VOTING AND SIMULCAST FOR REPEATERS

PACIFICON 2014

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INTRODUCTION

- Licensed as KA6SQG, 1981
- Upgraded to Technician, 1983
- First repeater, 1984
  - Motorola J74-BBY, homebuilt 6800-based controller
  - Los Altos Hills
- www.firescan.net

WHY REPEATERS?

- **Reliable** VHF/UHF propagation is line-of-sight
- Simplex operation:
  - What you can see
- Repeater operation:
  - What the repeater can see…
  - …for all repeaters you can see
- Repeaters create a shared communication environment
  - Everyone in the repeater coverage area can be in the conversation

EXPANDING THE CONVERSATION

- First step to maximizing repeater coverage:
  - Location, location, location
- Put the repeater where it can see all the users
- In flat country: top of a tall tower in the center of the users
- In mountain country: mountaintops
- But the best place is often not “the closest peak”
- Lower frequency can work too, but there are tradeoffs

BEYOND ONE SITE

- So what if there's no one site that can see all users?
  - Multiple repeaters
  - Multiple repeaters, same frequency
  - Multiple linked repeaters, different frequencies
  - Remote receivers
  - Receiver voting
  - Simulcast

MULTIPLE REPEATERS

- Install multiple repeaters on different frequencies
- Dispatch (“Net Control”) placed to see all repeaters
  - Or linked via RF or wireline to each repeater
- Users choose correct repeater based on where they are
- Users in an area are part of a conversation, but not shared between areas
- By default, this is what ham radio already has

MULTIPLE REPEATERS, SAME FREQUENCY

- Install multiple repeaters on the same frequency
- Use different CTCSS at each repeater
- Dispatch ("Net Control") placed to see all repeaters
  - Or linked via RF or wireline to each repeater
- Users select proper repeater tone for their location
- Users can often hear adjacent repeaters, but not all users are part of the same shared conversation
- Used locally by Cal Fire, State Parks

MULTIPLE LINKED REPEATERS

- Install multiple repeaters
- Link the repeaters together
  - In-band (“remote base”)
  - Simplex RF link, Duplex RF link
  - Link to hub repeater
  - VoIP
- Users select proper repeater for their location
- All users are part of the same conversation

REMOTE RECEIVERS

- Repeater transmitter is more powerful than handheld
- Can balance system by improving receiver coverage
- Install one or more remote receivers on repeater input frequency, RF or wireline link back
- User can select remote receiver with different CTCSS tone
  - Or system always prefers local/remote

RECEIVER VOTING

- Instead of having the user pick the right CTCSS tone for their area, let the repeater decide
- Link all remote receivers back to repeater site (matched delay)
- Voter picks best
  - First-to-unsquelch
  - Signal strength telemetry over link
  - Noise or signal-to-noise comparator
- Can continuously vote or lock (latter required for data applications)

USER-SIDE VOTING

- User radio scans for best repeater in linked system
- Re-scans automatically if signal is low
- User is always on “the right repeater for the area”
- Used by some trunking systems, but not implemented in Amateur handheld/mobile radios

SIMULCAST

- What if the user didn't need to pick the repeater site at all?
- Linked repeaters, all on the same frequency…
- …combined with receiver voting

SIMULCAST ADVANTAGES

- All users participate in the same conversation on the same frequency
- Nothing to adjust as user moves through or between coverage areas
- Conserves spectrum – no need for multiple frequency coordinations
- Overlapping coverage areas form a “virtual” repeater coverage area larger that can be achieved by any single choice of repeater site
- Otherwise “impossible” repeater coverage in our geographic area – fills shadows

WHAT'S THE CATCH?

- If it is so good, there must be a catch, right?
- Requires very precise frequency control
  - 1 Hz at 400 MHz is .0025 PPM
  - Typical amateur stability 5 PPM, commercial 1.0-2.5 PPM
  - Doppler effects from user motion matter at this scale: 60 MPH at 400 MHz = 36 Hz
- Requires precise audio phase control
  - For 10% phase error in overlap area at 3000 Hz, modulation must arrive at each transmitter within 10 microseconds of each other
  - Modulator response must be matched at each transmitter
  - Links to transmitters must have identical frequency/phase response
  - Maximum error in overlap area should be 50-60 microseconds
  - Speed of light from repeater to user matters at this scale: 1.86 miles/microsecond

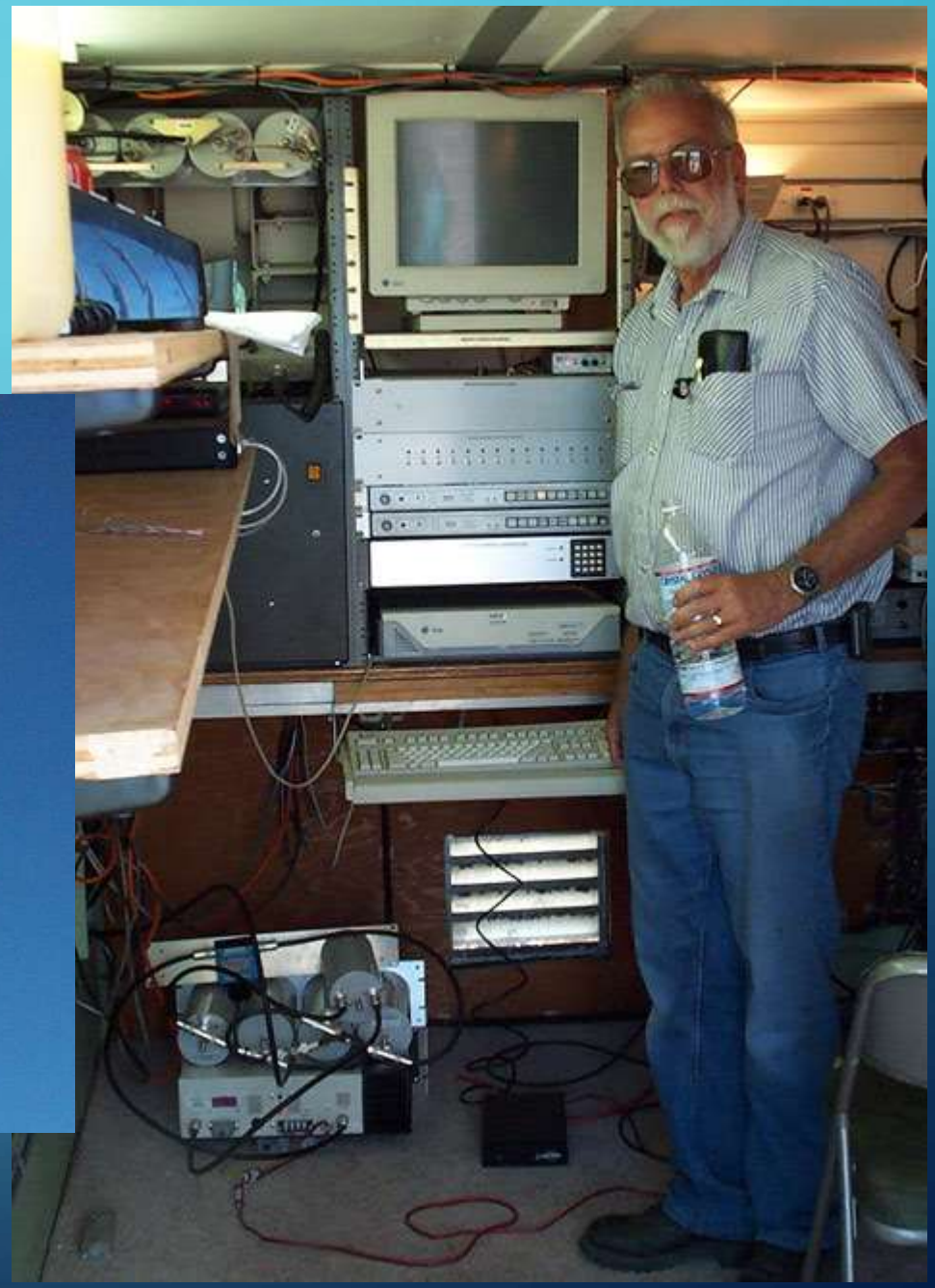
HOW TO BUILD A SIMULCAST SYSTEM

- Obtain matched repeaters with external frequency reference input
- Obtain high-stability reference oscillators (Rubidium or OCXO, with GPS discipline)
- Link all repeaters to central site over high-quality audio paths (T-1 digital wireline or microwave)
- Use signal-to-noise voter to select best receiver and send back out to repeater sites
- Insert precision audio delays in return path to each transmitter
- Tune and maintain system, re-adjust if T-1 path lengths change
- Note: You can't afford to purchase one of these ($250k-$1M and up)

THE WB6ECE/R SIMULCAST SYSTEM

- 7 repeater sites, 5 on simulcast system, and growing
- All can operate standalone (CTCSS-selected) as backup
- GPS-locked frequency and audio phase
- Receiver audio phase matching allows rapid voter decisions
- VoIP linking with all audio processing and voting in software
- Amateur microwave links between sites

MOUNT UMUNHUM



MOUNT ALLISON

MOUNT TORO

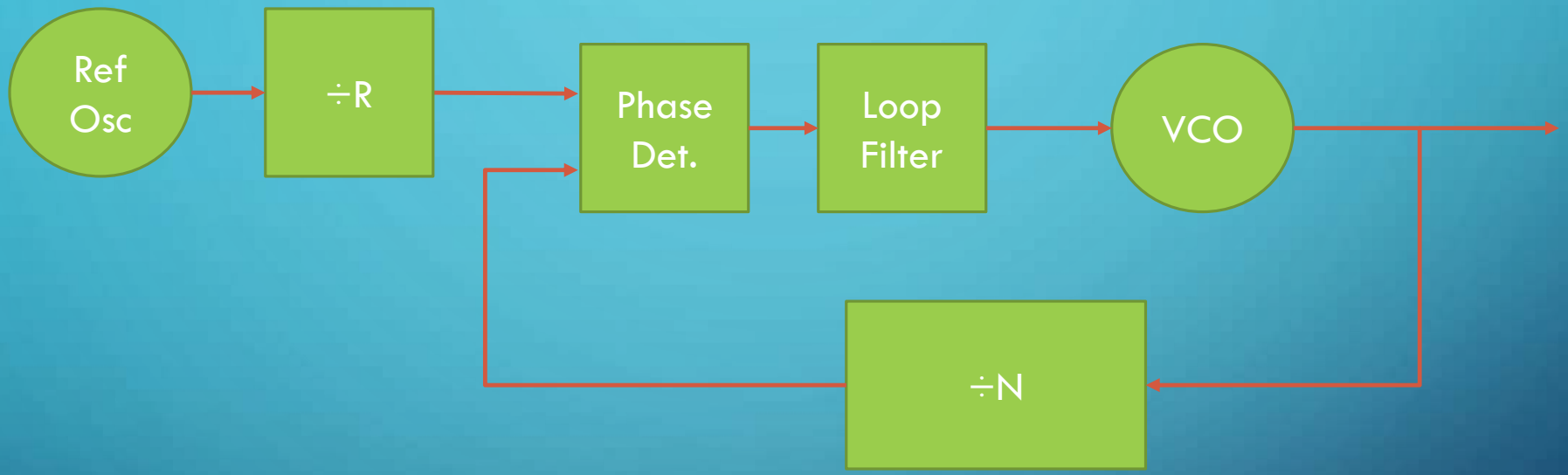
EVOLUTION

- Home repeaters
  - J74-BBY… Micor Mobile… GE MVP
- Mountaintops
  - Vertex VXR-5000
  - Kings Mountain, Mt. Umunhum, Mt. Toro, Mt. Allison, Empire Grade (x2)
- Initially operate as standalone repeaters, CTCSS-selected
- …but then Simulcast frequency stability becomes financially viable

SIMULCAST FREQUENCY STABILITY

- HP Z3801A becomes available on surplus market
- Change of plans – instead of voting + CTCSS site selection, why not simulcast?
- 10 MHz reference
  - Double oven OXCO - accurate to 1 part in 10^{11} short term (1 second)
  - GPS discipline – accurate to 1 part in 10^{12} long term with no site visits to adjust
- Now we just need to get the repeater transmitter locked to this reference

FREQUENCY SYNTHESIZERS



Output frequency is N x Reference Frequency (for a simple integer-N, one-loop synthesizer)
Reference Frequency choice controls step size
Most VHF/UHF radios want steps like 2.5 kHz, 5 kHz, 6.25 kHz
So we see reference choices like: 10.24 MHz, 12.8 MHz, 16.8 MHz, 19.2 MHz
None of them are 10 MHz – but we can synthesize any of these from 10 MHz fairly easily

LOCKING TRANSMITTER TO 10 MHZ REFERENCE

- VXR-5000 transmitter uses a MC145190 PLL locked to a 12.8 MHz TCXO reference
- PLL is programmed via serial data from control board
- My transmit frequency is 441.300 MHz, reachable using a 10 MHz reference and new divisors
- Instead of building a 12.8 MHz synthesizer locked to 10 MHz, we can just fix this in software…
- New serial data stream (sent from PIC microcontroller, easier than reverse-engineering firmware)
  - Reset reference divider for 10.0 MHz from 12.8 MHz
  - Reset frequency divider to get 441.300 MHz with 10 MHz reference
- Remove power from the TCXO and remove coupling cap on PC board
- RG-174, capacitor, and BNC connector replace TCXO

LINKING AND VOTING EXPERIMENTS

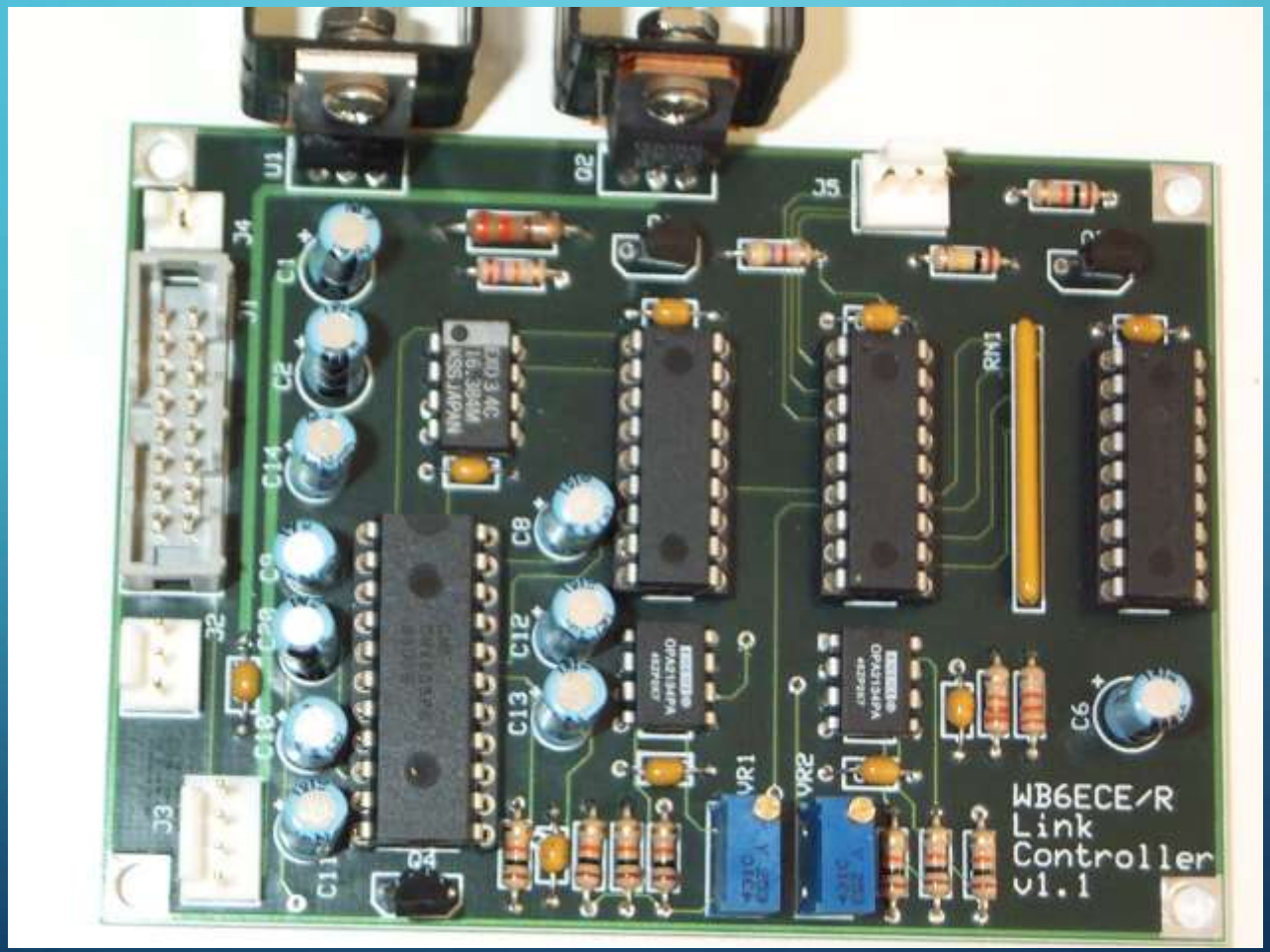
- GE Mastr Exec II Canadian ambulance duplex version
- Hamtronics boards in rack cases
- Icom F420-9 (again from Canada)
- M2 yagis, Motorola T1504 duplexers

- LDG RVS-8 voter
- Software DSP voting

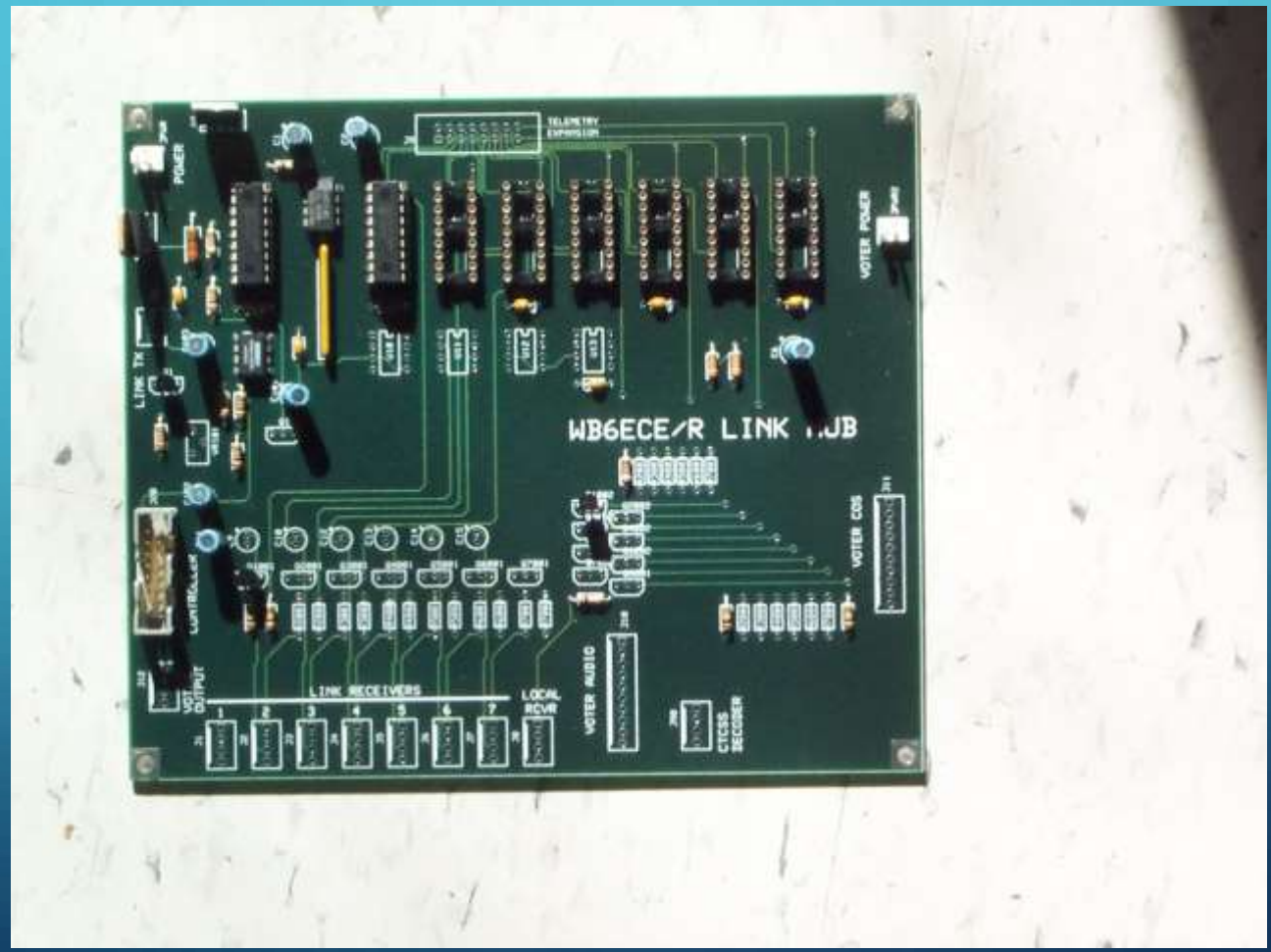
DELAY EXPERIMENTS

- Allen Avionics passive phase delay
- PIC-based linking controller with CVSD codec-based delay
  - 3 PIC microcontrollers: receive link digital signaling, transmit link digital signaling, delay controller
  - Fits the “turn hardware problems into software problems” philosophy
  - And the “PC boards are the easiest way to prototype” philosophy

LINK CONTROL AND DELAY BOARD



LINK HUB BOARD



EXPERIMENT OUTCOME

- Audio quality through 420 links isn't that great
  - Even if you take care to skip all the extra pre-emphasis/de-emphasis steps
- Getting a repeater and duplex link all working at the same time is hard and involves lots of duplexers, filters, cable, etc.
- The central site assembly involves lots of gear… half-dozen 420 receivers, bandpass filters, voter (which doesn't work very well), outbound link transmitter… all with control electronics and delay electronics
- Never really works… but it was fun trying

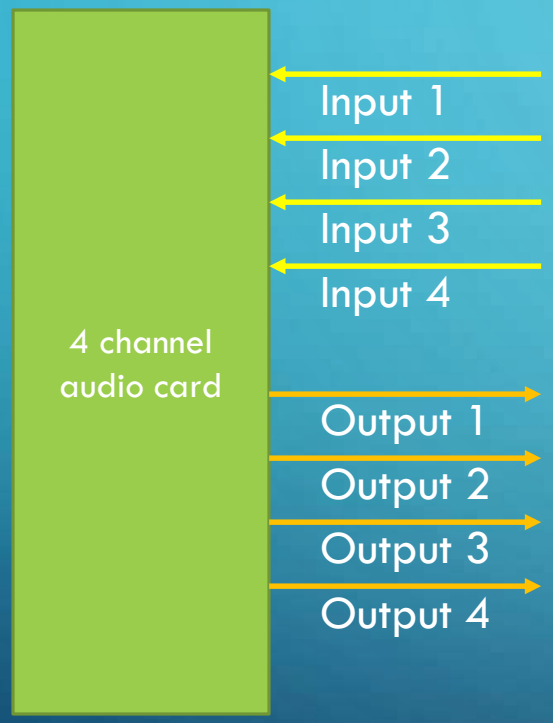
VOIP LINKING

- Voice over IP is already used to build multiple-repeater networks
  - EchoLink, IRLP, AllStar link
- Aha! Align the audio outputs of multiple sites **in software**
  - This was the only blocker to moving to VoIP linking
  - Had already been investigating building software-based voter
- Built a new link controller using a Soekris net5501 and M-Audio Delta 44 sound card
- All that remains is getting IP network to the sites, and writing software

AUDIO SYNCHRONIZATION

- Problem:
  - Unknown delay from input signal to samples appearing in software
  - Unknown delay from generated samples in software to actual audio output
  - Need all sites to produce samples at exactly the same time (within 10 microseconds)
  - Have 1 PPS GPS signal from GPS as reference
- Could build custom hardware (and may still do this for lower latency)
- But a software-only solution ships sooner

ONE-WIRE AUDIO SYNCHRONIZATION

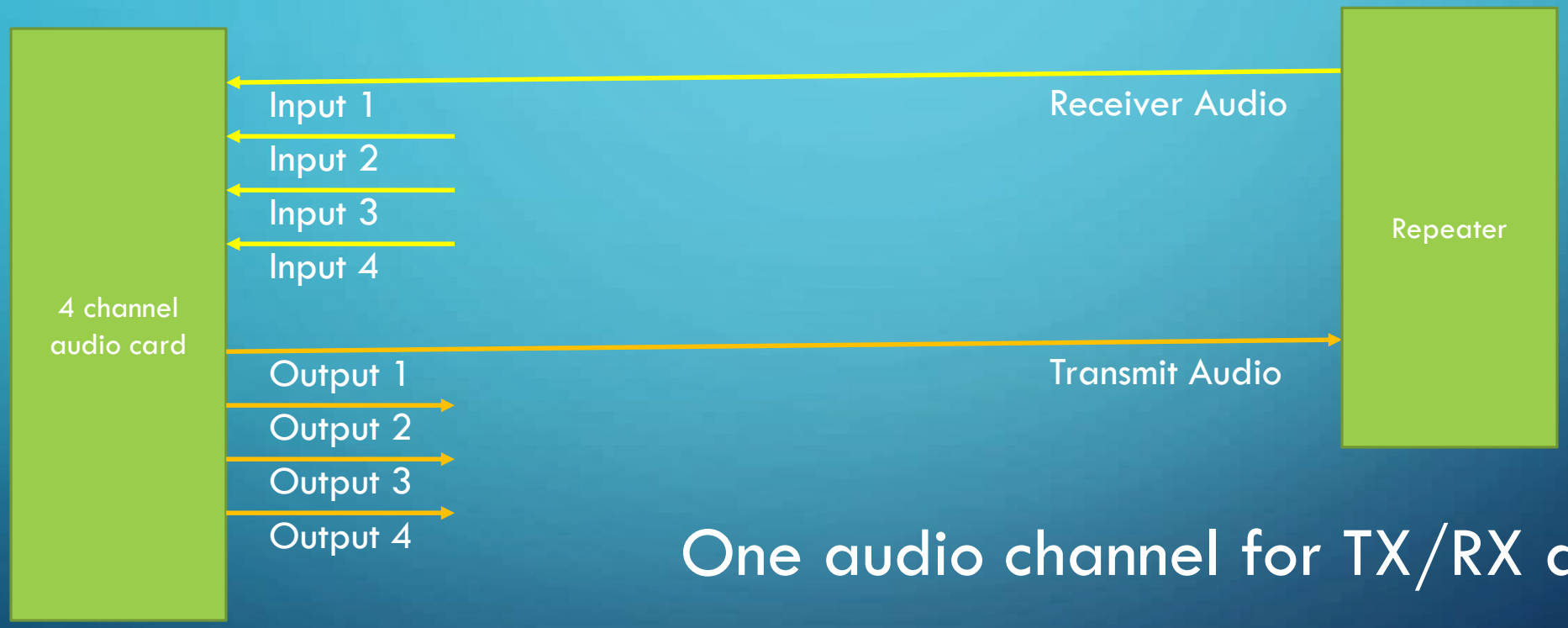


4-channel PCI audio card

96 kHz sample rate

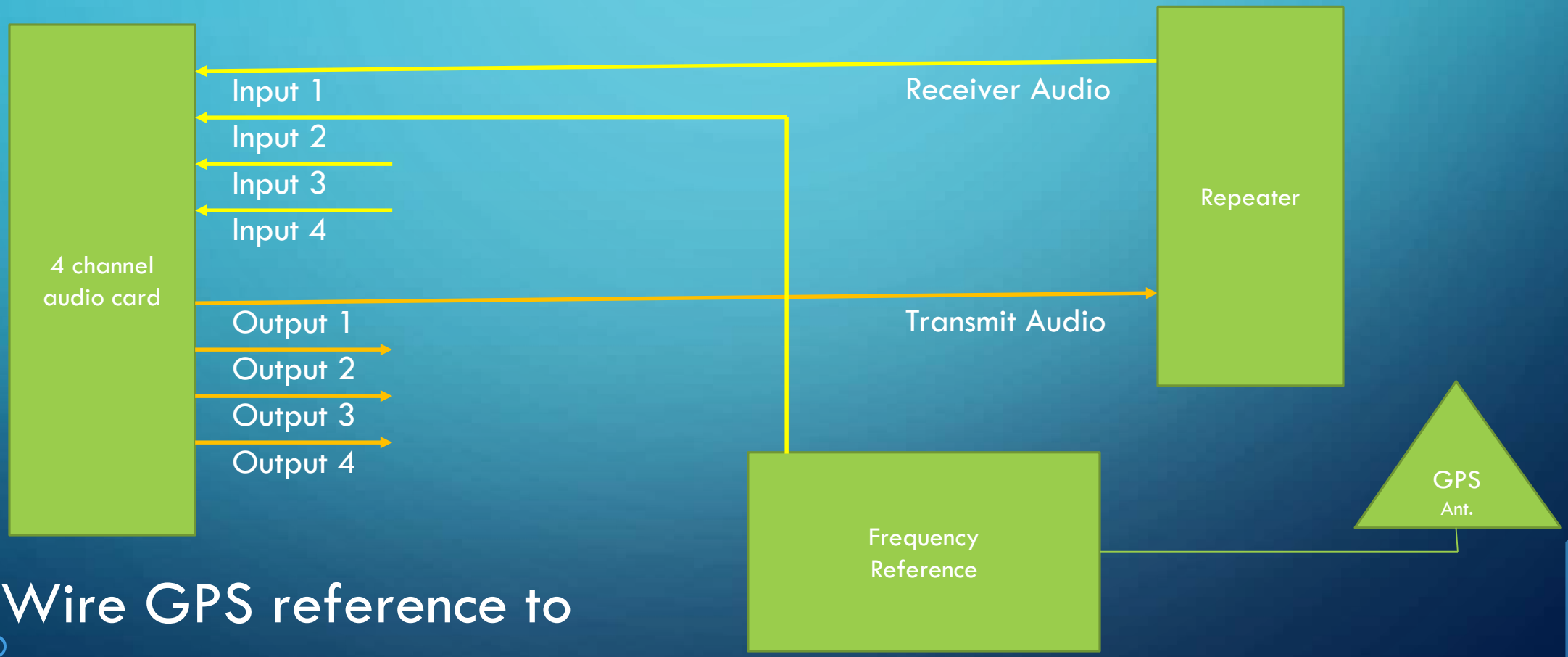
16/24 bits per channel

ONE-WIRE AUDIO SYNCHRONIZATION



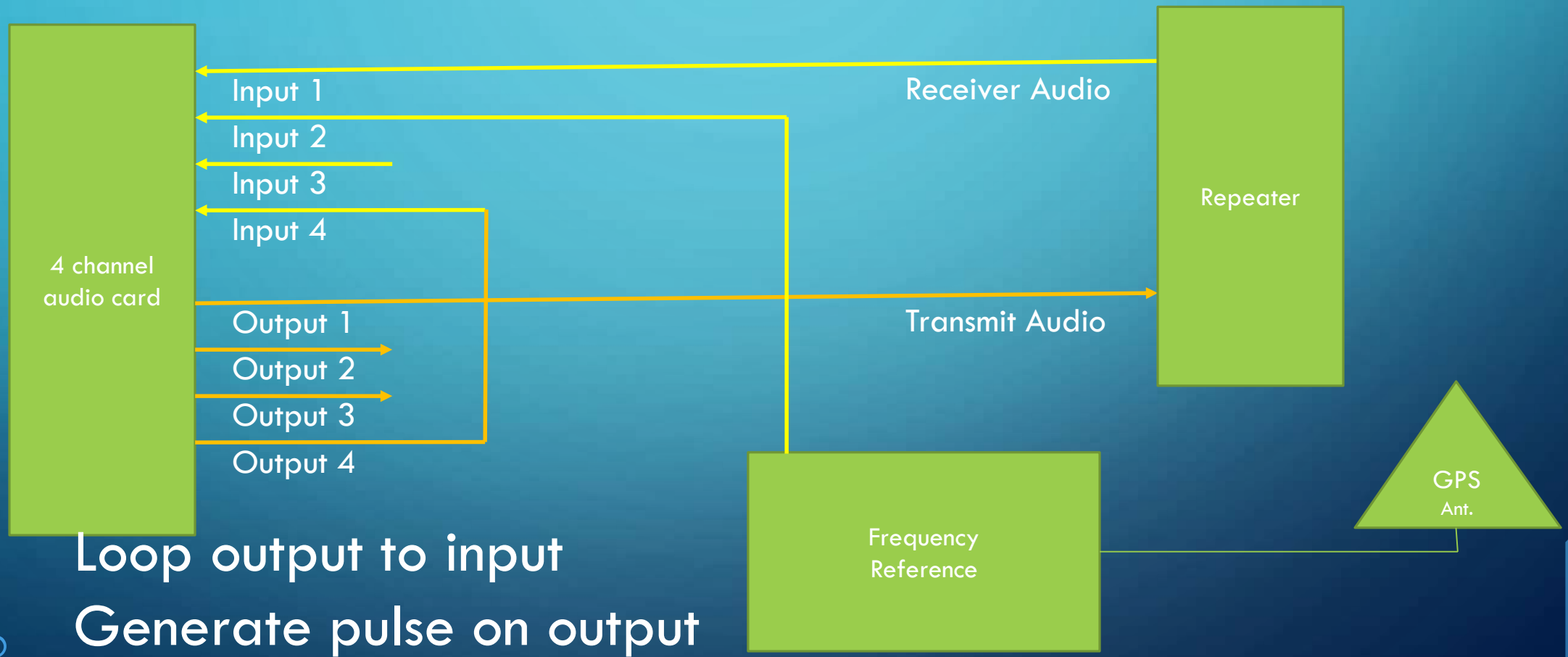
One audio channel for TX/RX audio

ONE-WIRE AUDIO SYNCHRONIZATION



Wire GPS reference to audio input – now know RX sample time

ONE-WIRE AUDIO SYNCHRONIZATION



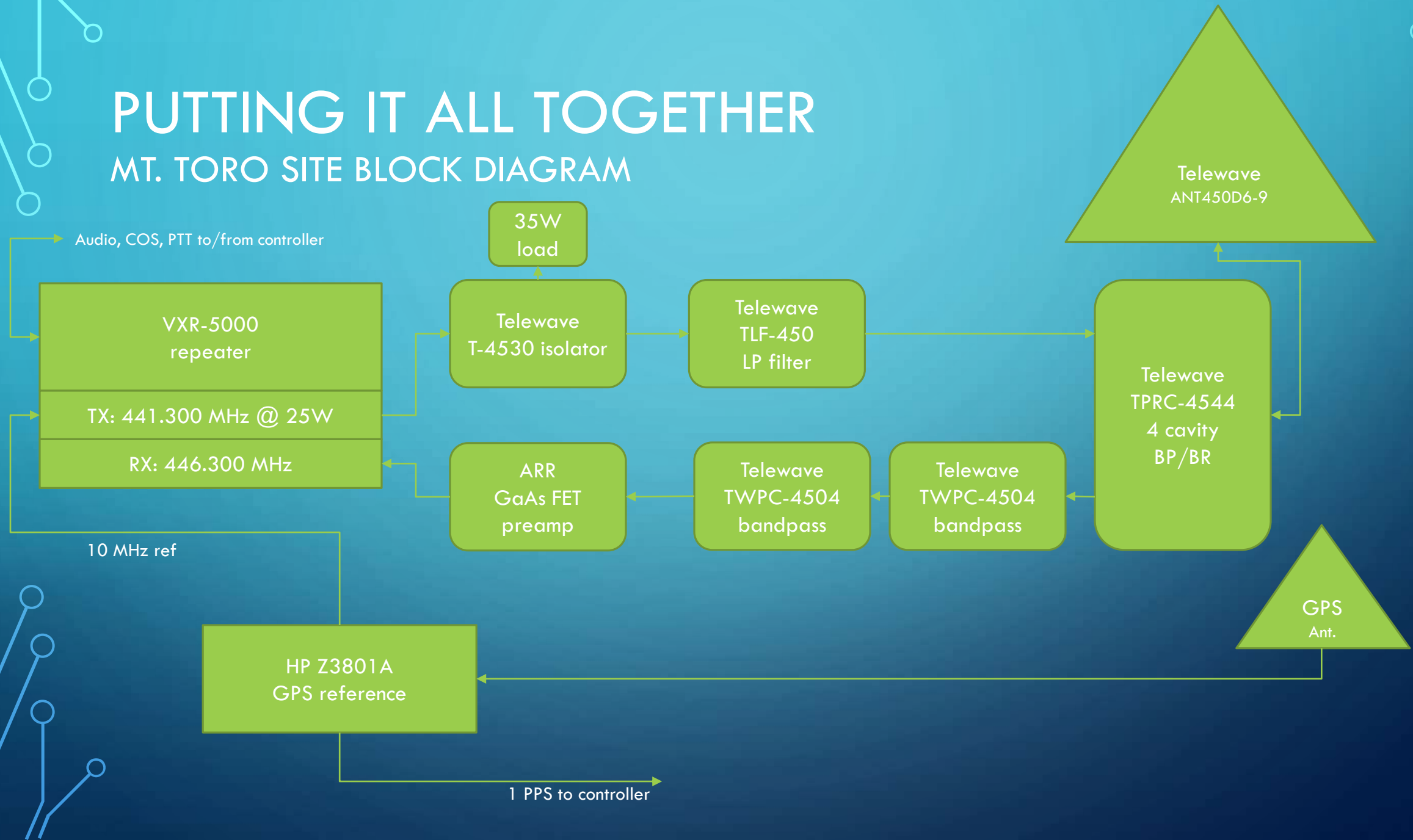
Loop output to input

Generate pulse on output

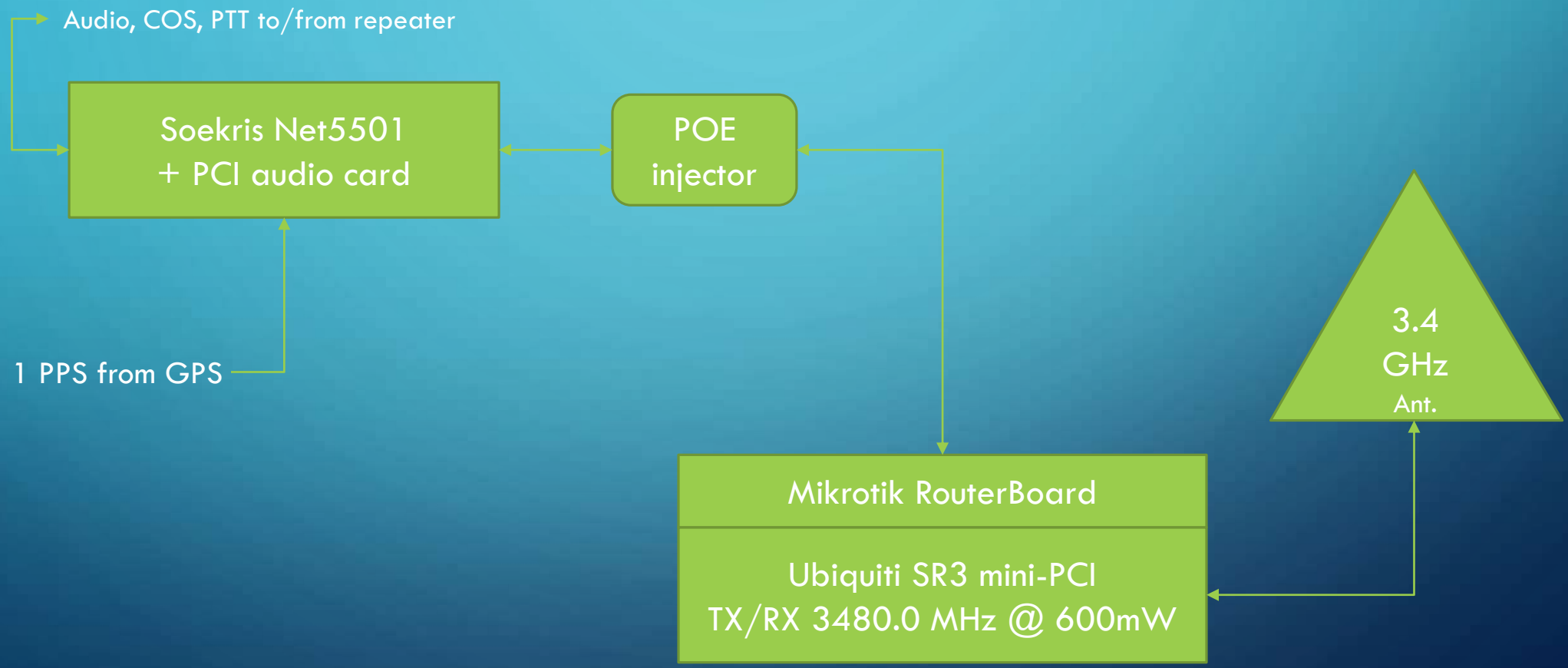
Phase lock to match GPS 1 PPS – now know TX sample time

PUTTING IT ALL TOGETHER

MT. TORO SITE BLOCK DIAGRAM



CONTROLLER AND LINKING BLOCK DIAGRAM



CURRENT MT. TORO INSTALLATION

MICROWAVE LINKS

- Mt. Umunhum is the voter site
  - Internet available here via commercial microwave
  - 5800 MHz path to my house – 92 Mbps
- Mt. Allison is on same commercial microwave network
- Bonny Doon site is a 14 mile path at 5900 MHz – 100 Mbps
- Mt. Toro site is a 46 mile path at 3400 MHz – 6/24 Mbps
- Next planned path is 54 miles at 3500 MHz
  - Bonny Doon to Point Sur
- Links provide Internet access – can support cameras, VoIP phones, EchoLink/IRLP boxes, etc. for other users at site

MT. TORO MICROWAVE

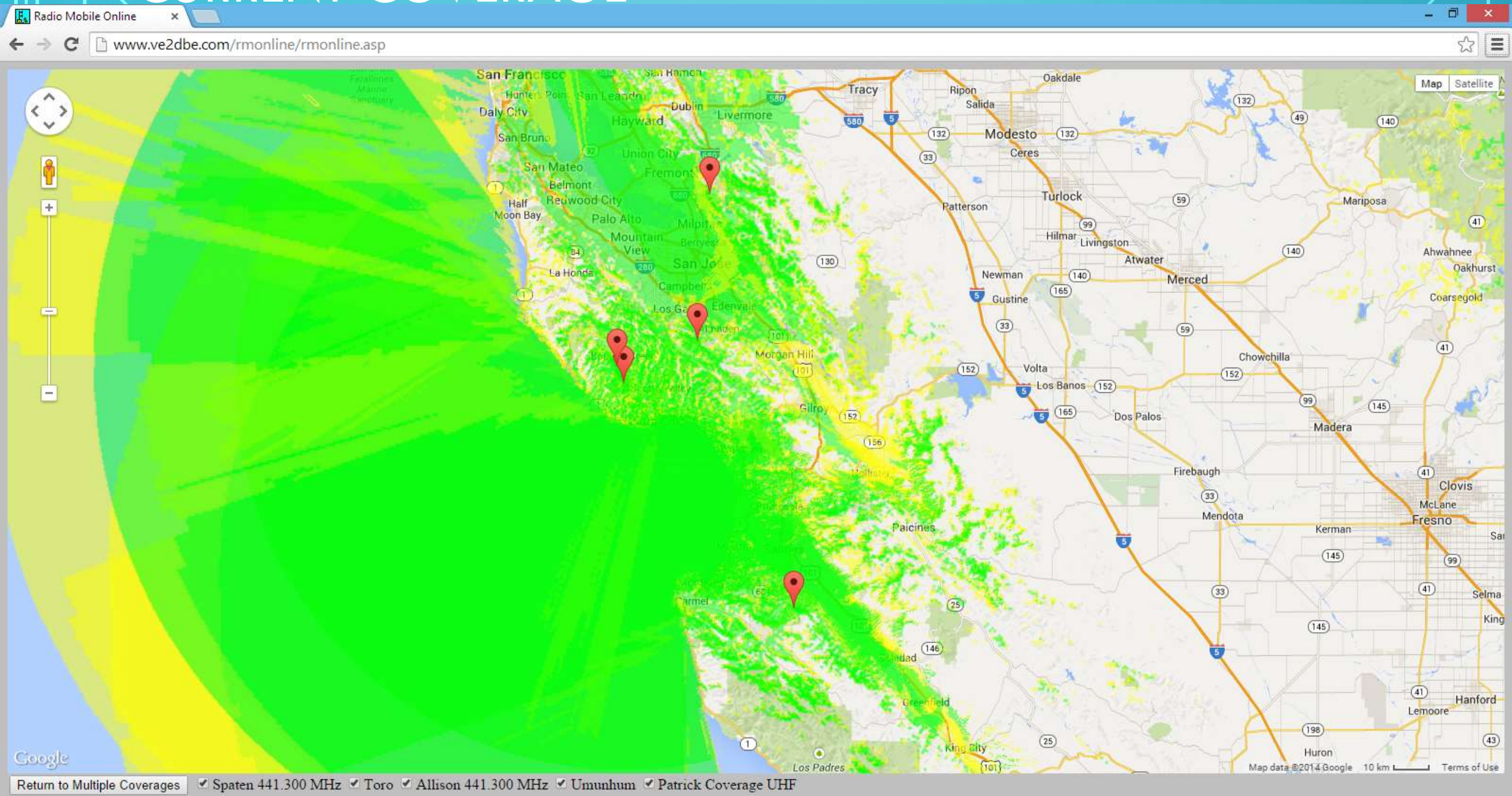
MT. UMUNHUM TO TORO AND BONNY DOON

FINALLY: UPGRADING TO SIMULCAST

- April 8, 2009 – Bonny Doon (Comcast) site online
- April 16, 2009 – Mt. Umunhum site upgrade to GPS-lock, online
- April 20, 2009 – Simulcast software running
- September 19, 2009 – Microwave to Mt. Toro installed, online
- July 18, 2010 – Lower Bonny Doon site installed, online

- Conclusion: It works! Only issues have been the occasional failed reboot and a couple of Z3801A failures. And I spent a lot less than $250,000.

CURRENT COVERAGE



FUTURE

- ARES/RACES MOUs
  - Get on ARES frequency lists for entire section
  - Section-wide weekly net?
  - Extremely wide-area resource or travel net
- 501(c)3 formed to own/operate the system
- Hardware advances:
  - New GPS units
    - Trimble Thunderbolt now available surplus – smaller, more reliable
  - New controllers
    - AllStar link (Asterisk-based VoIP repeater linking) folks have built a PIC-based simulcast controller
    - May build something similar – reduced latency, higher reliability
- Add digital access to Microwave network for shelters/EOC/command posts
  - 3.4 GHz ham band APs + sector antennas at site, small fixed and portable client stations
  - Section-wide ham Intranet, emergency Internet access, cross-connect with packet systems

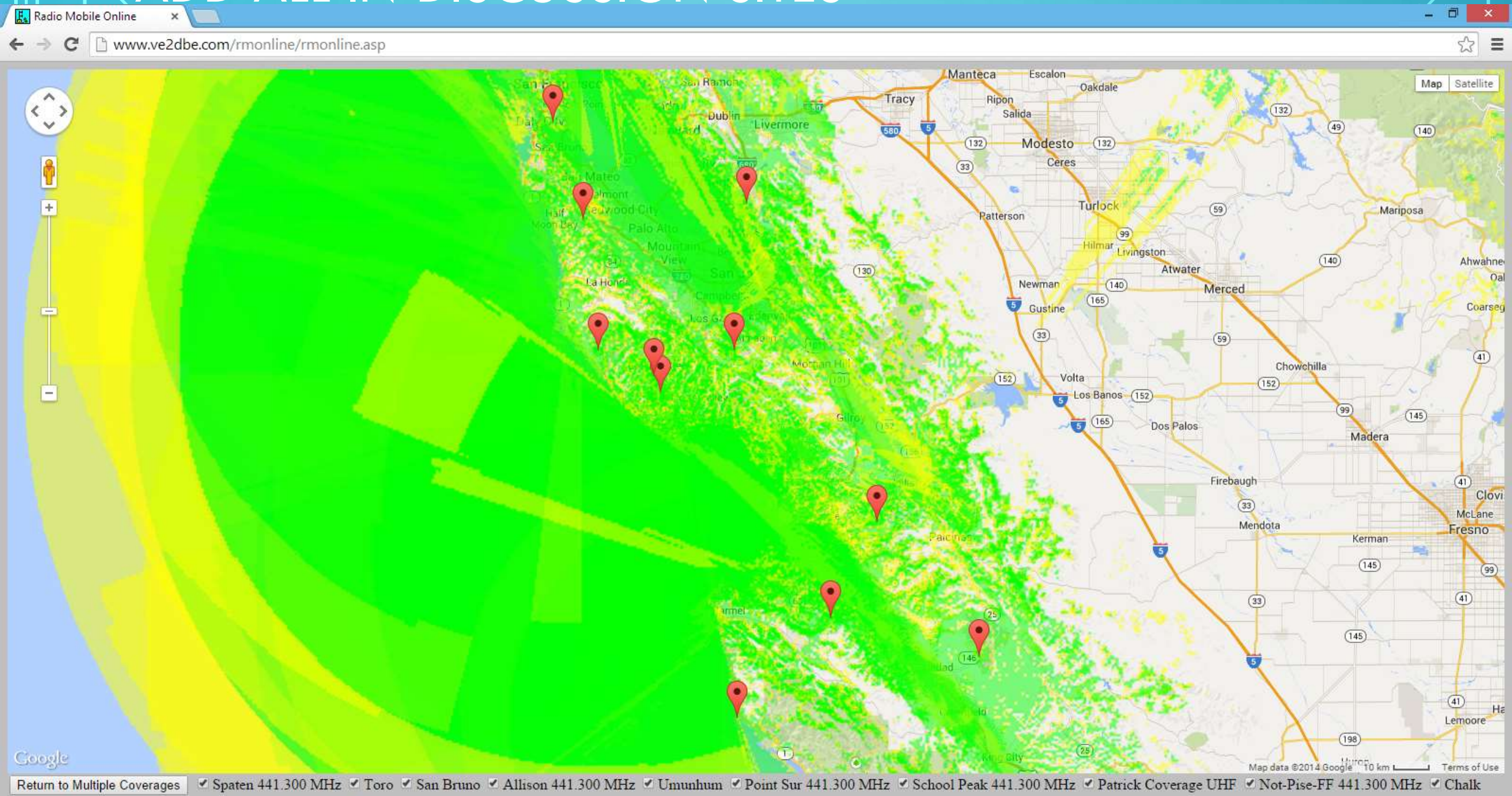
SYSTEM EXPANSION

System growth (have hardware, need to acquire or develop sites):

- Replacement site on Empire Grade for upper San Lorenzo Valley
- San Bruno Mountain
  - fill at north end of San Mateo County, San Francisco shadows
  - Secondary Internet access and good microwave paths back to San Mateo Coast sites
- San Mateo coast
- Big Sur
- Salinas Valley south end and south
- San Benito County (School Peak, Call Mtn.?)
- Carmel Valley
- Improve Santa Cruz north coast

Note: 440 MHz, so blocked to the East and North by Beale PAVE PAWS restrictions ☹

ADD ALL IN-DISCUSSION SITES



Q&A

For more information: http://www.wb6ece.org

Or hear you on the air: 441.300(+), 100 Hz