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Verification Tests for FRB Detections

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ABSTRACT

The one-off nature of most Fast Radio Bursts (FRBs) requires extra scrutiny in reporting an astrophysical FRB and triggering automated follow-ups with a telescope network. The ALFABURST commensal FRB survey at Arecibo Observatory has been in operation since June 2015. In that time a number of false-positive events, which on initial inspect appear to be FRB-like, have been found to be of local origin. Here we report on one such event as an example of the difficult challenge of fully automating an FRB search. We discuss observational and post-processing techniques which are useful to further automate an FRB search survey.

Key words: radio continuum: transients – methods: observational

1 INTRODUCTION

In the two years of the initial ALFABURST survey(Chennamangalam et al. 2017) over 125k 8-second windows have been recorded in which our Fast Radio Burst (FRB) search pipeline detected an event above the minimum Signal-to-Noise Ratio (SNR) detection threshold. The vast majority of these events have been due to Radio-frequency Interference (RFI), some of the events are due to bright single pulses of known pulsars. Sorting through these false positive events is the main focus of our post-processing methods. Most of the events are clearly RFI which are classified with an automated classifier model. A small number of windows contain FRB-like events which only on further inspection of the data, the telescope operation status, and contextual information is it clear that these events are from local sources.

We expect a number of false-positives to pass our post-processing detection tests, as we would like to severely limit the potential for type-II errors in our classifier by accepting a number of type-I errors. So far, all false-positives we have detected are explainable as relating to the telescope or RFI by examining the observing situation after the fact. This creates a challenge of automating the triggering of follow-up signalling to other telescopes. Either there will be an excess of false-positive triggers but with a short delay between detection and triggering. Or, a non-automated, expert examination of the event is required to verify, creating a delay in any follow-up.

In this letter we report on FRB-like signals detected with our ALFABURST system, and discuss how we have improved our post-processing pipleine and observing system to handle unexpected, but explainable signals. These improvements are valuable to incorporate into any FRB search survey.

2 AN EXAMPLE OF A FRB-LIKE SIGNAL DETECTED WITH ALFABURST

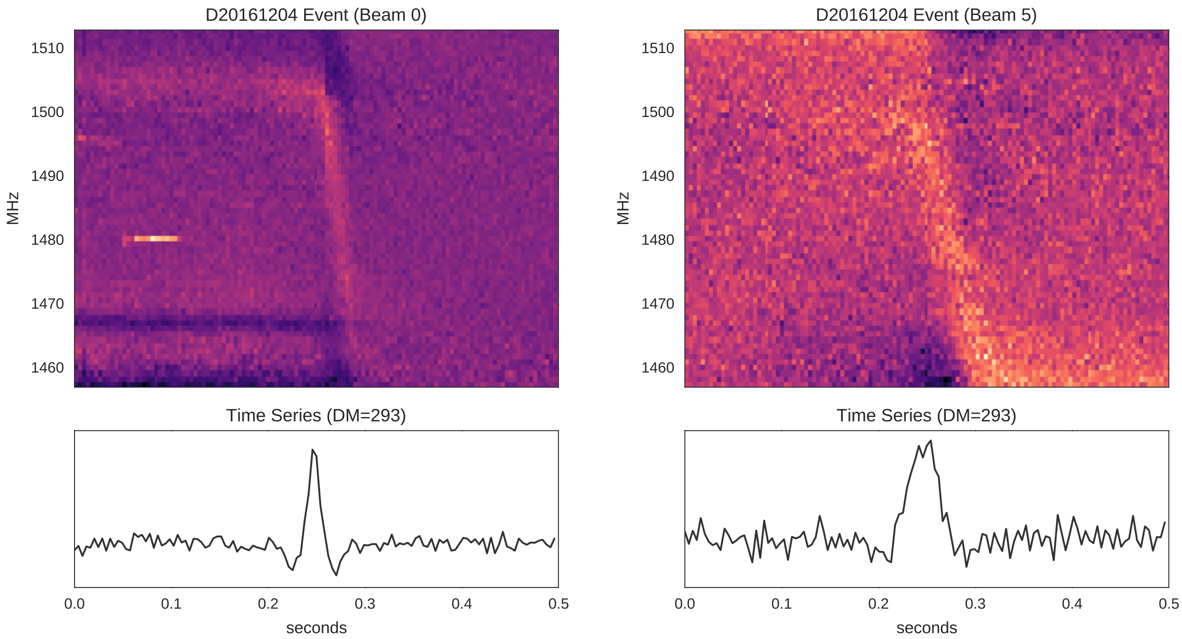
A narrow-in-time, broad-in-frequency, millisecond pulse was detected with the ALFABURST system at MJD 57726.563263913 / Unix time 1480858266 (09:31:06 Arecibo local time) in Beam 0 (the central beam) of the Arecibo L-Band Feed Array (ALFA) receiver[1] (Figure 1a). ALFABURST was processing 56 MHz of bandwidth between 1457 MHz and 1513 MHz. The SNR of this pulse is maximized (10.46) when the pulse is dedispersed with a Dispersion Measure (DM) of 293 and the 256 microsecond resolution is decimated by a factor of 16 to 4 ms time resolution. The dedispered time series shows an approximately 20 ms Full-Width at Half-Maximum (FWHM) pulse. The dip before and after the pulse is due to the DM-zero removal (i.e. the moving average is subtracted) during pulse detection. This is a simple way to remove a drifting gain baseline at the cost of removing some of the overall pulse power, particularly at low DM. The bright, narrow-band signal at approximately $t = 0.1$ seconds is locally generated RFI which we will cover later in this section.

On initial inspection this event looks like a promising new astrophysical FRB. The flux density of the event can be computed with the radiometer equation

$$S = \mathrm{SEFD}\frac{\mathrm{SNR}}{\sqrt{D\ \Delta\tau\ \Delta\nu}}$$

using an System Equivalent Flux Density (SEFD) of 3 Jy for the ALFA receiver. This results in a flux density of $S = 66$ mJy from Beam 0, which would be lower flux than any previously detected FRB (Petroff et al. 2016). This flux estimate is an lower limit, as we are assuming the source was at the

[1] http://www.naic.edu/alfa/



(a) Detected FRB-like event in beam 0 of ALFA. The characteristic dip before and after the event is due to zero-DM removal which is part of the ALFABURST RFI exciser. The strong, narrowband source at 1480 MHz around 0.1 s is due to a local RFI source.

(b) Detected FRB-like event in beam 5 of ALFA. The event width appears wider than the beam 0 event as the zero-DM dips are not as prominent.

Figure 1. Dynamic spectrum (top) and dedispersed time series (bottom) of an FRB-like event that was detected simultaneously in beam 0 and 5 of the ALFA receiver on December 4, 2016. The dynamic spectrum has been bandpass normalized.

centre of the beam. The width is on the high end for FRBs but still within the range of those previously reported.

We inspected all other events in the same time window as the Beam 0 event. An event was found in Beam 5 only (Figure 1b). This pulse lines up exactly in time with the Beam 0 event but the FRB was maximized (15.99) with a DM=829 dedispersion. Upon further inspection and testing different DMs for dedispersion we found that this event appeared to narrow in width at lower DM trials. We see that there was RFI clipping in this event which is known to introduce a bias, resulting in a maximized SNR at a different DM trial. The beam 0 and beam 5 event are the same event.

The beam 5 detection has a lower SNR than the beam 0 detection at DM trial 293. This is still reasonable as the beam 0 sidelobes overlap with all the other beams, as does the beam 5 sidelobe overlap with the beam 0 primary beam. This would indicate that the sky source is somewhere between the beam 0 and beam 5 pointing centres. And, the detection was from the edge of the primary lobe or in the sidelobe of each beam.

The width of the dedispersed pulse in beam 5 appears wider, but this is likely due to the lower SNR of the event having a smaller effect on the spectrum normalization.

One can look at the immediate period before and after the pulse to see that there are no similar events (Figure 2). The event appears to be isolated in time, with a fairly compact representation in DM-space. The event would be detected with significant SNR at higher DM trials due to the wide width of the pulse, but peaks at a DM trial of 293.

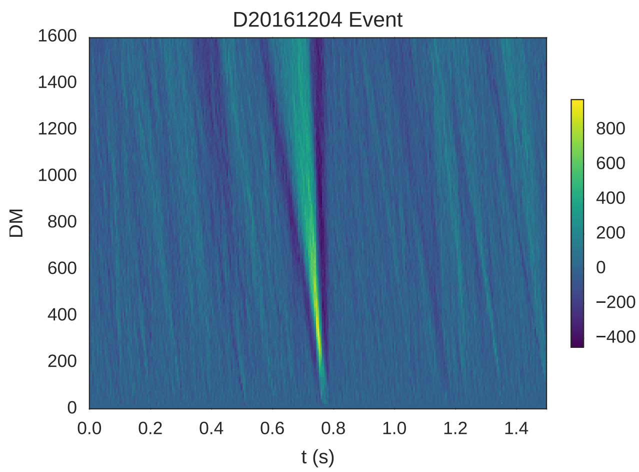


Figure 2. DM vs. time plot of for a 1.5 second window centred on the December 4th event in beam 0. The SNR peaks at a DM of 293. There is a significant detection at larger DM trials due to the width of the pulse.

The Arecibo telescope logging data is reported locally in SCRAM packets which provide pointing, frequency tuning, and receiver information at approximately one second resolution. From these logs the telescope was pointed at a fixed Dec (+15:11:28.34) and drifting in RA (event detected at RA=14:42:26.18), i.e. a fixed (alt,az) pointing during the event. No known pulsar or RRAT is within the beam at this pointing.

We considered that the observing band could have been changed in that time. We have setup the automated system to restart observations when the Intermediate Frequency (IF) frequency is changed. During the time of the event there was no change in the IF during that time.

The SCRAM logs do provide the first indication that this event is due to a local source. Beyond the pointing and IF, the SCRAM logs report the position of the receiver turret and if ALFA is active. ALFA is at a position angle of approximately 26.64° in the turret, the system reported the turret was at 206°. ALFA is not in, or even near the focus. Our commensal observation script checks if ALFA is active before we run ALFABURST. This is a check on whether the analogue receiver chain is properly setup for ALFA, which almost always means that ALFA is in the focus. But, as we have found out, there are times when this is not true.

The SCRAM logs do not report the active project or observing schedule. During the time of the event it appears that no receiver was in use, otherwise ALFA would not have been active, and we see that ALFA was deactivated approximately 20 minutes after the event when a new observation began. Looking at the observation schedule for the morning of December 4, project P3080[2] was using ALFA to perform an FRB survey of the Virgo cluster until 09:00 local time. After 09:00 local time Project R3037[3] was scheduled, this is an S-Band RADAR observation.

Looking at the average bandpass of beam 0 and 5 during the time of the event, we see that the shape and system noise appear different to what is expected during typical observations (Figure 3). The detection band of ALFA was chosen because it is the most sensitive region of the band, and relatively flat. But during the event there is a noticeable shape and slant to the bandpass which is different than the typical bandpass. Beam 0 and 5 bandpasses look related in elements of their bandpass shape, and the narrow-band features due to the short, bright RFI events that occur during the recorded time window. The system noise appears to be higher during the event, which leads to the bandpasses appearing smoother than the typical bandpass. In the detection pipeline the data is normalized, so all absolute scaling is removed in the process. This indicates that the SEFD is too low in our flux calibration. This increase is system noise is due to the change in turret position, and the ALFA feed picking up reflections from other equipment in the dome, and the dome as a warm source.

We then looked at previous recorded events close in time to the event. Approximately 80 seconds earlier another window was recorded which has large structures across the band (Figure 4a). Though not as narrow in time as the event, they appear related to the same phenomenon.

The DM - time plot (Figure 4b) shows that much of the structure would be detected as dispersed pulses. In particular, the structure around 4 seconds would be detected as a wide-in-time, highly dispersed pulse. And the structure immediately proceeding it would be detected as a negative dispersed pulse. We do not detect these as pulses because we have limited our search space to narrow-in-time width pulses, and positive DMs. Our choice of search space is reasonable for the type of events we wish to detect given limited computing resources. But, there are practical advantages to searching negative DMs and wider-in-time pulse widths. We expect astrophysical pulses to have positive DMs. But, system variation and RFI can produce signals which result in positive and negative DM detections. A statistial measure can be made on any time window to differentiate times of significant, but low-level RFI or system variation from actual astrophysical pulses. Testing out to larger pulse widths is computationally cheap as the time window is decimated, reducing the memory usage. Full sampling of larger pulse widths or negative DM trials like the positive DM trials is not necessary. Only a subset can be computed to provide a useful information on the stability of the system and RFI environment.

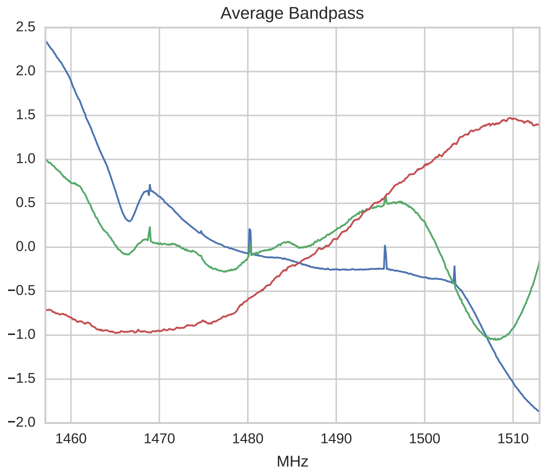


Figure 3. Average bandpass response during the December 4, 2016 event for beam 0 (green) and beam 5 (blue). A typical bandpass (red) is plotted for reference. These bandpasses have been normalized in the detection pipeline.

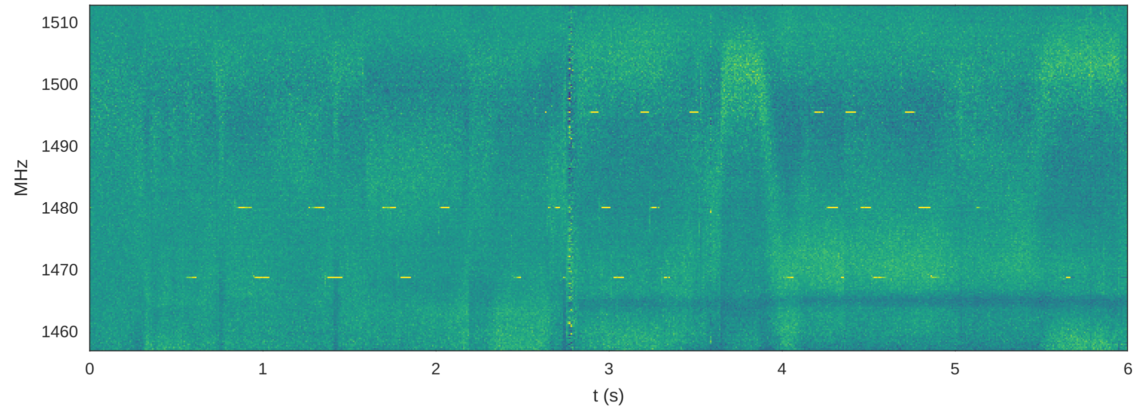
The narrow-in-frequency, periodic RFI at 1468, 1480, 1496, 1504 MHz not usually seen in this band. In the high time and frequency resolution view these short pulses in 12.5 MHz steps have a characteristic dampened harmonic oscillation due to frequency locking with a Phased-locked Loop (PLL) (Figure 5).

Currently, we are considering that the event is due to ALFA being covered to protect against the RADAR system while it was still the active rx. It could be that this event is due to some standing-wave coupling between the ALFA and the cover.

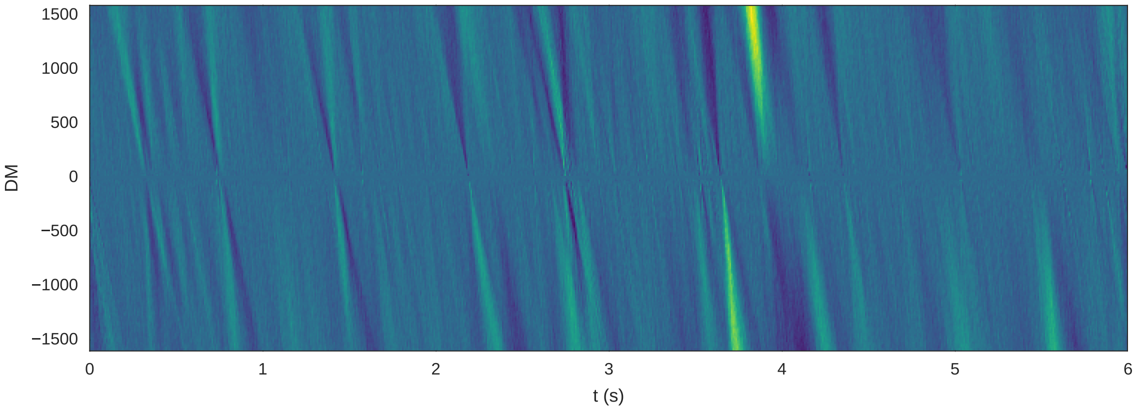
In isolation, and the one-off, transient nature of FRBs make the initial Beam 0 detection look very reasonable. It is only with an extended study of the meta-data, earlier-in-time evolution of the band, and use of multiple beams to confirm that this is indeed not an FRB.

Jupyter notebooks and information on the filterbanks files are hosted on our public git repository[4].

[2] http://www.naic.edu/vscience/schedule/tpfiles/MichillitagP3080tp.pdf
[3] http://www.naic.edu/vscience/schedule/tpfiles/TaylortagR3037tp.pdf
[4] https://github.com/griffinfoster/ab-survey-2017



(a) Dynamic spectrum shows frequency evolution of the bandpass as a function of time with structures similar to the D20161204 event.



(b) DM trials from -1600 to 1600 show that there would be both positive and negative pulse detections during this time window.

Figure 4. Dynamic spectrum (top) and DM-time plot (bottom) of 6 seconds from beam 0 approximately 80 seconds before the D20161204 event.

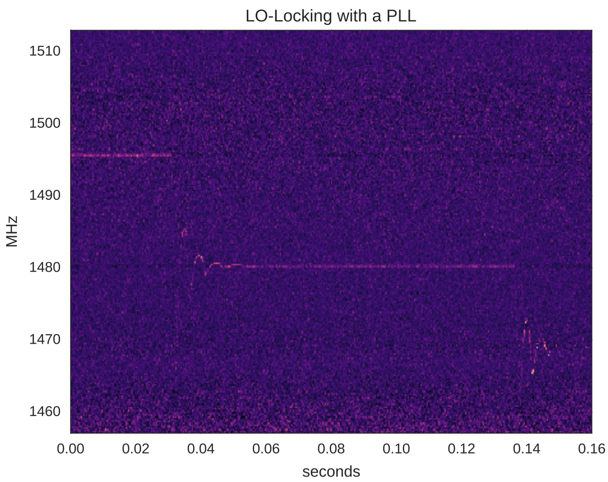


Figure 5. Dynamic spectrum when a local oscillator in the receiver dome is being locked with a phased-locked loop circuit. This LO is not related to the receiver analogue mixing chain, but rather it is associated with RFI monitoring equipment.

REFERENCES

Chennamangalam J., et al., 2017, ApJS, 228, 21
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This paper has been typeset from a TEX/LATEX file prepared by the author.