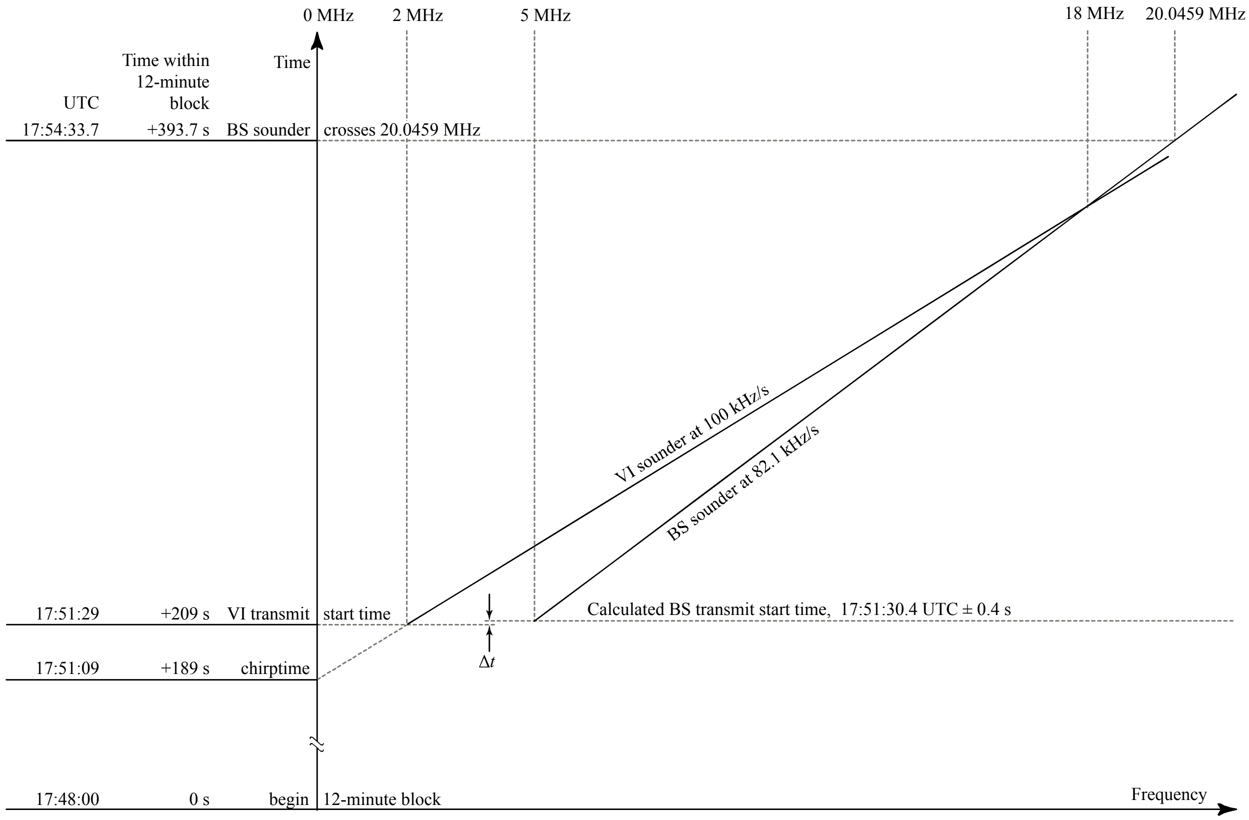

Figure 7 – BS and VI sounder timing for the Texas ROTHR at 1748 UTC on 4/17/2010.

The BS sounder starts sweeping at 5 MHz. To sweep from 5 MHz to 20.0459 MHz at 82.1 kHz/s ± 0.2 kHz/s takes 183.3 ± 0.4 seconds. (See Figure 7).

Subtracting 183.3 s from 17:54:33.7 UTC gives us a calculated transmitting start time of 17:51:30.4 UTC ± 0.4 s. If the VI sounder started at the same time, it too would have started transmitting at 17:51:30.4 UTC ± 0.4 s.

Backing 20 seconds off the transmitting start time to obtain a VI chirptime, I obtain 17:51:10.4 UTC ± 0.4 s.

The nearest 12-minute block starting prior to 17:51 UTC occurs at 17:48 UTC. Therefore, the calculated chirptime would be 3 minutes and 10.4 seconds ± 0.4 seconds into the 12-minute block, or in chirptime notation, 720:190.4 ± 0.4 seconds.

The closest observed ROTHR chirptime observed by Peter Martinez is the Texas ROTHR VI sounder at 720:189.

The 1.4 second difference (Δt as shown in Figure 7) between the VI start time and the calculated BS start time may have several causes.

Either:

1) The BS sounder started transmitting 1.4 seconds after the VI sounder started transmitting.

Or, the BS and VI sounders start simultaneously and:

2) The narrow bandwidth (~100 kHz) over which the BS sounder sweep rate was calculated may not provide an accurate enough measure of its average sweep rate from 5 MHz to 20 MHz.
3) Random pauses occur in the BS sweep. As shown in Figure 6, the BS sounder in that instance paused for 0.5 seconds just below 18 MHz, then picked up again at the same frequency. The signal at 17:51 UTC was too weak below ~19 MHz to tell whether this occurred for that event. Also, it is unknown whether any pauses occur below 17 MHz. Two such pauses would bring the BS sounder's calculated start time into agreement with the VI sounder's start time.
4) The PC system clock in the machine on which RSP was running is not perfectly accurate. An SNTP client adjusts the system clock to UTC every two hours if the offset is greater than 50 ms. The system clock should therefore always be within 50 ms of UTC. However, I have not verified its performance with a GPS-locked clock.

I therefore conclude the following:

1) The 1.4 s difference between the VI start time and the calculated BS start time is due to measurement error and a poor understanding of the exact profile of the BS sweep.

2) The signal observed crossing 20.1 MHz at 17:54:34 UTC was generated by the Texas ROTHR where the VI sounder started transmitting at 17:51:29 UTC.

I suspect that the ROTHR BS and VI sounders start transmitting at the same time; however, carefully timed observations of the RF spectrum from below 2 MHz to above 5 MHz are needed to confirm this.

Figure 8 is a Google Maps image of the Texas ROTHR site, roughly 30 miles WSW of Corpus Christi, Texas.[10]

Figure 8 – The Texas ROTHR site, image © Google, Inc.

Summary

The double spikes in my two-channel RSP charts are radar signals, specifically ROTHR BS sounders. Timing of one such event evinced a signal from the Texas ROTHR BS sounder. The ROTHR VI signals are visible in spectrograph plots below 20 MHz, but not above 20 MHz. Other types of ionosondes may sweep above 20 MHz; however, I have not observed any.

Acknowledgements

This investigation was a group effort and would not have been possible without the contributions of the following individuals. Peter Martinez, G3PLX, patiently explained chirptimes and the characteristics of ROTHR signals, provided accurate chirptimes, and determined the physical location of the Texas ROTHR. Brooke Clarke, N6GCE, initially recognized my observation as that of a ROTHR and kindly put me in touch with Peter Martinez. Whitham Reeve and Peter Martinez provided valuable comments on early drafts of this paper. Richard Flagg, Wes Greenman, and Whitham Reeve provided valuable input during this investigation.

References

[1] RJ Receiver Manual, < http://radiojove.gsfc.nasa.gov/telescope/rcvr_manual.pdf >.

[2] Radio-SkyPipe II, < http://www.radiosky.com/skypipeishere.html >.

[3] RF-Space SDR-14, < http://www.rfspace.com/RFSPACE/SDR-14.html >.

[4] WCCRO Spectrograph, < http://jupiter.wcc.hawaii.edu/spectrograph_software.htm >.

[5] Spectravue, < http://www.moetronix.com/spectravue.htm >.

[6] RJ Antenna Manual, < http://radiojove.gsfc.nasa.gov/telescope/ant_manual.pdf >.

[7] Sony Vegas, < http://www.sonycreativesoftware.com/vegaspro >.

[8] AN/TPS-71 ROTHR,
< http://www.fas.org/nuke/guide/usa/airdef/an-tps-71.htm >,
< http://www.janes.com/articles/Janes-C4I-Systems/Relocatable-Over-The-Horizon-Radar-ROTHR-AN-TPS-71-United-States.html >.

[9] G3PLX, Passive Ionospheric Sounding and Ranging,
< http://www.jcoppens.com/radio/prop/g3plx/index.en.php >.

[10] Google Maps view of 27.52635N 98.110185W,
< http://maps.google.com/maps?ll=27.52635,-98.110185&t=h&z=17 >.

For more information, please contact
Dave Typinski
AJ4CO Observatory
davetyp@typnet.net

Dave Typinski, AJ4CO, has been involved with amateur radio astronomy since 2009. He lives in High Springs, Florida, where he runs a company that decorates ceramic tile.