

Readout

Cost & Construction

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FDM (Frequency Domain Multiplexing)

● Pros

- Known cost structure
- Proven end-to-end at Stage 2 (PB-1, SPTPol, 'legacy DfMux')
- Proven w/ large focal planes in Stage 3 (SPT-3G 15k detectors), reasonably scales to ~50k detector focal plane
 - No power dissipated at mK stage
 - Thermal loads from readout components and wiring subdominant at all temp stages

● Cons

- Complex assembly process
 - Tedious, time consuming for assembly and testing
- Requires high resistance TES (~ 1 Ohm) due to parasitic impedances in series
 - Lower responsivity makes current noise sources in readout harder to overcome
 - More difficult to achieve high loop gain, good linearity
- Susceptible to environmental noise (EMI, grounding)

● Known cost structure

- Cost to readout 300k detectors with 68x FDM: ~\$11.5M (Brute projection using SPT-3G 68x FDM tech)
 - ~\$5.5M Warm Electronics
 - ~\$2.8M Squids
 - ~\$3.2M = Flex cables, striplines, LC boards & chips, wire harness

TDM (Time Domain Multiplexing)

- Pros

- Known cost structure
- Proven at Stage 2 (BICEP, ACTPol) and Stage 3 (BICEP Array, AdvACTPol)
- High yield fab

- Cons

- Complex assembly process
 - High wirebond count
- More SQUIDs than uMUX
 - More fab
- More power on 4K stage from amplifiers (?)
 - Could increase cooling requirements

- Cost with 66x TDM (notional costing):

- SQUID multiplexer fabrication: ~\$12.2M
- SQUID array amplifier fabrication: ~\$1.1M
- Room temperature electronics: ??

μ mux (microwave multiplexing)

● Pros

- Fabrication cost structure is known
- Simplest SQUID fab of all three
- Less complex assembly
- Scalable to high MUX factor (~ 2000) and 100k detector focal plane
- Wiring thermal loads comparable or lower than other designs

● Cons

- Less known cost structure
 - Simons Obs planned, not demoed yet
- Warm electronics power consumption (?)
- Design and implementation cost unknown
- More power on 4K stage from amplifiers (?)
 - Could increase cooling requirements

● Microwave Multiplexing (μ mux) (notional)

- Multiplexer fabrication: \$20/channel = \$6M
- LNAs: \sim \$2k/multiplexing unit, assuming 2000x \rightarrow \$300k
- Room Temperature Electronics: \$5-6M

Cost & Construction Summary

Hardware cost / channel is similar between readout technology to a factor of a few

FDM	TDM	μ mux
Known Costing & Integration - Purchased at Stage 3 level Complex Assembly Process - Many Components	Known Costing & Integration - Purchased at Stage 3 level Complex Assembly Process - Many Squids	Less Complex Assembly - Less Squids than TDM