6.S092 Track 2 Project: Amateur Radio Satellite Phased Array Receiver

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Background

- There are various satellites in orbit with amateur radio payloads, usually repeaters and sometimes digital transponders
- Licensed amateurs can use these for communications or experimentation, which is cool because it's space
- Since the duplexer (cavity filters) that ground-based repeaters carry is too large for a CubeSat, these satellites usually uplink on VHF and downlink on UHF (sometimes this is reversed)
- Ham radio operators usually use motorized mounts or manual, by-hand tracking to aim an antenna at a satellite to pick up its weak downlink signal
- Receiving signals is possible with even a handheld radio, but the antenna must be very directional
- Modern electronically-steered antenna systems work by changing the phase relationships between RF signals to create constructive interference in a desired direction and destructive interference in other directions

Problem Overview

- Amateur radio satellites are a long way away and have very low-power transmitters
- Existing solutions for communicating with ham radio satellites usually involve mechanically-steered antennae, which are prone to failure and have limited tracking speed (and no ability to "hunt" for a signal by sweeping the approximate region of sky)
- Even modern ham radio mostly does not use phased arrays, except in either fixed (not steerable) setups like the Walker roof EME array or in very simplistic designs like "HF noise cancellers"
- I would like to build an electronically-steered phased array for receiving from ham radio satellites on UHF using an ordinary rig (no software-defined radios)

Basic RF Topology

- Four Yagi antennas, probably home-made, arranged in a square and tuned for UHF (not part of PCB)
- Four coax cables (not part of PCB)
- Four edge-mount through-hole (for strength) female SMA connectors
- (Possibly) four filters for the ham UHF band (420-450 MHz)
- Four LNAs with bias tees for power
- Four voltage-controlled phase-shifters
- RF power combiner
- (Possibly) RF attenuator
- Edge-mount through-hole female SMA connector for cable to radio

Non-RF Things

- Power circuitry to convert 13.8 V (standard for ham radio) down to 5 V for the LNAs, possibly also to a stable reference voltage for the DACs
- Microcontroller for electronic phase steering
- Four DACs for phase control signals
- Four op-amps for phase control signals

Expected Difficulties

- Literally everything because this is RF
- Impedance-matching traces
- Preventing MCU and power circuitry from coupling interference into RF things
- Preventing nearby ham transmitter from crashing/damaging MCU with induced fields
- Routing control and power traces without interrupting RF traces

Questions

- Choice of capacitor and inductor values for LNA bias-tee circuit
- Do I need filtering on the input for the LNAs to work properly, or can I just let the radio at the end do the filtering? If I need filtering, should it be implemented as discrete components on the PCB or as a module?
- How do I down-regulate 13.8 VDC to 5 VDC without creating RF noise? / Is the RF noise from a switching converter a problem?
- Some footprints for Mini-circuits modules have lots of vias in their grounds–why? Should I use those?
- Do I need an attenuator at the end to reduce the combined power to avoid damaging the radio?

Questions

- What microcontroller should I use (this choice may be dictated more by supply than by choice...)? Should the DACs be integrated with it or separate?
- How do I make sure the DACs output voltage will be stable/reliable when the power voltage is not (i. e. what voltage reference should I use)?
- Do I need RF shielding boxes around things?
- Should the DAC outputs / bias voltages have some kind of bypass capacitance on them to stop RF affecting them?
- Is it a good idea to have a USB-serial converter for talking to the MCU, or is that going to be unavoidably noisy?