TSIM Rev 3/4 Manual

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1 Introduction

TSIM is a transponder signal simulator to be used in conjunction with TBAD (transponder-based aircraft detector) as a validation tool. TSIM provides aircraft-like pulse patterns across a range of signal strengths in both free-space and direct-wired configurations. In the free-space arrangement, together with the relative pointing angle of the receive (TBAD) antenna, TSIM can:

- verify that TBAD is capable of receiving and reacting to incident 1090 MHz signals
- check the sensitivity to theoretical and to empirical/historical expectations
- map out the angular response (in reflection-free environment)
- verify proper handling of saturation signals
- verify proper activation hold-off for beam events (*N* pulses required to activate shutter)

TSIM employs a number of modes to test these various features. Modes may be selected one at a time using the mode knob, or a "medley" mode setting is also available that cycles through key modes in a repeating sequence to provide a full sampling of tests. This mode is intended to be the default mode for normal validation operations.

Please refer to the list of abbreviations and acronyms at the end to resolve any ambiguities.

2 Physical Interface

The TSIM package was designed to have as simple an interface as possible, the idea being that tests could be carried out by simply applying AC power via a remote-controlled relay or IP switch. The knobs are inside of a sealed box, so that only the AC input (IEC 320 C-13) and RF output (BNC) are externally available (Fig. 1).

Internally, an ON/OFF switch and two setting knobs are available (Fig. 2). as well as an LED that blinks each time an RF pulse sequence is produced. The knobs go by the name of Mode and Parameter. Each has a range of 0–15, and may be rotated continuously (can go from 15 to 0 without going the long way back around).

The PCB has one jumper, allowing external drive of the pulse pattern (see Fig. 3). In testing, it can be useful to generate continuous RF output, which is accomplished by connecting 5 V DC

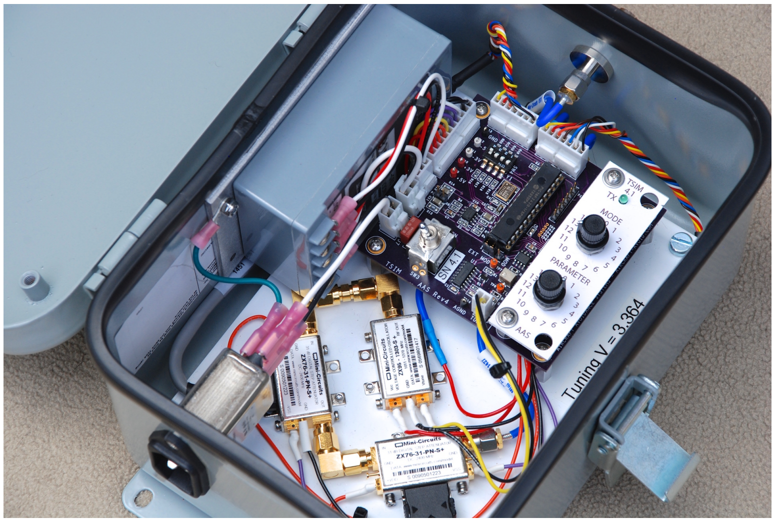

Figure 1: TSIM in its weatherproof box.

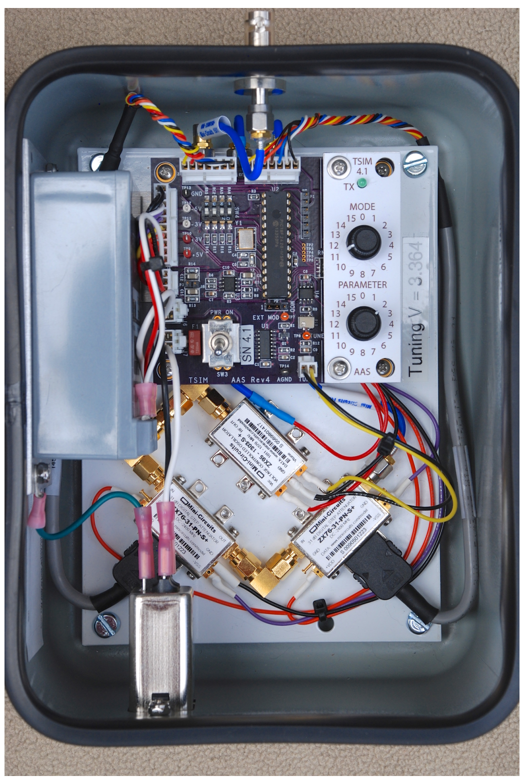

Figure 2: TSIM internals. The ON/OFF switch is on the lower-left corner of the PCB and the mode and parameter switches are on the panel at upper right. The RF components consist of a voltage-tuned oscillator, two digital attenuators in series, and an RF switch (under the PCB).

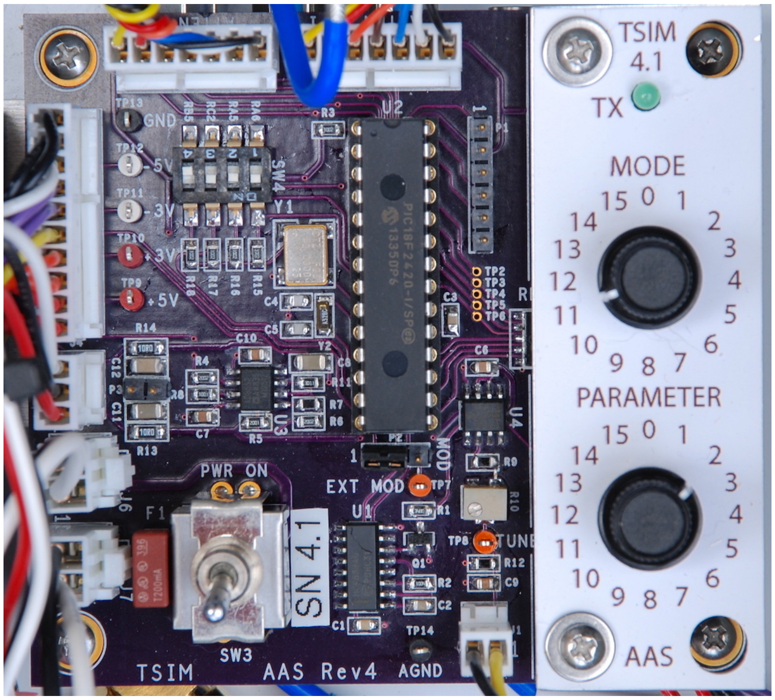

Figure 3: TSIM PCB, showing the MODE and PARAMETER knobs, as well as the transmit (TX) LED. The red test point at center labeled EXT allows an external logic signal applied to this point to drive the TSIM output pattern. In order to activate this drive, the adjacent jumper must be moved toward the right. In normal operation, the jumper should be in the left position, as seen here. The SW4 dipswitch at upper left controls alternate operational states for TSIM. In this picture, the leftmost (position 4) is in the OFF (up) position, and the rest ore in the default ON (down) positions.

to the EXT test point (can use red test point labeled +5V as source). Should it be necessary, the frequency of the oscillator can be tuned via the potentiometer R10, monitoring the orange test point labeled TUNE with respect to the nearby black test point labeled AGND.

A dipswitch, labeled SW4 on the PCB silkscreen, allows control of a few variations in TSIM behavior. The default behavior corresponds to all four switches being in the “down” (labeled ON) positions. The leftmost (position 4) controls the behavior for MODE 15, while the other three allow alternative (stronger-than-default) levels for MODERATE, STRONG, and VERY STRONG, as defined below.

3 Physical Setup Options

TSIM can be configured either for free-space transmission or direct wired transmission. Direct wiring produces more reliable results (no environmental interference, multipath reflections, etc.), but does not test the *entire* TBAD system (bypasses antenna). Also, direct connection, if unattenuated, is more powerful than typical operational levels. Still, direct connection is used for bench-testing TBAD and forms the basis of the acceptance-testing checkout sheets shipped with TBAD.

3.1 Free-Space Testing

For free-space testing, attach the TSIM single-patch antenna to the TSIM output using a BNC cable suiting your physical environment. Long runs may merit a low-loss cable such as RG-8 ($\sim$ 0.25 dB/m) to keep the 1.09 GHz attenuation from being a large problem. For runs shorter than 5 m, RG-58 ($\sim$ 0.55 dB/m) is not a bad choice, and for testing purposes RG-174 ($\sim$ 1.1 dB/m) would probably suffice.

Place the TSIM antenna in front of the TBAD antenna separated by something in the 2–4 meter range (designed for observatories where dome wall is roughly this far from telescope front). Orient the TSIM antenna patch in the same direction as the TBAD patches, up to 180° so that polarizations are not crossed (refer to feedpoint to identify symmetry direction). Ideally, free-space testing would be done in the void of space with no nearby conductors (or ground) in the space between the planes defined by the two antennas. A less expensive option is a terrestrial anechoic chamber. Short of this, coming in under the millions-mark is an outdoor or lab setting with some thought put into isolating the antennas from local structures as much as is practical. Beam patterns should not be fully trusted in imperfect environments, but results should still make some sense.

3.2 Direct-wired Tests

TBAD acceptance testing is performed via direct wiring, whereby TSIM output is coupled directly to one or both TBAD discriminator inputs (where the TBAD antenna normally connects) via coaxial cable. Signals are approximately 20 dB (100$\times$) stronger than the free-space approach, so be prepared to utilize only the lower power range of TSIM.

It is very convenient to possess a splitter so that both TBAD DIREC/ARRAY and OMNI/SINGLE inputs can be driven simultaneously. For consistency with original checkout sheets, choose a -6 dB resistive 2:1 splitter rather than the more common -3 dB reactive units (JFW 50PD-016 or MiniCircuits ZFRSC-42-S+ as possibilities). The signal is already strong, so no need for greed. Also very handy is a 0–10 dB variable attenuation to put on the OMNI leg for simulating in-beam and out-of-beam transmissions (examples: JFW 50R-019; ATM Microwave AS013-10-1). This could, in principle, be done with in-line fixed attenuators, but less gracefully. Finally, one may wish to have an overall attenuation in the 10–20 dB range, which could be accomplished by fixed attenuators (MiniCircuits VAT-20+ or BW-S20W-2), or by the luxury route in a wide-range adjustable step attenuator (such as: JFW 50DR-046; ATM Microwave AS113-50-1 or AS013-60-10). Of course you'll want to have the various cables and adapters and elbows, etc. to assemble the components in useful configurations. SMA is recommend where possible, even through TSIM puts out BNC.

A separate document details how TSIM may be used to replicate the acceptance-test checkout sheets, and verify other performance aspects. The rest of this manual describes the operational modes of TSIM available to the user.

4 Operational Modes and Principles

The **MODE** knob selects the overall operational mode of TSIM. For most modes, the **PARAMETER** knob (PARAM) controls some aspect of the behavior, although its interpretation is **context-**

Table 1: MODE Settings

MODE #	Mode Name	Description	PARAM Interpretation
0	Medley	repeating sampling	varied
1	Full ramp	every power level explored	no effect
2	Weak ramp	only sub-threshold power levels	sets peak signal
3	N-moderate	produce N moderate-strength packets per frame	sets N
4	High-rate moderate	50 Hz burst (1 sec) at moderate strength	mid-range signal level
5	High-rate background	produce N moderates in sea of weak	sets N
6	Variable rate	moderate-level packets emitted at fixed rate	sets rate
7	Mode-S	56-bit and 112-bit test patterns	even/odd→56/112 bit
8	Strong packet	single high-strength packet per frame	high-end signal level
9	2-per-frame	two packets per frame	full-range signal level
10	5-per frame	five packets per frame	full-range signal level
11	10-per frame	ten packets per frame	full-range signal level
12	20-per-frame	twenty packets per frame	full-range signal level
13	50-per-frame	fifty packets per frame	full-range signal level
14	100-per-frame	100 packets per frame	full-range signal level
15	500-per-frame	500 packets per frame	full-range signal level
15-alt	nuisance signals	glitches, pulses, DME analog	some signal levels

dependent, depending on the mode. When controlling power levels, a higher PARAM number always corresponds to higher power.

Table 1, at first glance, likely generates more questions than it answers. First, some terminology.

TSIM operation can be divided into two fundamentally different mode types. **Manual mode** covers MODE knob settings from 1–15. **Medley mode** pertains to the MODE knob setting of 0. Medley mode rotates through a sequence of behaviors, each one separately accessible in manual mode. It is not unusual for the PARAM knob to carry different meanings in manual vs. medley mode.

TSIM operates on the principle of **frames**. A frame nominally lasts 10 seconds. When a frame is done, either the same behavior repeats (manual mode), or a new behavior is selected (medley mode). Every frame in medley mode begins with a **heartbeat** signal: a moderate-level single pulse to announce the beginning of a frame to ensure that TBAD can hear *something*. Depending on the behavior, a two second pause may be appended to each frame. The rationale is to give TBAD a chance to relax the shutter before a new shutter-closing offense is inflicted.

For some modes, signal levels are characterized as **weak**, **moderate**, or **strong**, and are set in the firmware. Positions 1, 2, and 3 of the TSIM dipswitch (SW4) allow user control of variants to these (ON or "down" positions being default). Table 2 details the definitions of these levels under the default firmware (checksum 0x0744). WEAK signals are not expected to exceed the TBAD DT threshold, under normal tunings and circumstances. Thus even if in the center of the beam, TBAD will deem the signal too weak to create a shutter trigger. For normal TBAD settings, weak signals will be invisible, and will not make an entry in the log. Tuning TBAD's OT setting to a higher voltage will permit visibility of the weak pulses. MODERATE signals are meant to have a high enough level to surpass the DT threshold, and therefore create a shutterable offense (if in-beam)

Table 2: Standard Signal Level Definitions

Level Name	Nominal Strength	Alternate Strength (SW4 OFF)	Used by Modes
WEAK	−46 dB = "21"	—	2
MODERATE	−30 dB = "41"	SW4:2 −26 dB = "45"	0, 3, 5, 6, 7, 15alt
STRONG	−14 dB = "61"	SW4:3 −10 dB = "65"	0
VERY STRONG	−6 dB = "71"	SW4:4 0 dB = "77"	0

and a TBAD log entry. The TBAD-controlled shutter will only close after *NB* events have been recorded in the last 10 seconds, depending on the knob setting on the front of the TBAD decoder unit (*NB* represents *N* "in-beam" events in 10 seconds). STRONG signals could potentially cross the saturation thresholds (DS and OS), depending on level and settings. A single saturation event will close the shutter. The medley mode tests the reaction to STRONG signals, but also VERY STRONG. The goal is to generate DS events with the former and OS (plus DS) events with the latter.

Programmable attenuators within TSIM provide 32 possible signal levels, in steps of 2 dB (a factor of 1.58 per step, corresponding to aircraft distance steps in factors of 1.26). At TBAD, each 2 dB step corresponds to 0.05 V with respect to the various thresholds. In other words, changing any threshold by 0.1 V corresponds to two steps of TSIM signal level adjustment, or 4 dB in signal strength.

Each transmission has an associated code. They all share the common features that the first framing pulse is present (mandatory based on how TBAD interprets the first pulse of any sequence), and also the X bit, but no final framing pulse. This makes the TSIM signals look different from any legitimate aircraft transmission. There are four octal digits also associated with each transmission. The first two (AB) indicate the mode, and the second two (CD) reveal the power level. Certain constraints are imposed on possible codes, so that particular emergency and common aircraft codes may be avoided. For instance, the D digit always has the least-significant bit set, to avoid the possibility of a code ending in zero. Thus D will always be odd. Likewise, the middle bit on A is never set, so only 0, 1, 4, and 5 are possible A digits (many emergency/special codes begin with 7). When the most significant bit in A is set (4 or 5, in practice), this indicates that the current behavior is being accessed from the medley mode, as opposed to manual mode (direct knob setting).

Now we have the language to discuss operating modes in more detail. Note that all modes have defined behaviors in medley mode, even if the current medley firmware does not utilize that modality in its sequence.

4.1 Full Ramp: MODE Knob Position 1

The full ramp visits every TSIM output power in steps of 2 dB, going from the weakest to the strongest in the first five seconds of the frame, then descending through the same sequence over the following 5 seconds. The PARAM knob has no effect. A two second pause is inserted at the end. The AB code is either 01 or 41, depending on whether the ramp is accessed from the mode knob (in position 1) or via medley mode, respectively. CD values will ascend through 01, 03, 05, 07, 11, ..., 67, 71, 75, 77 before descending through the same 32-bit sequence. Only the top of the "mountain" will be usually be recorded by TBAD, which is useful for elucidating the signal level corresponding to threshold settings.

4.2 Weak Ramp: MODE Knob Position 2

The weak ramp is very similar to the full ramp—stepping through power output in 2 dB steps—except that it does not ascend all the way to the maximum signal. In manual mode, the PARAM knob sets the maximum signal level, the 16 positions covering the lowest 16 power settings of TSIM in 2 dB steps. In medley mode, the peak power is hard-coded in the software, and not responsive to the PARAM knob position. Packets are sent at a fixed cadence, so that a weaker ramp completes more quickly than a stronger one (more steps in the stronger sequence). After the weak ramp is complete, a pause is added to pad out the frame. Because the level may typically be below TBAD thresholds, the frame may appear to be empty besides the heartbeat packet. In medley mode, the weak ramp is often used to allow TBAD to relax the shutter. The AB code is 02, or 42 if accessed via medley mode.

4.3 N-Moderate: MODE Knob Position 3

Produces N packets of moderate-strength at a fixed cadence. The purpose is to test that TBAD closes the shutter on the NBth packet, as set on the TBAD front panel. The strength is hard-coded, and the PARAM knob sets the value for N. The pattern corresponds exactly to the TBAD knob settings, running through the sequence: 0, 1, 2, 3, 4, 5, 6, 8, 10, 12, 15, 20, 25, 30, 35, 40. Nominally, the PARAM knob should match the setting of the TBAD knob. In medley mode, this sequence is applied with one less packet than the setpoint ($N-1$), then the exact number (N), and later one plus the setpoint ($N+1$). This checks that TBAD does *not* trigger on $NB-1$, but does on NB or more. The heartbeat is factored into the calculation, looking just like the other moderate packets. The AB code is 03 in manual mode, 43 in medley mode.

4.4 High-Rate Moderate: MODE Knob Position 4

Sends out a burst of pulses at 50 Hz for one second to check that TBAD can respond to high-rate signals. In manual mode, the PARAM knob controls the signal strength, covering the middle 16 possible values in steps of 2 dB. In medley mode, the strength is hard-coded and the PARAM knob is ignored. The AB code is 04 in manual mode, 44 in medley mode.

4.5 High-Rate Background: MODE Knob Position 5

Intended to check that TBAD can respond to shutterable offenses in the midst of a high background rate, this mode provides a flood of weak signals (signal strength hard-coded) with interspersed moderate signals (also hard-coded strength). The PARAM knob sets the number of moderate packets in the frame, just as for MODE 3 (following TBAD NB knob sequence). In medley mode, the number is adjusted to accommodate the heartbeat. Note that unless the OT is set to accept weak signals, the background will be unobservable, and therefore does not constitute a novel test for TBAD beyond what happens in MODE 3. The AB code is 05 in manual mode, or 45 in medley mode.

4.6 Variable Rate: MODE Knob Position 6

Ten moderate-strength packets are emitted at a variable rate. Manual mode produces rates from 10–160 Hz, in steps of 10 Hz. For instance, a PARAM knob setting of 5 will produce a 60 Hz rate. In medley mode, the rate is adjusted with the passing of each second of time. So within the ten second frame, the first second sees 10 Hz, the second second sees 20 Hz, etc., ending at 100 Hz. The AB code is 06, or 46 in medley mode.

4.7 Mode-S; ADS-B: MODE Knob Position 7

This mode emulates 56-bit Mode-S patterns or 112-bit ADS-B patterns depending on whether the PARAM knob is even or odd, respectively. Patterns are 0123456789ABCD for the shorter code and FFEEDDCCBBAA9988776655443322 for the longer code. Signal strength corresponds to the moderate definition. Codes emerge once per second, including the preamble so that TBAD may process these signals differently. Because these codes do not follow the ABCD octal Mode A/C pattern, the mode and strength are not encoded in the transmission as for all other modes.

4.8 Strong Packet: MODE Knob Position 8

A single high-strength packet is emitted per frame, allowing tests of saturation limits and single-event shuttering in response. In manual mode, the strength is set by the PARAM knob, in steps of 2 dB, spanning the upper 16 values in the full range. In medley mode, the strength is hard-coded (testing both strong and very strong levels). The two-second rest at the and of the frame is preserved in both manual and medley modes, to give TBAD time to open the shutter. The AB code is 10 in manual, 50 in medley.

4.9 Two Per Frame: MODE Knob Position 9

This setting emits two packets in each frame, equally separated, and with no two-second rest at the end (in manual mode), giving a steady 0.2 Hz rate. In medley mode, the signal strength is hard-coded to be moderate. In manual mode, the signal strength is adjustable across the full range using the PARAM knob, in steps of 4 dB. The AB code is 11 in manual mode, 51 in medley mode.

4.10 Five Per Frame: MODE Knob Position 10

This setting behaves just like the previous, but with five packets in each frame, giving a steady 0.5 Hz rate in manual mode. The AB code is 12 in manual mode, 52 in medley mode.

4.11 Ten Per Frame: MODE Knob Position 11

This setting behaves just like the previous, but with ten packets in each frame, giving a steady 1 Hz rate in manual mode. The AB code is 13 in manual mode, 53 in medley mode.

4.12 Twenty Per Frame: MODE Knob Position 12

This setting behaves just like the previous, but with 20 packets in each frame, giving a steady 2 Hz rate in manual mode. The AB code is 14 in manual mode, 54 in medley mode.

4.13 Fifty Per Frame: MODE Knob Position 13

This setting behaves just like the previous, but with 50 packets in each frame, giving a steady 5 Hz rate in manual mode. The AB code is 15 in manual mode, 55 in medley mode.

4.14 One-Hundred Per Frame: MODE Knob Position 14

This setting behaves just like the previous, but with 100 packets in each frame, giving a steady 10 Hz rate in manual mode. The AB code is 16 in manual mode, 56 in medley mode.

4.15 MODE Knob Position 15

This mode has two wholly different behaviors depending on the position of the number-4 dipswitch on SW4.

4.15.1 Five-Hundred Per Frame

When the SW4:4 dipswitch is in the ON (down) position, this setting behaves just like the previous, but with 500 packets in each frame, giving a steady 50 Hz rate in manual mode. The AB code is 17 in manual mode, 57 in medley mode.

4.15.2 Nuisance Pulses

When the SW4:4 dipswitch is OFF (up), this mode tests TBAD's response to various nuisance signals. The signals emerge one after the other, 0.25 s apart.

1. Glitch: single pulse, strength following PARAM knob. TBAD should report only if BT, DS, or OS conditions are met, but should not close the shutter. The code should be 0000, and the '`FXF`' field will only have the first framing pulse (initial pulse always identified with first framing pulse, even if erroneous), and therefore read `F..`
2. Short Pulse: ~3 µs pulse, strength following PARAM knob. This is long enough that the C1 sample bit is flagged. TBAD should report only if BT, DS, or OS conditions are met, but should not close the shutter. The code should be 0010.
3. Medium Pulse: ~10 µs pulse, strength following PARAM knob. Should have exactly the same impact as the Short Pulse.
4. Long Pulse: ~20 µs pulse, strength following PARAM knob. Should have exactly the same impact as the Short Pulse.

Table 3: Medley Sequence.

Step	MODE	AB code	Action
1	1	41	Full Ramp
2	2	42	Weak Ramp
3	3	43	N-moderate with $N = NB - 1$
4	3	43	N-moderate with $N = NB$
5	2	42	Weak Ramp
6	3	43	N-moderate with $N = NB + 1$
7	2	42	Weak Ramp
8	8	50	Strong Packet with signal $>$ DS
9	8	50	V. Strong Packet with signal $>$ OS
10	4	44	High-rate moderate with signal $<$ DT
11	4	44	High-rate moderate with signal $>$ DT
12	2	42	Weak Ramp
13	5	45	High-rate background with $N = NB$
14	2	42	Weak Ramp

5. Pulse Pair: two 400 ns pulses 5.5 µs apart, producing code 2000. Signal level is "moderate" if the second dipswitch position from left (SW4:3) is down (ON), but "very strong" if this dipswitch is up (OFF). This tests TBAD's response to a "single-bit" saturation event.

6. DME: a pair of fat pulses 12 µs apart are produced whose strength follows the PARAM knob, but with a pre-step that tests TBAD's lookback function. The level of the pre-step is set by the dipswitch second position (SW4:3). Expected code is 0011.

These modes test TBAD's ability to ignore nuisance parameters, and some TBAD settings impact the response behavior. For example, item 5 tests the function of the TBAD's decoder dipswitch, position 2. When engaged, this feature ignores double pulse (interpreted as first framing plus "single bit" stimulation) saturation events. Item 6 tests the lookback feature of TBAD for ignoring in-beam pulses for which the "background" just prior to the DT-crossing pulse is higher than the DC threshold.

5 Medley Mode

As currently programmed in firmware V12, medley mode runs through the sequence listed in Table 3. Alternate definitions of moderate, strong, and very strong are used depending on the SW4 dipswitch positions, as defined in Table 2

The Weak Ramp is used as a filler when TBAD is expected to have closed the shutter and not had adequate time to recover (re-open) prior to the next frame.

6 Example Walk through the Medley

The encoding scheme should permit identification of the circumstances of any given packet's creation. The AB code corresponds to the MODE in which the packet was generated (including distinction between medley and manual modes), so that the manual mode knob position may be known. The CD code is unique for each of the 32 transmit power levels. The X-bit should be present, and the final framing bit (F) missing. One should never see a value for A of 2, 3, 6, or 7. D should never be even.

The following are examples from preliminary tests on Keck-2, using firmware version 6. We'll look at each frame in sequence as the medley progresses. There are some anomalous behaviors, indicating in some cases the need to revisit and correct the firmware [this section should be updated with a new data capture].

6.1 Step 1: Full Ramp

First, we look at a sequence from the strong ramp, in medley mode:

```
2013-01-06, 22:30:16.911, o4141..BPFX.F3
2013-01-06, 22:30:16.913, o4143..BPFX.F5
2013-01-06, 22:30:16.913, s4145..BPFX.FB
2013-01-06, 22:30:16.934, s4147..BPFX.FD
2013-01-06, 22:30:17.095, s4151..BPFX.F8
2013-01-06, 22:30:17.255, s4153..BPFX.FA
2013-01-06, 22:30:17.415, s4155..BPFX.FC
2013-01-06, 22:30:17.575, s4157..BPFX.FE
2013-01-06, 22:30:17.735, s4161..BPFX.F9
2013-01-06, 22:30:17.900, s4163..BPFX.FB
2013-01-06, 22:30:18.015, s4165..BPFX.FD
2013-01-06, 22:30:18.175, s4167.DBPFX.15
2013-01-06, 22:30:18.335, s4171.DBPFX.10
2013-01-06, 22:30:18.495, s4173.DBPFX.12
2013-01-06, 22:30:18.655, s4175ODBPFX.35
2013-01-06, 22:30:18.815, s4177OD.PFX.23
2013-01-06, 22:30:18.975, s4177OD.PFX.23
2013-01-06, 22:30:19.135, s4175ODBPFX.35
2013-01-06, 22:30:19.294, s4173.DBPFX.12
2013-01-06, 22:30:19.415, s4171.DBPFX.10
2013-01-06, 22:30:19.575, s4167.DBPFX.15
2013-01-06, 22:30:19.735, s4165..BPFX.FD
2013-01-06, 22:30:19.895, s4163..BPFX.FB
2013-01-06, 22:30:20.055, s4161..BPFX.F9
2013-01-06, 22:30:20.215, s4157..BPFX.FE
2013-01-06, 22:30:20.375, s4155..BPFX.FC
2013-01-06, 22:30:20.535, s4153..BPFX.FA
2013-01-06, 22:30:20.695, s4151..BPFX.F8
2013-01-06, 22:30:20.855, s4147..BPFX.FD
2013-01-06, 22:30:20.975, s4145..BPFX.FB
2013-01-06, 22:30:21.135, s4143..BPFX.F9
2013-01-06, 22:30:21.295, s4141..BPFX.F7
```

We see that: 1) the pulses come out in a steady rate; 2) the shutter closed on the third detection ($NB = 3$); 3) the signals are all “in beam” (except when saturation interferes); 4) all have the characteristic “FX.” sequence indicating that the X bit is on and the final F is off; 5) the mode is 41 (medley-requested full ramp); 6) the signal enters the DT-detectable range at a power corresponding to CD = 41, and thereafter counts up all the available odd octal digits to 77; 7) that the directional array begins to saturate at a power level corresponding to CD = 67, and the omni saturates at the top two power levels; 8) that the directional array becomes so saturated at the highest power level (77 is 8 dB, or 0.2 V higher than 67) such that the in beam assessment is predictably thwarted; 9) the response is symmetric; 10) no packets are missing; 11) a 4.5 second pause enters at the end, before the weak ramp heartbeat comes along. Note that the moderate signal level was pre-programmed to come in at level CD = 41, which it turns out is just on the edge of the DT setting. Not as much margin as was intended.

6.2 Step 2: Weak Ramp

This one is empty, except for the heartbeat.

```
2013-01-06, 22:30:25.855, s4241..BPFX.F8
```

6.3 Step 3: N-moderate

Meant to be just two pulses (if NB set to 3), but came out as four, including heartbeat. Also notice they are piled right on top of each other.

```
2013-01-06, 22:30:34.293, s4341..BPFX.F9
2013-01-06, 22:30:34.294, s4341..BPFX.F9
2013-01-06, 22:30:34.295, s4341..BPFX.F9
2013-01-06, 22:30:34.295, s4341..BPFX.F9
2013-01-06, 22:30:44.095, o8888...P...B3
```

Not sure why the shutter was still closed at the beginning of the sequence: the last weak ramp should have supplied ample time to release the shutter hold. Sometimes if TBAD is kept really busy, the time counter is not allowed to advance. This always fails safe: the shutter is more likely to come on, and takes longer to turn off. Note that the time stamp is from the logging computer, not TBAD itself. At the end of the sequence, the shutter does open, ten seconds after the last offense, as expected.

6.4 Step 4: N-moderate

Meant to be 3 pulses (if NB = 3), but came out as four, including heartbeat. Again piled up, but at least started out with shutter open, closing on the third offense. The sequence starts 12 seconds after the previous one, as expected (ten second frame plus 2 second rest).

```
2013-01-06, 22:30:46.323, o4341..BPFX.F5
2013-01-06, 22:30:46.324, o4341..BPFX.F5
```

```
2013-01-06, 22:30:46.324, s4341..BPFX.F9
2013-01-06, 22:30:46.325, s4341..BPFX.F9
2013-01-06, 22:30:56.095, o8888...P...B3
```

6.5 Step 5: Weak Ramp

Time to rest. Only the heartbeat at the beginning is seen.

```
2013-01-06, 22:30:58.294, o4241..BPFX.F4
```

The shutter was already open before this mode came along.

6.6 Step 6: N-moderate

This one was meant to be four moderate pulses, and actually is. A broken clock is right twice a day, perhaps.

```
2013-01-06, 22:31:05.855, o4341..BPFX.F5
2013-01-06, 22:31:05.975, s4341..BPFX.F9
2013-01-06, 22:31:06.055, s4341..BPFX.F9
2013-01-06, 22:31:06.175, s4341..BPFX.F9
2013-01-06, 22:31:16.678, o8888...P...B3
```

Curiously, the shutter closes on the second, rather than third offense, but opens at the expected time.

6.7 Step 7: Weak Ramp

Time for rest. Shutter is already open.

```
2013-01-06, 22:31:17.855, o4241..BPFX.F4
```

6.8 Step 8: Strong Packet, DS Trigger

The heartbeat does not close the shutter, but the strong signal does, even though 65 is actually not strong enough to trip DS.

```
2013-01-06, 22:31:25.855, o5041..BPFX.F3
2013-01-06, 22:31:25.975, s5061..BPFX.F9
2013-01-06, 22:31:35.639, o8888...P...B3
```

6.9 Step 9: Very Strong Packet, OS Trigger

This time, a level of 75 is enough to trip both omni and directional antennas, closing the shutter in the process.

```
2013-01-06, 22:31:37.855, o5041..BPFX.F3
2013-01-06, 22:31:37.975, s5071ODBPFX.31
2013-01-06, 22:31:47.585, o8888...P...B3
```

6.10 Step 10: High Rate, Moderate, Signal $<$ DT

Because the signal was sub-threshold, only the heartbeat is heard.

```
2013-01-06, 22:31:49.855, o4441..BPFX.F6
```

6.11 Step 11: High Rate, Moderate, Signal $>$ DT

Open the floodgates.

```
2013-01-06, 22:32:02.911, o4441..BPFX.F6
2013-01-06, 22:32:02.913, o4441..BPFX.F6
2013-01-06, 22:32:02.913, s4441..BPFX.FA
2013-01-06, 22:32:02.914, s4441..BPFX.FA
2013-01-06, 22:32:02.914, s4441..BPFX.FA
2013-01-06, 22:32:02.914, s4441..BPFX.FA
2013-01-06, 22:32:02.914, s4441..BPFX.FA
:
2013-01-06, 22:32:11.775, s4441..BPFX.FA
2013-01-06, 22:32:11.815, s4441..BPFX.FA
2013-01-06, 22:32:11.815, s4441..BPFX.FA
2013-01-06, 22:32:11.855, s4441..BPFX.FA
2013-01-06, 22:32:11.855, s4441..BPFX.FA
```

A total of 495 events spanning about 9 seconds. The shutter closes on the third event, which is expected behavior.

6.12 Step 12: Weak Ramp

The usual heartbeat, and that's all.

```
2013-01-06, 22:32:14.278, s4241..BPFX.F8
```

6.13 Step 13: High Rate Background, $N = 3$

After the heartbeat, there are three moderate signals mixed in with (unseen) lower-strength signals at a high rate.

```
2013-01-06, 22:32:21.855, s4541..BPFX.FB
2013-01-06, 22:32:22.175, s4541..BPFX.FB
2013-01-06, 22:32:22.375, s4541..BPFX.FB
2013-01-06, 22:32:22.615, s4541..BPFX.FB
```

Shutter has been on through last few frames, for some reason.

6.14 Step 14: Weak Ramp

Same old story, but shutter is still on.

```
2013-01-06, 22:32:23.855, s4241..BPFX.F8
```

6.15 Now Repeat

Next comes the full ramp again. First we see the heartbeat, then a pause while the ramp is in the unseen low-signal territory, picking up again at level 41 and climbing.

```
2013-01-06, 22:32:32.407, s4141..BPFX.F7
2013-01-06, 22:32:34.455, s4141..BPFX.F7
2013-01-06, 22:32:34.615, s4143..BPFX.F9
2013-01-06, 22:32:34.775, s4145..BPFX.FB
2013-01-06, 22:32:34.935, s4147..BPFX.FD
```

And so it goes. The sequence took about 137 seconds to run its course.

7 List of Abbreviations and Acronyms

AB	refers to first two digits in the transmitted ABCD code, signifying operating mode
AC	Alternating Current
BNC	Bayonet Neill-Concelman: standard twist-lock co-ax connector
CD	refers to the last two digits in the transmitted ABCD code, signifying power level
DS	Directional Saturation threshold in TBAD
DT	Directional Threshold setting in TBAD, indicating an aircraft within protected zone
IP	Internet Protocol
LED	Light Emitting Diode
NB	Number of in-Beam events (in last 10 seconds) required for TBAD shutter to activate
OS	Omni Saturation threshold in TBAD
OT	Omni Threshold for logging single-patch detections
RF	Radio Frequency
TBAD	Transponder-Based Aircraft Detector
TSIM	Transponder SIMulator