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of the FORTE Trigger Box*

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Tim Murphy

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By

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Abstract

We present the results of parameter studies designed to estimate the optimum settings for the trigger circuit which will be used by the fast on-orbit recording of transient events (FORTE) satellite. Real broadband data recorded by the Los Alamos Blackbeard experiment was processed by a computer model that simulated the action of the FORTE trigger. The probability of detection and false-event rate was determined for a variety of trigger-parameter settings, and the results are presented in the report. The result of the study is a well-defined set of parameters chosen to give the best possible triggering performance.

Introduction

One of the outstanding issues in broadband VHF signal detection is how to detect transient-impulse signals in an environment that includes continuously operating transmitters such as television or FM-radio stations. One would like to use as broad a band as possible to fully characterize the transient signals, but even though the transmitters operate in fairly narrow bands their overall power is such that they can dominate the power in a wide-band receiver. This means that simple level trigger techniques will not be able to detect transient events effectively. A promising approach to this problem is the use of multi-channel narrowband coincidence trigger techniques, which in some cases have demonstrated detection of broadband signals which have a signal-to-noise ratio (SNR) of 0 dB or less. The fast on-orbit recording of transient events (FORTE) satellite payload will incorporate triggering hardware of this type consisting of eight VHF channels spaced across twenty MHz of bandwidth. A trigger is generated when a sufficiently bright signal is seen in a user-defined number of these channels within a specified coincidence window.

In order to understand the expected performance of this system, we have developed a software model of the FORTE trigger box designed to faithfully imitate the actual hardware while also allowing some additional flexibility. In this report we describe the results of applying the software to a set of broadband data records recorded in orbit by the Blackbeard VHF detector. We find that with our initial guesses at settings for the trigger parameters we achieve excellent performance in detecting transionospheric pulse pair (TIPP) events in regions with low background. When operating against artificial impulse sources in high-background regions we achieve good results for sources with good low-VHF spectral strength, which includes detection at or below -10 dB SNR with a detection efficiency of about 50% to 70%.

FORTE Trigger Model

The FORTE trigger model, TRIGBOX, is described in detail in another paper¹. Here we will only review the features of the trigger that are important for this study. The trigger hardware consists of eight 1-MHz-wide receiver channels, evenly spaced across a 20 MHz band, and associated logic circuitry. A trigger is generated when simultaneous signals are seen in a specified number of the channels within a given coincidence window. The threshold level (S) in each channel, the number (N) of simultaneous channels required, and the length (W) of the coincidence window are all adjustable parameters. In addition, there is also an adjustable cutoff time (C) for each channel that is designed to prevent false triggers due to carrier turn-ons. The center frequency of the 20-MHz band in which the trigger channels sit is tunable over the range from 35 to 290 MHz.

Structure of the Parameter Study

The goal of this study was to optimize the performance of the trigger for detecting wideband transient events in a carrier-dominated background. In order to get as realistic a background as possible we used actual broadband data recorded by the Blackbeard experiment on board the Los Alamos National Laboratory / Department of Energy ALEXIS satellite². The data consists of time-series electric field values taken over approximately 60 MHz of bandwidth. The records used in this study are of three types. The first are records containing TIPP events, which are naturally occurring impulses believed to be related to thunderstorm activity^{3,4}. They usually, although not always, occur in pairs separated by 40–60 μ S. Although these events are bright they would have subzero dB SNR in most bands of interest over populated areas. Because Blackbeard uses a simple level-triggering scheme these events can only be seen over areas of low background. The second and third types of records are those which contain signals generated by a dedicated pulse generator, the Los Alamos Portable Pulser (LAPP). This source was operated with both helical and linear feeds, which have different spectral characteristics. The type-2 records are those with the helical feed, which is optimized to radiate in the

range from 100 to 150 MHz and has poor low-VHF output. The type-3 records are the data with pulses generated by the linear feed. Because most naturally occurring sources have a smoothly falling spectral distribution, the type 3-events are more like the natural sources we expect to see with FORTE.

Results for TIPP Events

We began the study by using TRIGBOX to look for TIPP events. The data used in this study were recorded primarily over Equatorial Africa or the Indian Ocean. This class of events should be the easiest to find because of the very low backgrounds in the these records where there are either no carriers at all or only very weak ones. We looked at data recorded in the Blackbeard low band (28–90 MHz) and started with the trigger parameters given in Table 1.

Table 1 : Trigger Settings for TIPP Events

<i>Parameter</i>	<i>Value</i>
Pass Band	45 - 65 MHz
Threshold (S)	17 dB
Cutoff Time (C)	5 μ s
Number of Channels (N)	5 of 8
Coincidence Window (W)	15 μ s

We examined over 300 Blackbeard records, each typically 1 Mbyte long. Of these records, 123 contained TIPP events which had been found using visual inspection by a human analyst. The trigger model correctly found the TIPP in all 123 cases. In 5 of the 123 records the software found additional events which had not been previously recognized. Of the 128 transient events, 115 have two distinguishable pulses, although in some cases one of the pulses is much weaker than the other. The model generated separate triggers for the two pulses in 93 of the 115 pulse pairs. The model also generated a large number of triggers caused by onboard signals, primarily electromagnetic interference (EMI) but probably some spacecraft discharges too. Under most conditions, locally generated signals can be distinguished from earth-generated events because they are not dispersed. It is possible to implement a dispersion criterion in the trigger logic, but because the degree of dispersion depends on the pass band and the ionospheric conditions (primarily local time of day) such a criterion would have to be continually adjusted as the instrument moved through its orbit and/or is retuned. The FORTE design team decided that this was operationally too complicated, and therefore, no such criterion was included. Thus a trigger should be generated by EMI or discharge events, and in fact is. This is not expected to be as severe a problem on the FORTE satellite because of its more stringent EMI specifications.

Because of the excellent performance of the model for these records we did not try other trigger-parameter settings.

Results for LAPP Events

Encouraged by the success of the model with the TIPP data, we turned to the records that contain events generated by the LAPP pulse generator. These records were taken over the continental United States, where the noise environment produced by television, FM radio, and communications transmitters is severe. Although the LAPP is an intense source the signal it generates still has a subzero SNR as seen by Blackbeard, frequently -10 dB or lower. Because Blackbeard cannot trigger on such weak signals the events were recorded by firing the pulser in a predetermined time window during which Blackbeard was recording data.

We began with a small set of data recorded using the Blackbeard high band, from 110 to 165 MHz. We chose the trigger parameters to be the same as those used for the TIPP study except for the pass band and are in Table 2. The data set consisted of nine records, four with type-2 pulses (helical feed) and five with type-3 pulses (helix feed). The results were that the pulse was found correctly in all nine records and that there was only one on-board trigger generated. Because of these excellent results we did not experiment further with varying the trigger parameters.

Table 2 : Trigger Settings for TIPP Events

<i>Parameter</i>	<i>Value</i>
Pass Band	115 - 135 MHz
Threshold (S)	17 dB
Cutoff Time (C)	5 μ s
Number of Channels (N)	5 of 8
Coincidence Window (W)	15 μ s

Next we looked at low-band data. We began with a set of 18 records containing pulser events: 13 type-2 records and 5 type-3 records. We used the same trigger parameters as used in the TIPP data study given in table 1. The results were that we triggered on the event in 7 of 13 type-2 records and 4 of 5 type-3 records. Because of this relatively poor performance, particularly for the type-2 records, we decided to explore the effect of varying the trigger parameters.

The first thing we tried was varying the pass band while holding all other parameters fixed. This was done for a subset of 12 of the 18 records. The results are shown in Table 3. After seeing the very poor results for the 30–50 MHz band, we realized that because of the greater dispersion in this band we needed to increase the coincidence window. The second row in the table shows the results for this pass band with the coincidence window increased from 15 μ s to 30 μ s. This

improved the detection slightly but also resulted in approximately twice as many false triggers.

Table 3 : Detection Results for Various Pass Bands

<i>Pass Band</i>	<i>Type-2 Events</i>	<i>Type-3 Events</i>
30 - 50 MHz	0/7	3/5
30 - 50 MHz*	0/7	4/5
40 - 60 MHz	0/7	3/5
45 - 65 MHz	2/7	4/5
50 - 70 MHz	2/7	4/5
60 - 80 MHz	1/7	0/0

We expected the detection efficiency for type-2 events to decrease for the lower-frequency bands because of the spectral characteristics of the source, which we did observe. However, it did not increase as we went up in frequency, perhaps because of the increasingly severe noise environment. Given that the spectra of most quasi-impulsive sources decrease in power with increasing frequency, we would like to operate at as low a band as possible, consistent with good performance. Therefore, we have decided on the 45–65 MHz band as the best compromise.

Next we wanted to explore the effect of changing the length of the coincidence window. We have already seen that for operating at the low end of the VHF spectrum a larger window is required because of the greater degree of dispersion at those frequencies. However, we wanted to see the effect in the 45–65 MHz band. For this purpose we took the 5 type-3 records and compared the results with the default trigger settings and coincidence windows of 10, 15, and 20 μ s. The results are shown in Table 4. Because the 10 μ s window missed 3 of the 5 events we did not pursue it further. We then looked at 13 type-2 records using the 15 and 20 μ s windows. Five of the events were found with both windows, while the 15 μ s window found one event missed by the 20 μ s window, and there were two events seen by the longer window but not the shorter one. Because the longer window found all five of the type-3 events and performed slightly better for the type-2 events we have chosen it as the preferred setting.

Table 4 : Detection Results for Various Coincidence Windows

<i>Coincidence Window</i>	<i>Type 2 Events</i>	<i>Type 3 Events</i>
10 μ s	0/0	3/5
15 μ s	6/13	4/5
20 μ s	7/13	5/5

Because of the limited amount of Blackbeard data it is difficult to get a good idea of how much of a problem carrier actuations will be. We did not see a lot of false events due to this effect in the trials described above so we elected to leave the parameter C set at 5 μ s. Based on the above results we decided on the pass band, the coincidence window, and the carrier rejection cutoff time. The remaining parameters to experiment with were the number of coincident channels and the threshold level. As it turned out some subtle correlations appeared which made it difficult to optimize these parameters.

We ran an extensive series of trials in which we varied the number of coincident channels and the thresholds. We used all of the LAPP data available, 18 type-2 events and 44 type-3 events. The results for event detection are listed in Tables 5 and 6, and are shown graphically in Figures 1 and 2.

Figure 1. Detection Efficiency for Type-2 Events

Detection As a Function of Number of Coincident Channels, Horn Feed

Figure 2. Detection Efficiency for Type-3 Events

In our analysis we shall concentrate on the type-3 events, because their spectral characteristics are closer to those of the natural events of interest. In Table 6 we see a clear correlation between number of coincident channels and threshold level. The results are roughly equivalent if we decrease the number of coincident channels by one and simultaneously increase the threshold by one dB. Thus if we are interested in approximately 50% detection efficiency we could use 7-channel coincidence at a threshold of 15 dB, 6-channel coincidence with 16 dB, 5-channel coincidence with 17 dB, or 4-channel coincidence with 18 dB. The pattern in Table 5 shows a sharper decrease with the increasing number of coincident channels, probably because the helical-feed spectrum falls off rapidly with decreasing frequency in this band.

Table 5 : Detection Efficiency for Type-2 Events

N	$S = 15 \text{ dB}$	$S = 16 \text{ dB}$	$S = 17 \text{ dB}$	$S = 18 \text{ dB}$
4 of 8		0.78 (14/18)	0.72 (13/18)	0.56 (10/18)
5 of 8	0.78 (14/18)	0.61 (11/18)	0.44 (8/18)	0.33 (6/18)
6 of 8	0.39 (7/18)	0.22 (4/18)	0.06 (1/18)	
7 of 8	0.17 (3/18)		0.00 (0/18)	

Table 6 : Detection Efficiency for Type-3 Events

N	$S = 15 \text{ dB}$	$S = 16 \text{ dB}$	$S = 17 \text{ dB}$	$S = 18 \text{ dB}$
4 of 8		0.80 (35/44)	0.68 (30/44)	0.59 (26/44)
5 of 8	0.73 (32/44)	0.66 (29/44)	0.55 (24/44)	0.45 (20/44)
6 of 8	0.66 (29/44)	0.52 (23/44)	0.45 (20/44)	
7 of 8	0.52 (23/44)		0.23 (10/44)	

We have seen that a number of configurations exist which give approximately equal detection probabilities. The other task of the trigger is to reject false events. Tables 7 and 8 give the false-event rates for the same set of trigger parameters discussed above, while Figures 3 and 4 show the results graphically.

Trigger Rate As a Function of Number of Coincident Channels, Helix Feed

Figure 3. Trigger Rate for Type-2 Events

Trigger Rate As a Function of Number of Coincident Channels, Horn Feed

Figure 4. Trigger Rate for Type-3 Events

We see from Table 8 that there is a clear difference between the different configurations. Although 7 of 8 channels and a 15 dB threshold has the same detection probability as 6 of 8 channels and 16 dB, the false-event rate for the first case is almost three times as high as for the second. We also see that the case with 4 of 8 channels and 18 dB threshold is slightly worse, although this may simply be due to poor statistics. In any case, it is clear that the region to work in is 5 or 6 channel coincidence and 16 or 17 dB threshold. It appears from both Table 6 and Table 8 that the 17-dB-threshold results at all coincidence levels are slightly better than those at 16 dB with the coincidence levels increased by one. However, it is not clear whether this is a physical or a statistical effect. The results for the type-2 events in Table 7 indicate that the 16 dB threshold provides better results for false-event rejection, while Table 5 shows 17 dB is better for detection.

Table 7 : False Event Rate for Type-2 Events

<i>N</i>	<i>S</i> = 15 dB	<i>S</i> = 16 dB	<i>S</i> = 17 dB	<i>S</i> = 18 dB
4 of 8		629.8 event/s	162.8 event/s	92.2 event/s
5 of 8	1064.5 event/s	113.7 event/s	30.7 event/s	7.7 event/s
6 of 8	176.7 event/s	7.7 event/s	1.5 event/s	
7 of 8	21.5 event/s		0.0 event/s	

Table 8 : False Event Rate for Type-3 Events

<i>N</i>	<i>S</i> = 15 dB	<i>S</i> = 16 dB	<i>S</i> = 17 dB	<i>S</i> = 18 dB
4 of 8		405.9 event/s	57.8 event/s	12.9 event/s
5 of 8	908.2 event/s	68.6 event/s	5.7 event/s	1.5 event/s
6 of 8	174.3 event/s	8.3 event/s	1.5 event/s	
7 of 8	22.2 event/s		1.0 event/s	

We conclude that for naturally occurring events with a smoothly falling spectrum the best performance is obtained for a detection threshold of 17 dB above background. The coincidence level should be set as low as possible and will be either 5 or 6 of 8 channels depending on the event rate that the data-processing system can handle. Thus we have arrived at a set of parameter settings which we believe will give optimal or near-optimal performance for the FORTE trigger. These are given in Table 9. We look forward to on-orbit operational experience with the system.

Table 9 : Optimal Settings for Natural Events

<i>Parameter</i>	<i>Value</i>
Pass Band	45 - 65 MHz
Threshold (S)	17 dB
Cutoff Time (C)	5 μ s
Number of Channels (N)	5 of 8 or 6 of 8
Coincidence Window (W)	20 μ s

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