PILOT – Primordial Inflation Telescope
and
Receiver Topologies

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PILOT design: Todd Gaier, Kris Gorski, Casey Heeg, Charles Lawrence, Al Nash, Dave Pearson, Mauro Prina, Keith Warfield

- PILOT's scientific objectives are three-fold:
  - Search for evidence of primordial inflation by measuring B-mode polarization in the Cosmic Microwave Background
  - Determine the ionization history of the Universe
  - Full sky map of CMB polarization at large angular scales

- PILOT is based on HEMT amplifiers, and designed to be a relatively low-cost option for a future space mission

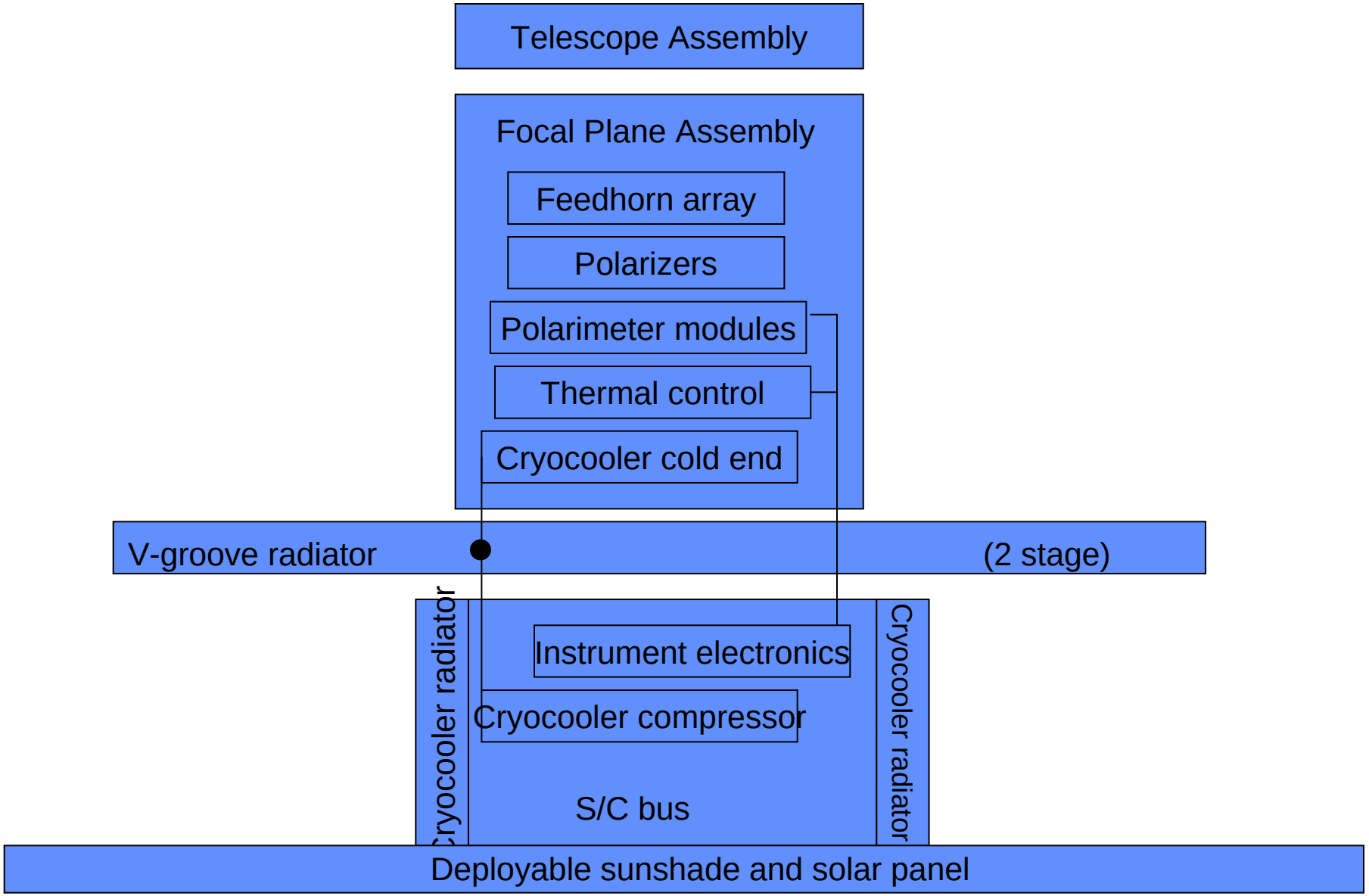
- Concept is meant to be a natural extension of our ground-based polarization experiment, QUIET

- Scan strategy developed by K. Gorski

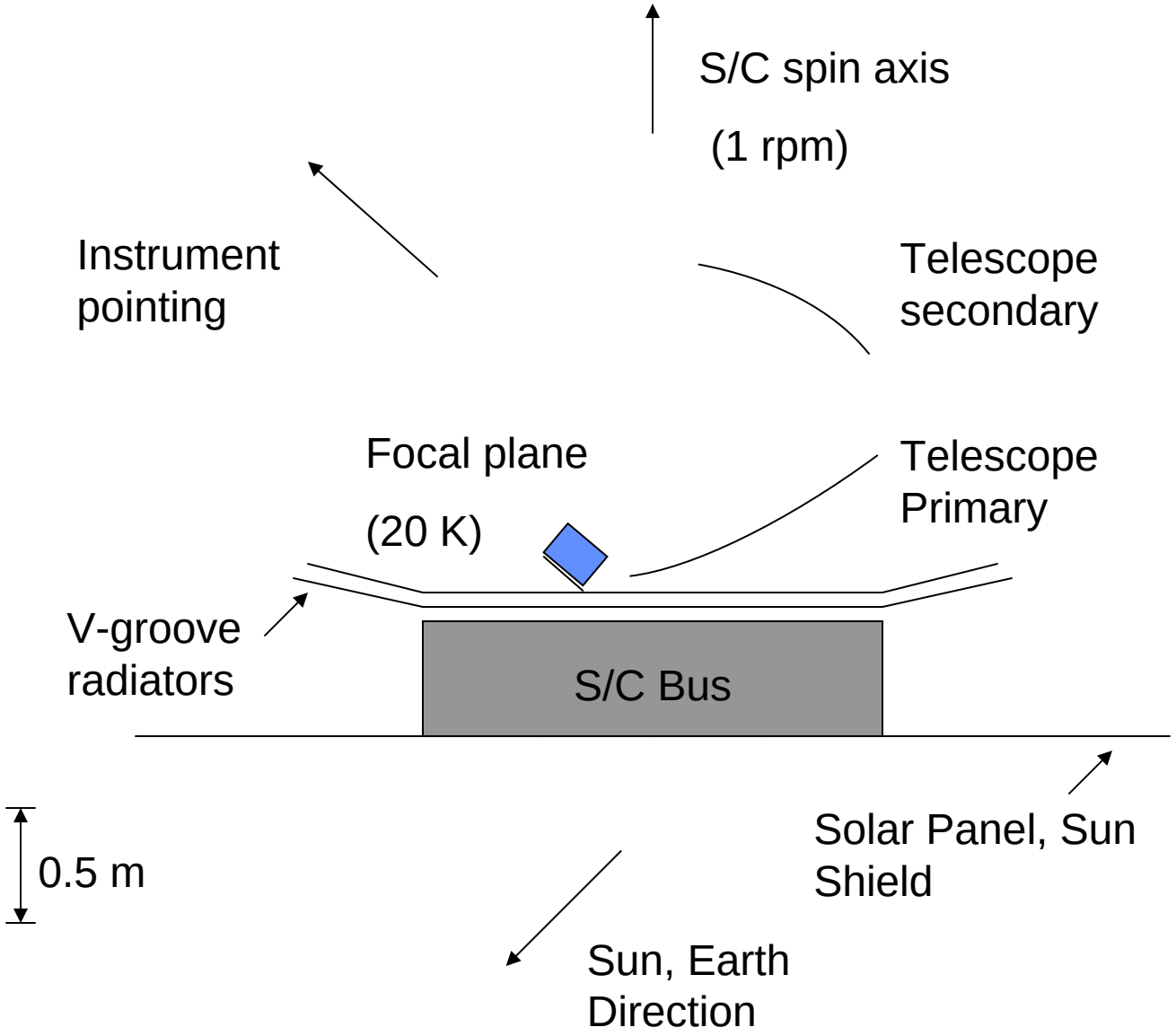
PILOT Mission Parameters

- L2 Halo Orbit
- Instrument observes the sky in continuous survey mode with 5 frequency bands between 30 and 150 GHz.
- Launch vehicle: TBD
- Mission duration: 4 years nominal
- Instrument cold end temperature: 20 K
- Pointing control: 5 arc minutes rms
- Reconstructed pointing knowledge: 10 arc sec
- Daily data volume: 7.5 Gbits/day
- Estimated instrument mass: 500 kg
- Estimated instrument power: 1500 W
- Cost target < $350M

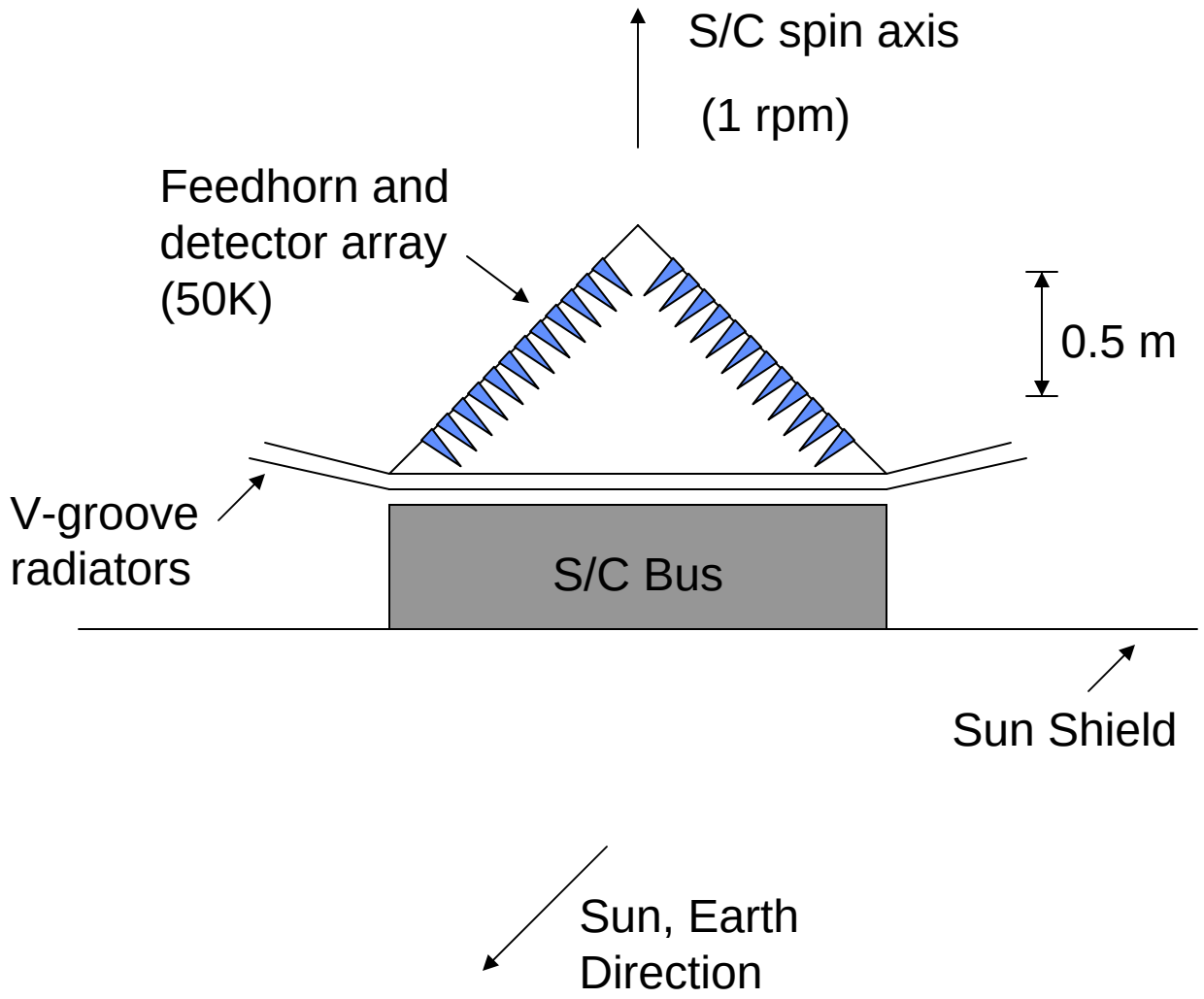
Configuration



Schematic


S/C spin axis
(1 rpm)
Instrument pointing
Telescope secondary
Focal plane
(20 K)
Telescope Primary
V-groove radiators
S/C Bus
0.5 m
Solar Panel, Sun Shield
Sun, Earth Direction

Passively cooled, no telescope version



PILOT Sensitivity

Freq	N	power mW	noise rcvr K	tcmb K	tsys k	delta t	delta t/freq
30	4	4	7	3	10	8.16E-05	4.08E-05
40	50	7	8	3	11	8.70E-05	1.23E-05
70	160	10	10	3	13	7.77E-05	6.14E-06
100	75	12	12	3	15	7.50E-05	8.66E-06
150	75	15	20	3	23	9.39E-05	1.08E-05

Num elements 364

Mission time

4 years
1461 days
126230400 sec

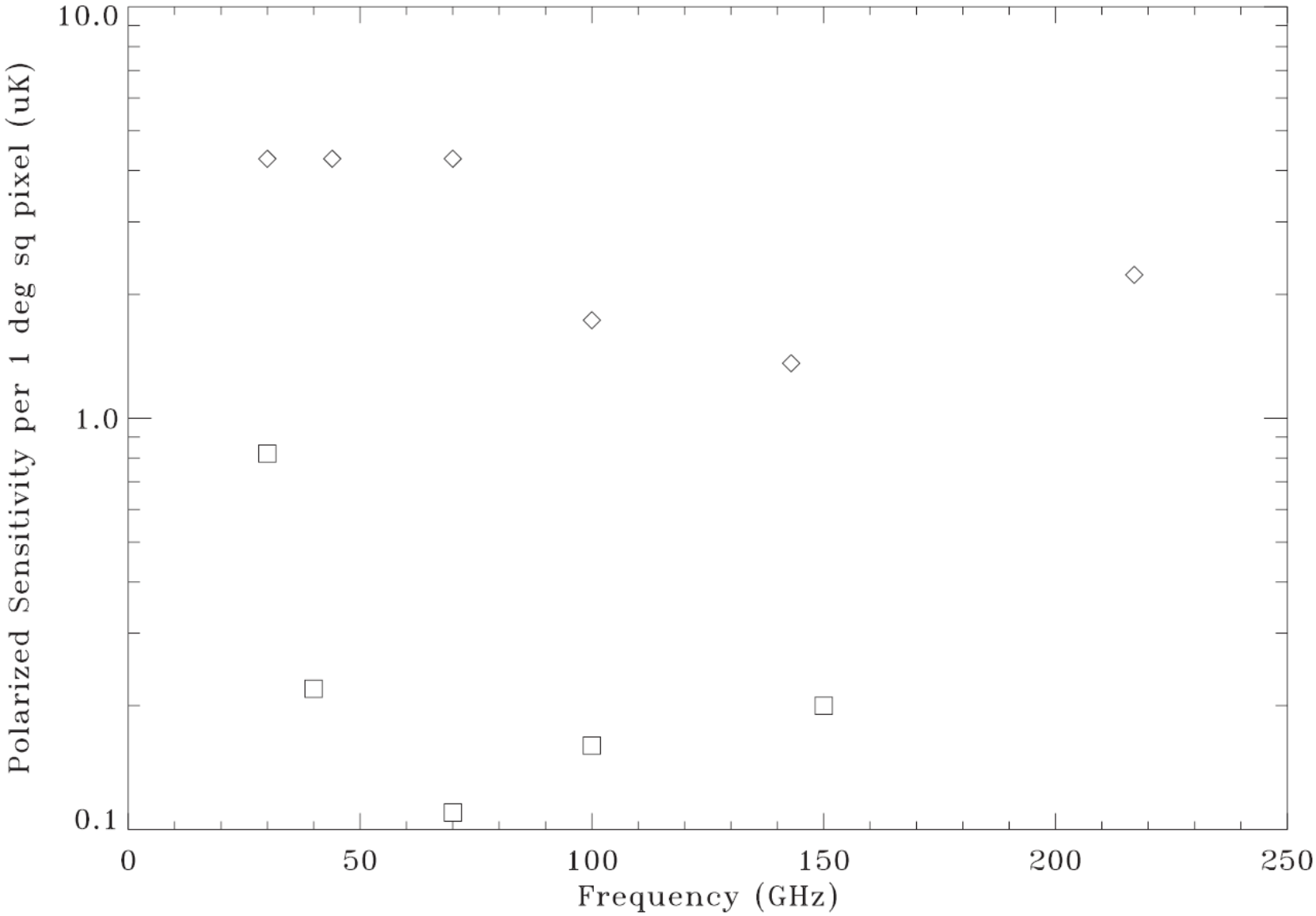
weighted sensitivity
4.24246E-06

total pwr (mw) =
3991

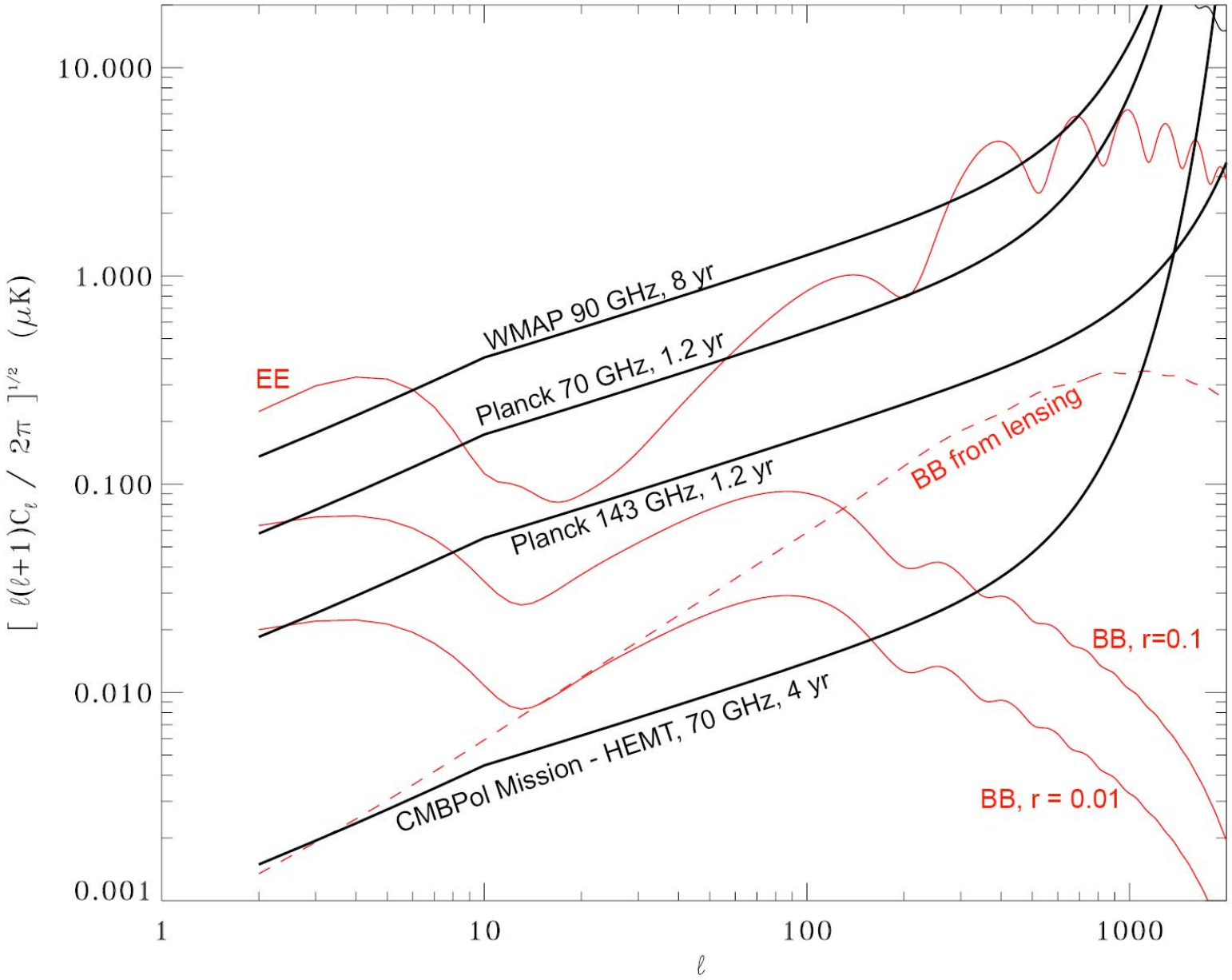
h/k=

Freq	pixel size (fwhm, arcmin)	time per 1deg pixel	sens per 1 deg pix
30		3060	0.738
40		3060	0.222
70	15	3060	0.111
100		3060	0.157
150		3060	0.196

Planck vs PILOT sensitivity

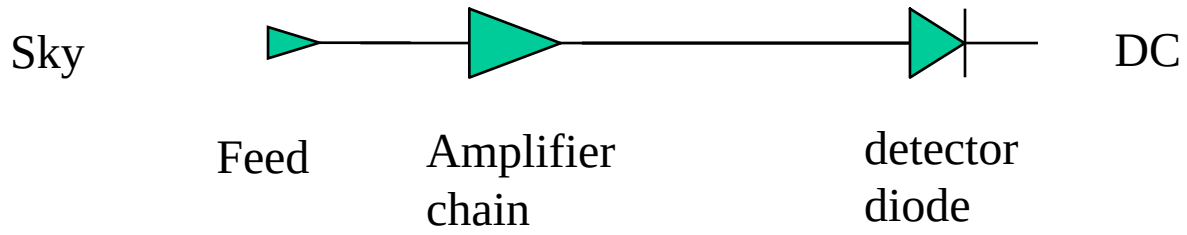


Science Reach



Receiver Topologies

Total Power Radiometer

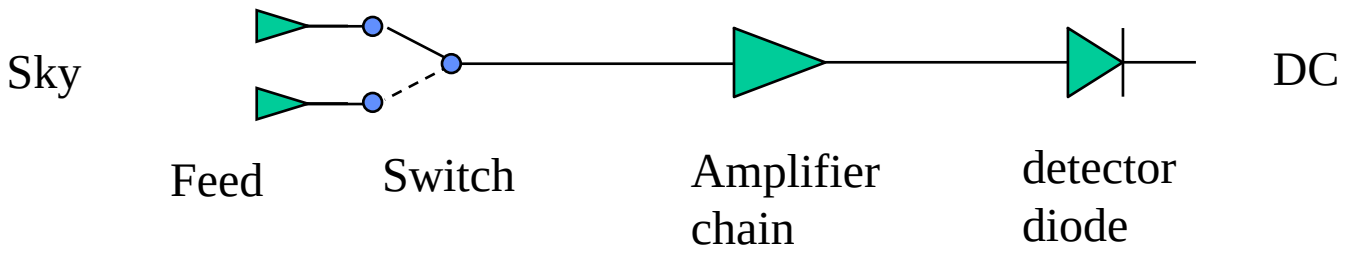


Simple topology

Several successful experiments have used this design

Gain fluctuations in the amplifier chain are often a problem

Dicke Switched Radiometer



Relatively simple

Gives up a factor of 2 in sensitivity with respect to a total power radiometer

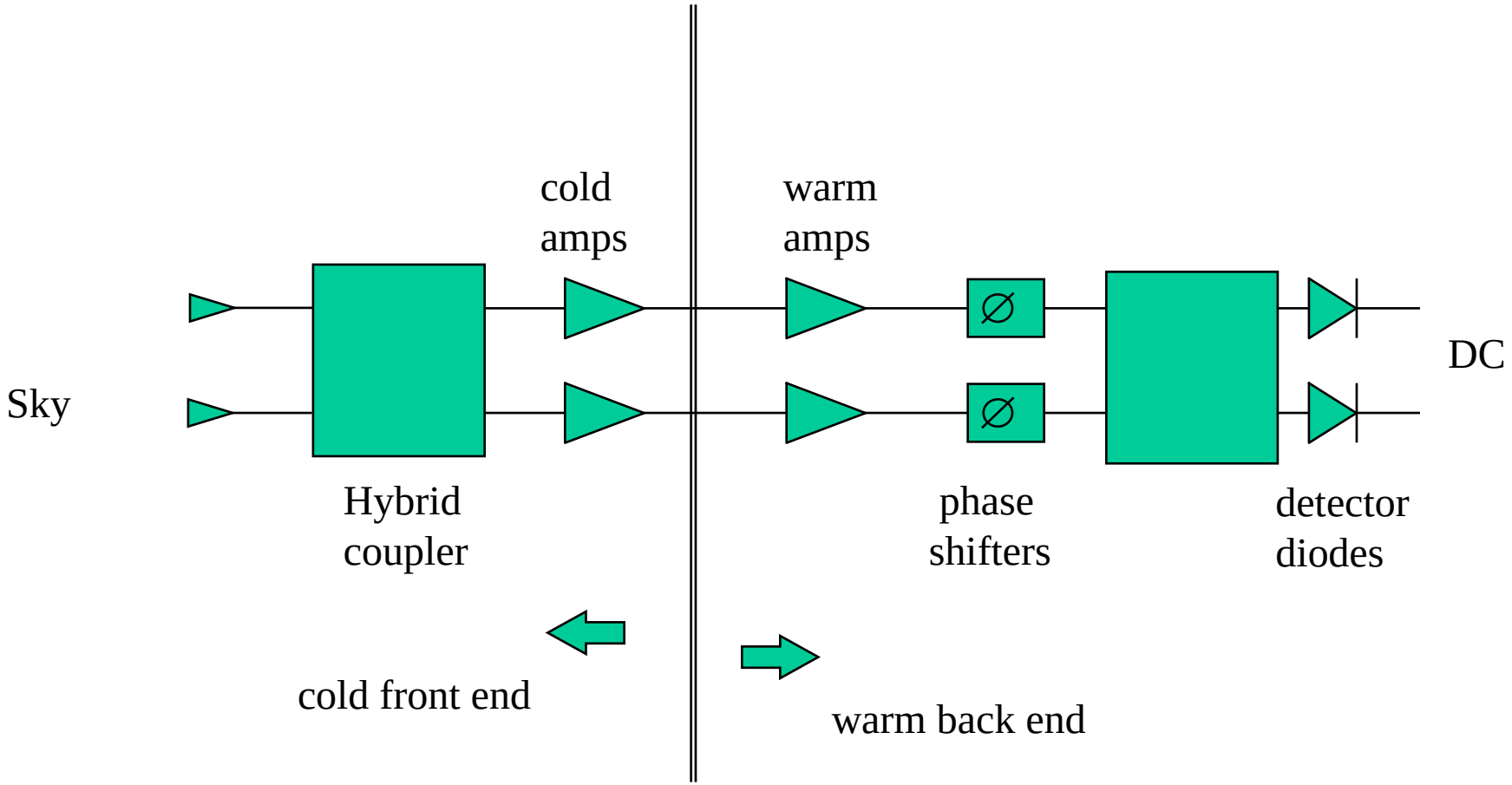
Used on COBE – DMR and many other experiments

Performance of the switch is often an issue:

- Ferrite switch
- MEMS switch

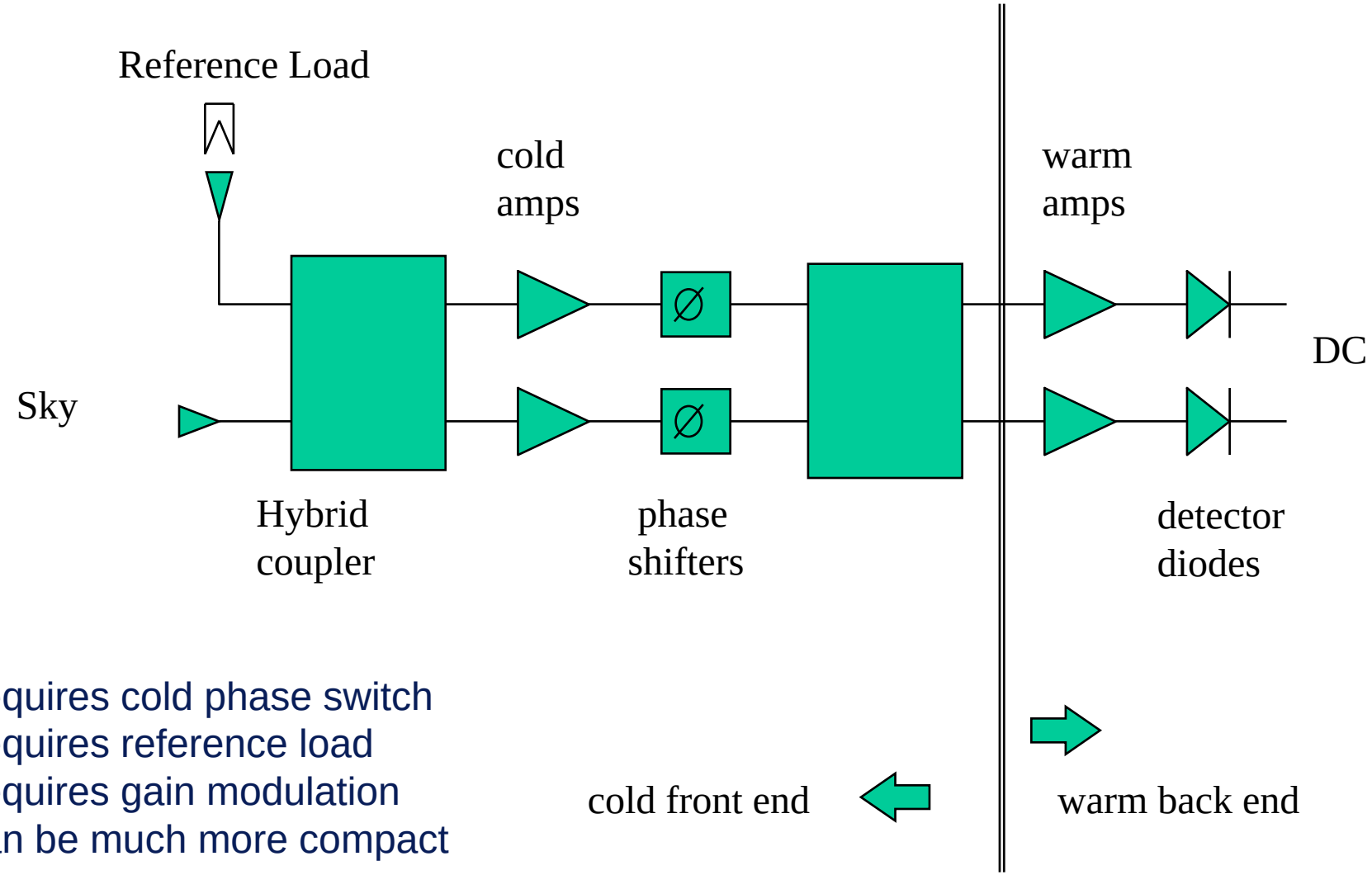
Balance is important, but noise adding or gain modulation can help

WMAP-like continuous comparison



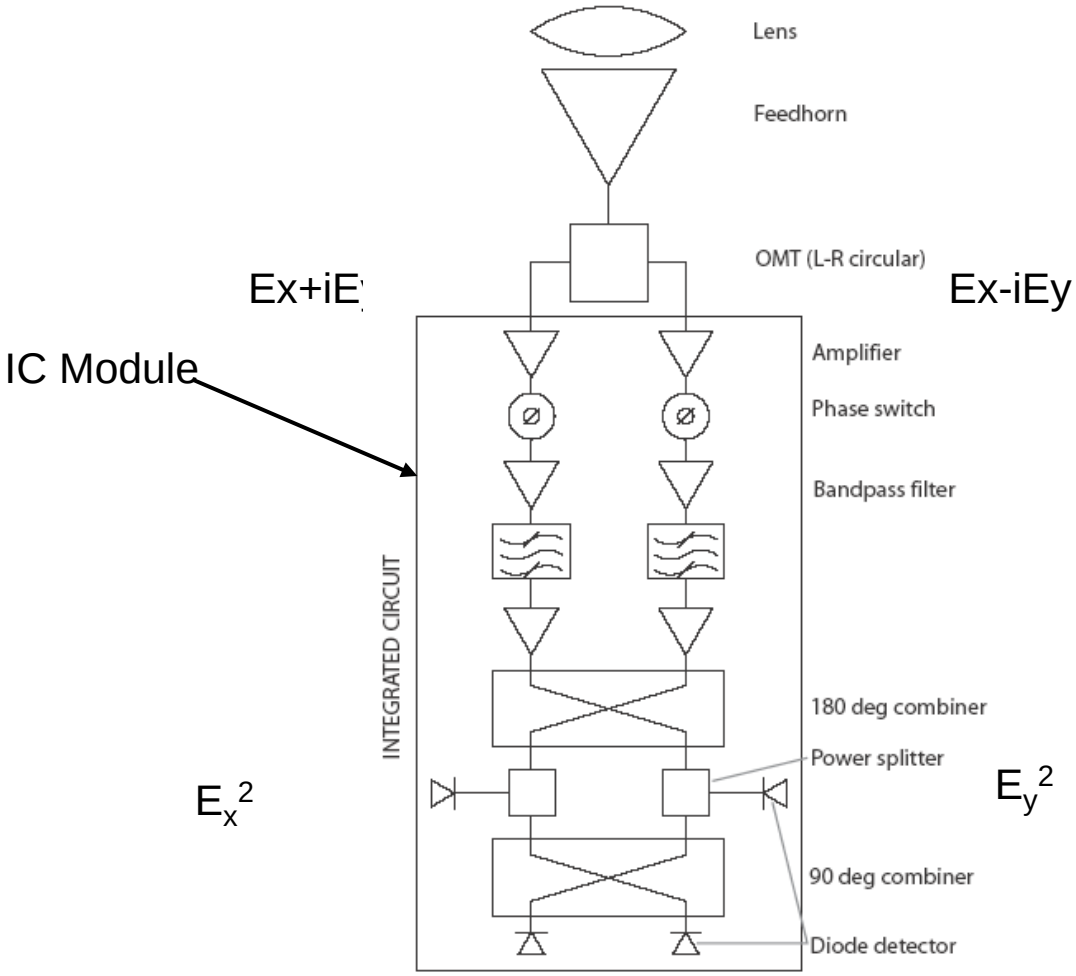
Requires phase and amplitude matching over length and wide bandwidth
Requires phase shifter, but loss not too important
Eliminates the need for high performance cold Dicke switch

Planck – LFI design



Requires cold phase switch
Requires reference load
Requires gain modulation
Can be much more compact

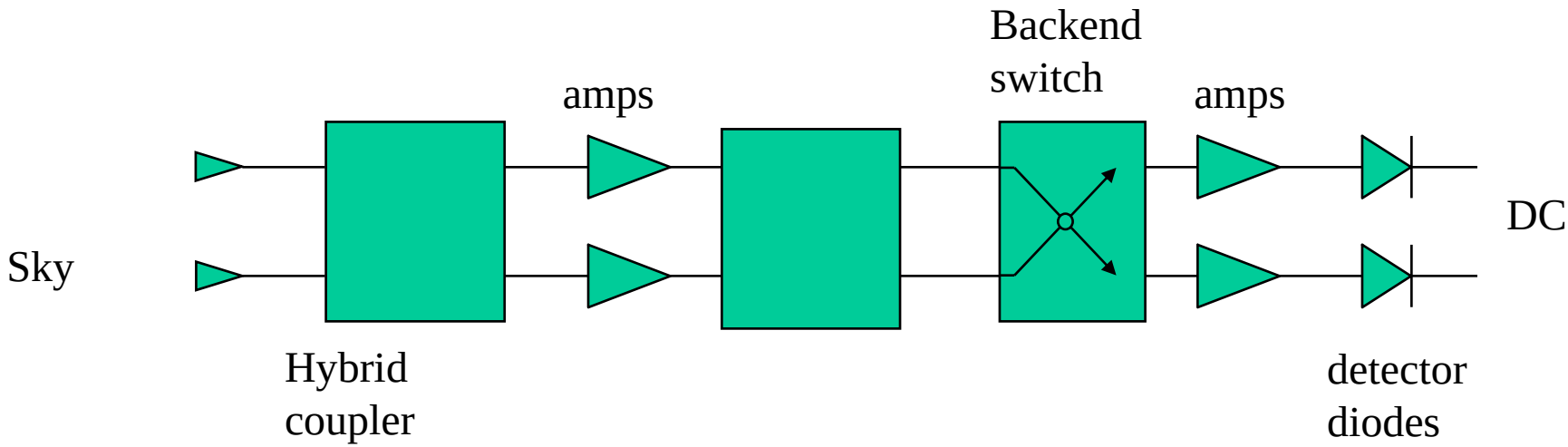
Polarimeter Functional Schematic



Phase switching options

- Normal operation is to only modulate one of the phase shifters.
- Options have been explored for both Planck (foxtrot phase shifting) and QUIET (double demod phase shifting) that involve operating both switches out of phase.
- This mode has been demonstrated on QUIET to reduce the module instrumental polarization, a leading systematic error concern
- We also expect that it will reduce the general problem of slight asymmetries in the phase shifter performance, e.g. differing bandpasses in the two states.
- Still a residual in instrumental polarization due (we guess) due to phase slope across the bandpass in the phase shifter. Generally speaking, optimizing the systematic performance of this type of radiometer requires flat amplitude and flat phase response across the bandpass, with good symmetry.

Back-end switch



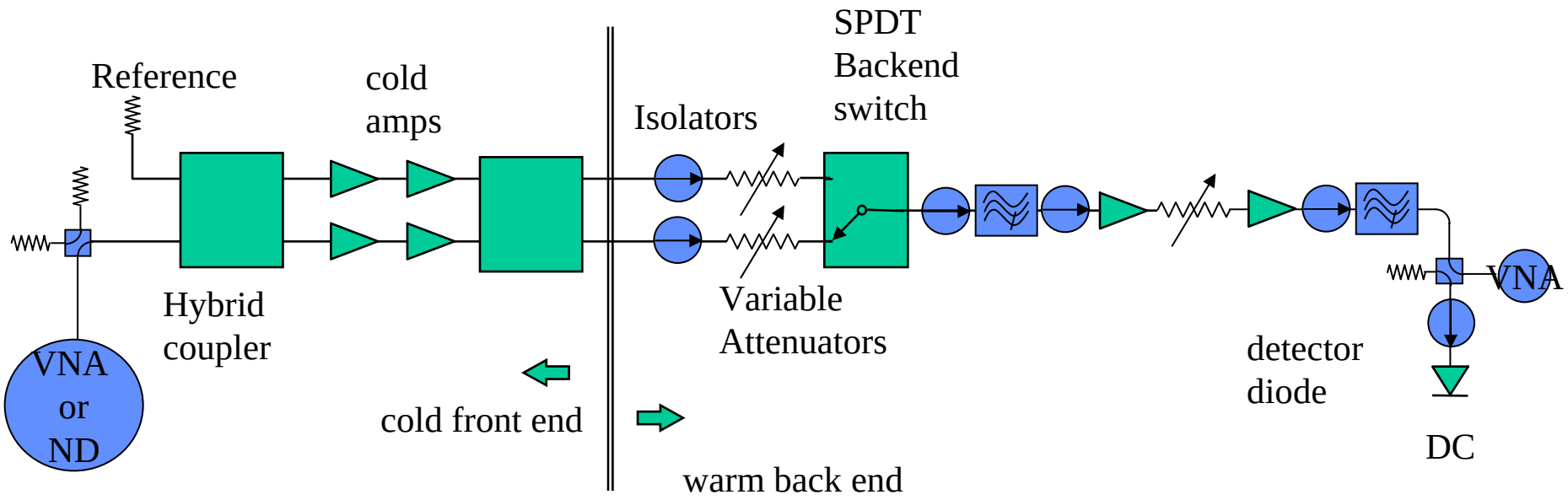
Phase, amplitude matching requirement much reduced

New switch required, but need not be low loss; must be fast; flat amplitude, balance still required

Amplifiers between hybrid couplers can have relatively low gain

Hybrid-amplifier-hybrid on one MMIC chip?

Back-end switch test



Tsys approximately 50 K
Bandwidth ~ 10 GHz centered at 90 GHz
f knee approximately 50 mHz

Conclusions

- PILOT mission concept may offer sufficient sensitivity at a lower cost than a bolometer-based mission.

- 2 key remaining issues:
  - Achieving radiometer sensitivity performance
  - Do we need to go to frequencies higher than 150 GHz

Many non-trivial radiometer topologies available. Careful sorting through the possibilities required to identify a design appropriate for a particular need.