Aircraft Avoidance Technologies

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plus

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Background photo by Jack Dembicky

Agency Compliance & Headaches

- For APOLLO, we must interface with four agencies for safety compliance
  - FAA (Federal Aviation Administration)
  - Holloman Air Force Base
  - White Sands Missile Range
  - Space Command (satellites)
- The FAA requires two human spotters with eyes on the sky, blocking the laser if an aircraft comes within 25° of the beam, or if the sky is obscured by clouds within 25° of the laser beam
  - spotters are difficult to schedule in remote areas
  - sometimes they get sick or don’t set their alarm correctly
  - spotters demand a continual cash-flow for payment
  - spotters do not have perfect attention and visual reliability
- Radar systems can be unwelcome at an observatory due to the high power RF interfering with other equipment

Two Complementary Technologies

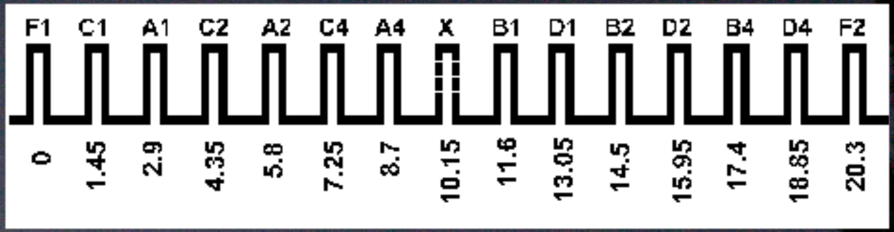
- APOLLO has chosen to explore infrared and RF transponder technologies for aircraft avoidance
- Infrared (IR) camera with motion-sensing software algorithm
  - works well for nearby (< 5 km) aircraft
  - works for low aircraft in radar shadow (low → close)
  - works for low-flying aircraft not required to have transponder
- RF Transponder Detector seeks 1090 MHz signal directionally
  - all aircraft above 10,000 ft (3,048 m: our observatory is at 9,200 ft) must have a transponder, unless within 2,500 ft (762 m) of surface
  - transponder transmissions are strong enough to detect very far away (> 100 km)
  - system is passive: transponder is continuously interrogated by ground radar systems, and the response is omni-directional: we just listen

IR Camera Details

- Camera, lens, and software produced by Image Labs International, in Bozeman, Montana, USA
- Thermal infrared sensor sees ~300 °K skin of aircraft against cold sky (effective sky temp at 8–10 μm < 100 °K)
- Field of View is 5°×7°, operating at video rate of 30 frames per second
- Worst-case angular velocity: aircraft traveling 100 m/s (360 kph; 220 mph) at range of 150 m travels 1.3° per frame period
  - software looks for 3 consecutive detections along a line to raise flag
  - worst-case still shuts laser in time
- Installed on telescope and running at APO, though currently bypassed and collecting data

Transponder Basics

- Almost all aircraft carry transponders that respond to ground interrogations by sending out pulse train at 1090±3 MHz
  - peak power must be > 70 W; > 125 W for commercial aircraft
  - pulse pattern carries information about either:
    - temporary aircraft identity ("squawk code"; called Mode-A)
    - encoded altitude (Mode-C)
  - depending on what the interrogator asks for (alternates)
  - pulse pattern consists of framing pulses plus four 3-bit codes for a total of 4096 combinations



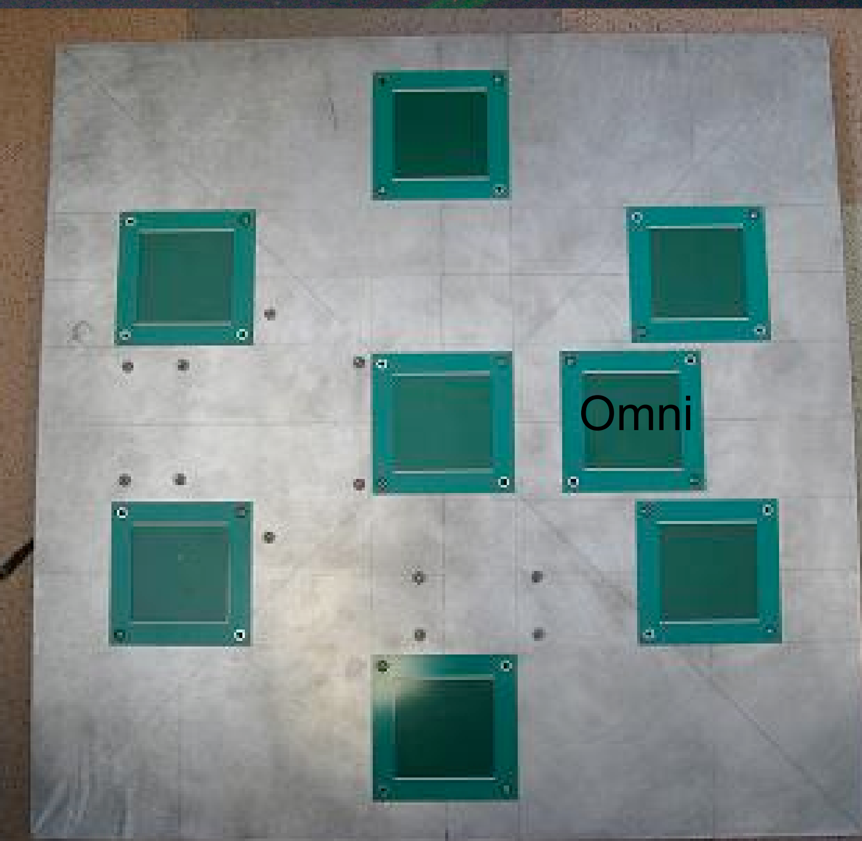
pulses 0.45 μs long, with pulse times given in μs. The F1 and F2 framing pulses are always present.

- The transponder signals are omni-directional, so all we need to do is determine if there is a source of 1090 MHz near our beam
  - aircraft also may emit strong DME signals near 1090 MHz, and these can leak into our receiver

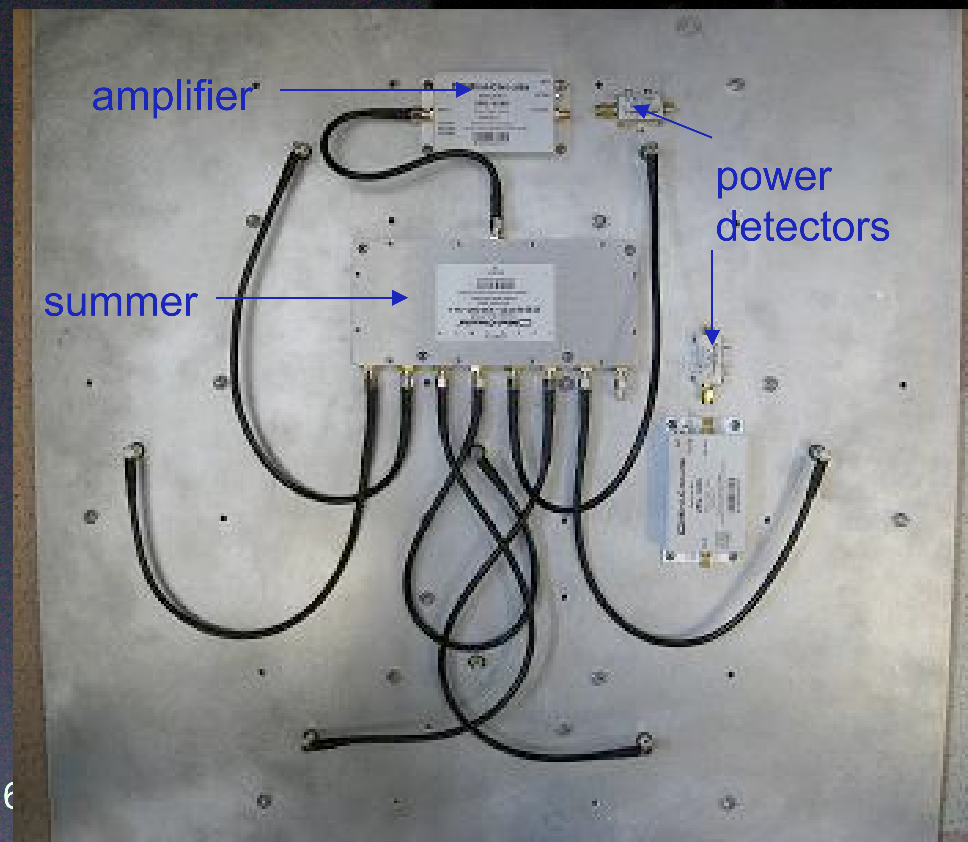
Patch Antenna Array

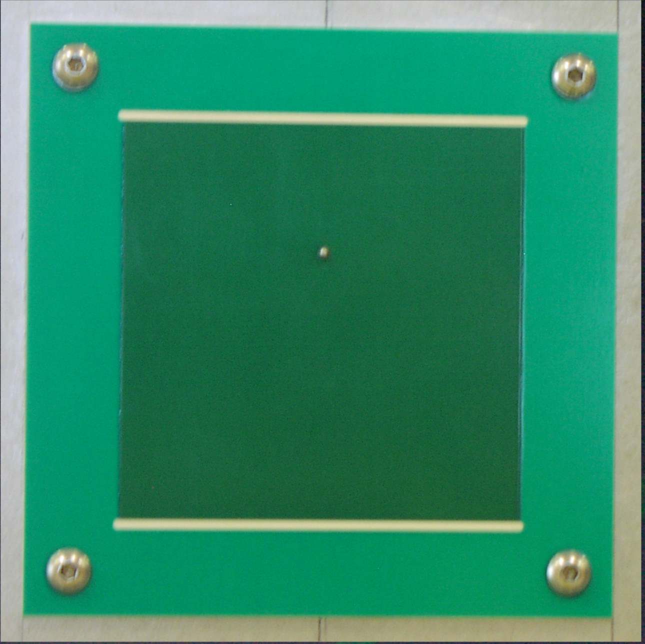
- Directional sensitivity can be accomplished via a phased array of patch antennas
  - thin patches are inherently narrowband (1% in our case)
- ~7 cm patches on 10 cm boards are arranged into a 7-element array spanning ~0.6 m, plus a separate single (OMNI) patch

Front



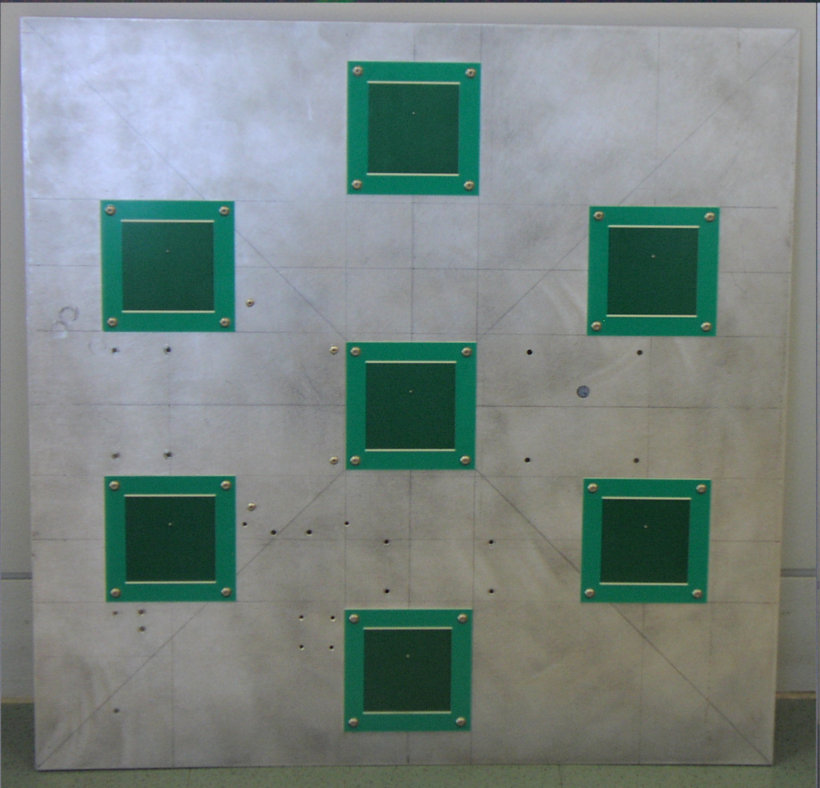
Back

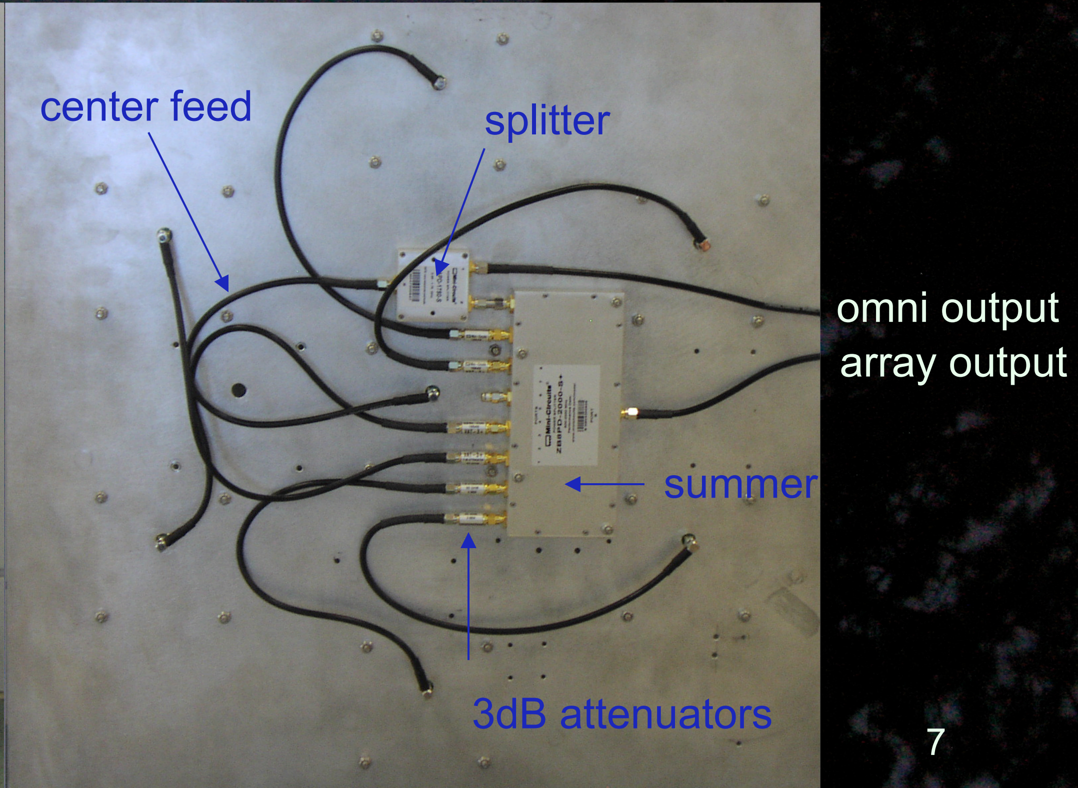




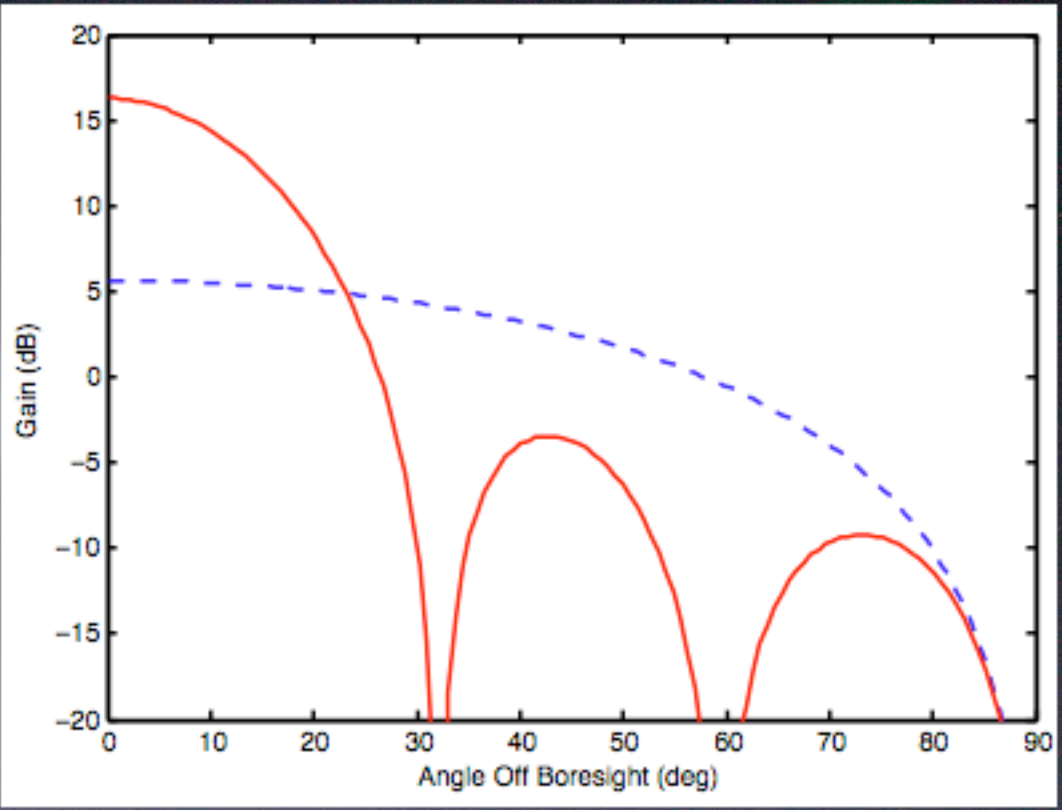
Alternate Scheme

- Can also use splitter on central element to double as omni-directional antenna
- Must then attenuate each perimeter element by 3dB to maintain beam pattern
- Advantage is elimination of parasitic coupling between array and omni antennae



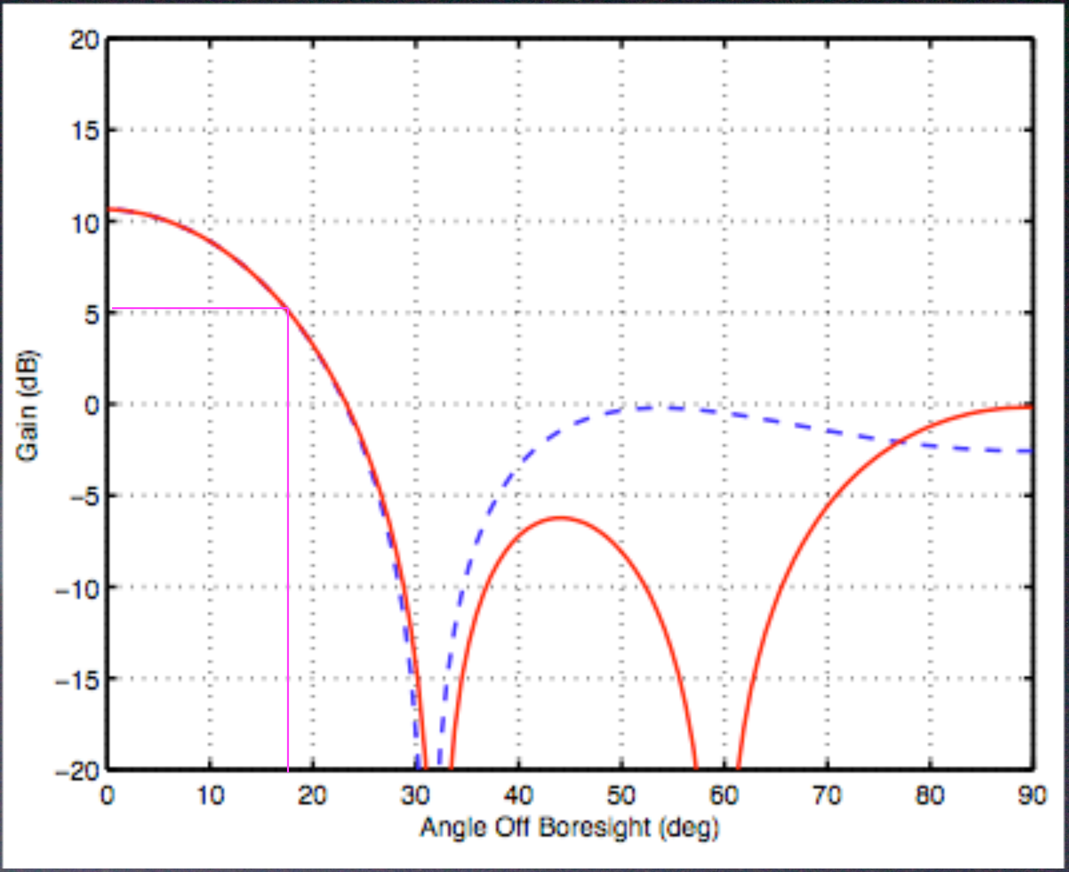


Beam Patterns



- An individual patch is relatively omni-directional (blue curve)
- The phased array of 7 patches has much higher gain on boresight, and sidelobes elsewhere (red curve)
- The difference at beam center is 11 dB = $10^{1.1}$ = 13×
- Note that the single (omni) patch is always higher than the array sidelobes, but not the main directional beam

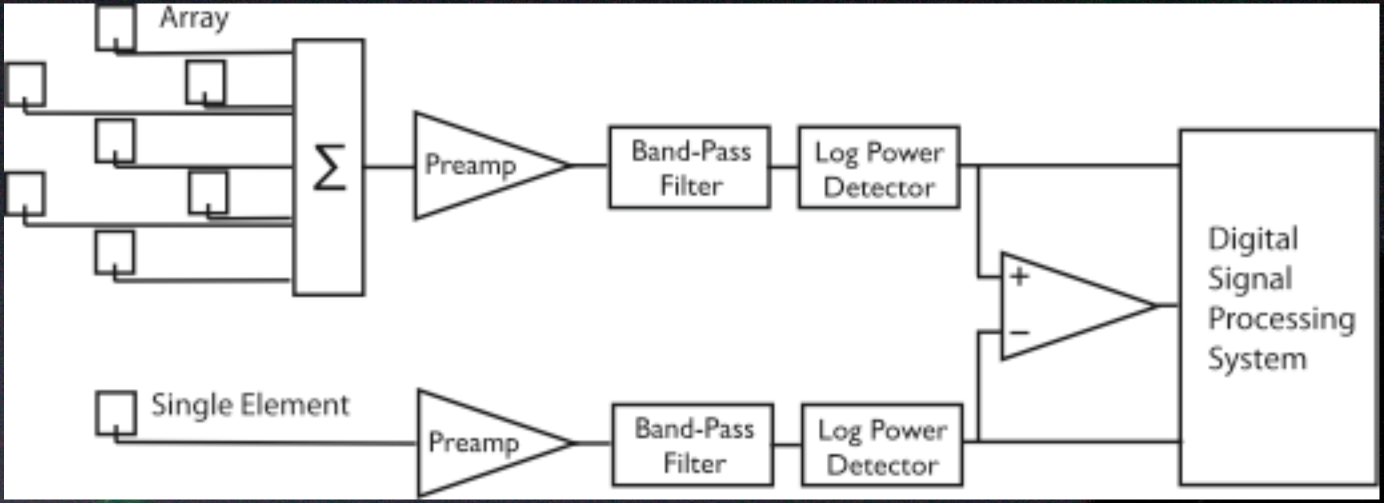
The Ratio is the Key



- The ratio between the directional signal and the omni-directional patch signal is shown at left
- Red and blue curves represent two different azimuthal cuts with respect to the hexagonal array pattern
- For both cuts, the sidelobes are always < 0 dB
- The peak is 11 dB, as we saw previously
- By using the ratio as the criterion, we are immune to distance, power, and polarization variables

Example: set ratio criterion at 5 dB, and the beam half-width becomes 18°

Implementation



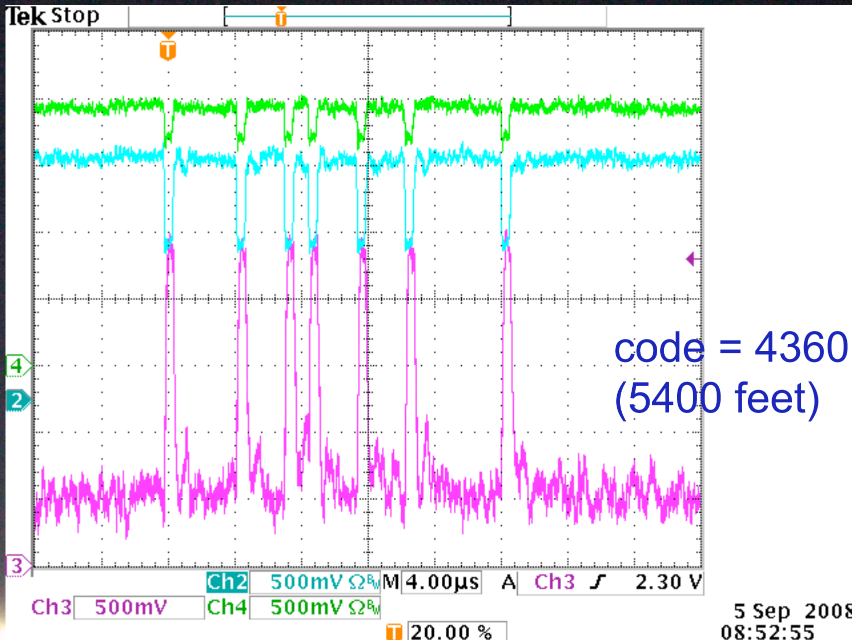
- The array elements are summed, then both array and omni signals are amplified, filtered, then passed to a logarithmic power detector
  - thus voltage difference is array/omni ratio
- Decisions are made based on the difference signal, and also on the raw power levels:

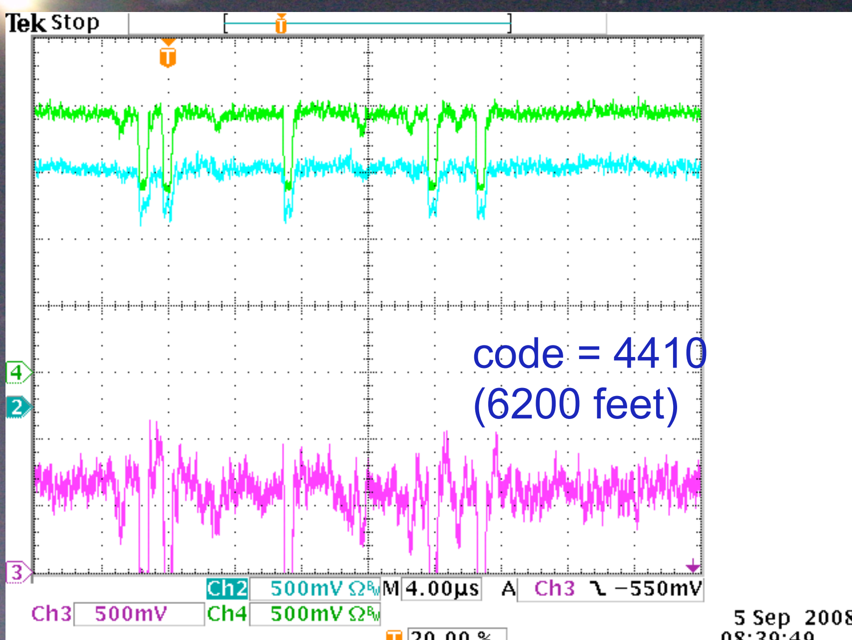
  DIFF > thresh_1 → in the primary beam

  ARRAY < saturation → otherwise DIFF not reliable

  OMNI < thresh_2 → if OMNI that hot, shut down for nearby plane
- Also processor decodes pulse train, and presents for logging

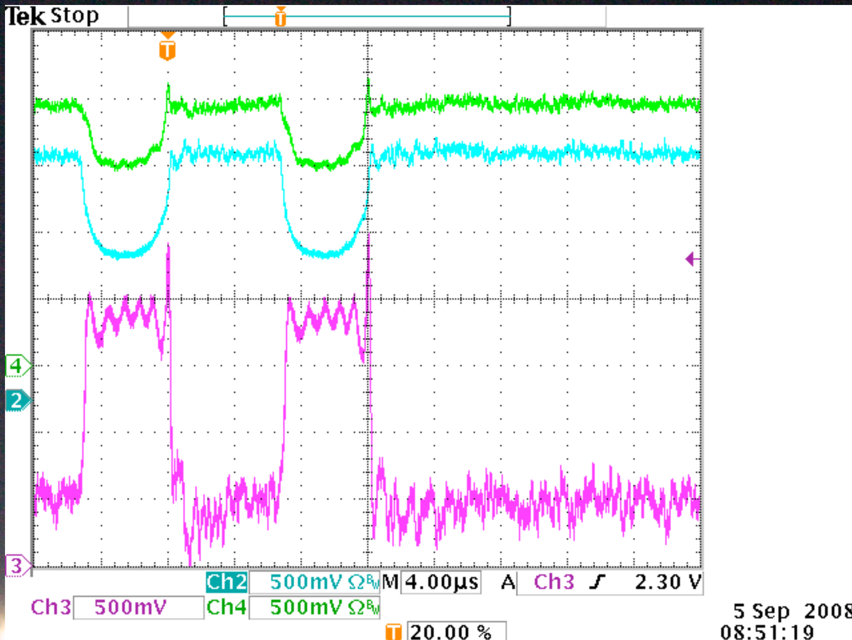
Example Pulse Patterns



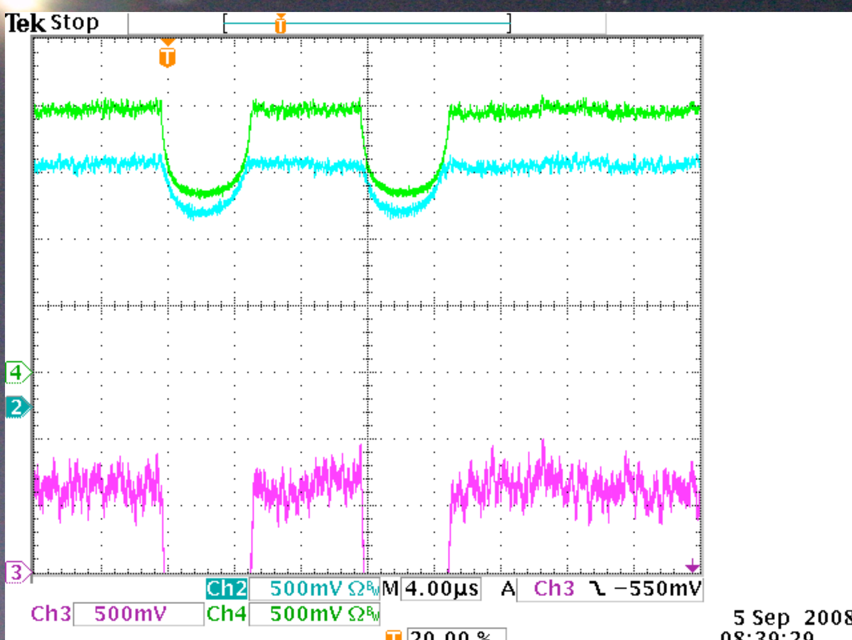


- ARRAY > OMNI, so DIFF is large (in beam)
  - note raw signals for OMNI and ARRAY are negative-going: negative dips are the signal pulses
- A threshold on the DIFF signal alerts the system that a plane is in the beam
- ARRAY < OMNI, so DIFF < 0
  - thus while sginals are present, the DIFF < 0 indicates that the plane is not in the main beam

DME signal works too…

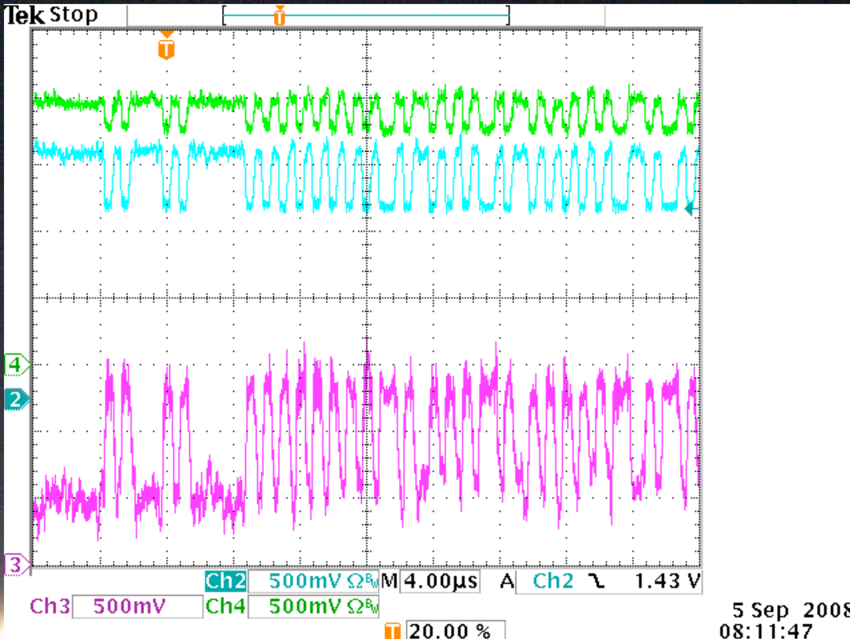


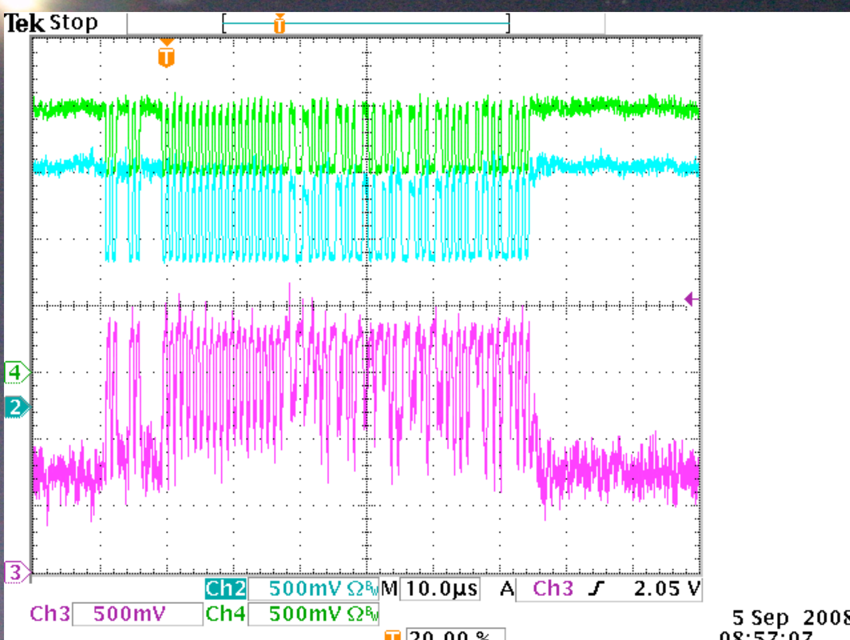
- ARRAY > OMNI, so DIFF is large (in beam)
- A threshold on the DIFF signal alerts the system that a plane is in the beam
- Note the flatness of the DIFF signal: the ratio works!



- ARRAY < OMNI, so DIFF < 0
  - thus while sginals are present, the DIFF < 0 indicates that the plane is not in the main beam
- Though DME ≠ transponder, who cares?! It's still an airplane

Mode-S transmission





- A new coding of information is sweeping the 1090 airwaves: Mode-S
- Mode-S carries permanent aircraft identity, and higher-precision altitude information
- The top plot is at the same time-scale as the previous plots, but to get the whole thing, we have to zoom out (below)
- All the same, these signals trigger the system if the source is in the beam

What Happens Next?

- The prototype is working at UCSD, with a few upgrades in the works
  - one such upgrade is splitting the central element to double-task it with the job of being the OMNI antenna — compactifying the arrangement
- Once deployed, we will begin logging data whenever the dome is open, so we build a case to present to the FAA
- Same goes for the IR camera
- Once verified and (hopefully) accepted, we will be able to shed the spotters
  - we may get help from the Keck, Palomar, and Lick observatories (among others?) as all are currently using spotters in conjunction with their laser guide star adaptive optics programs