local oscillator system

• recall that for a heterodyne receiver we must supply a ‘local oscillator’ reference signal

• the first LO is produced by a Gunn oscillator: basically a negative resistor in a tunable cavity; mechanically tune cavity length to change freq

• the local oscillators on all antennas must be synchronized - oscillating at \(10^{11}\) cycles per second, drift by less than 1 cycle over periods of hours – how is this possible?
mm phaselock

Mechanical tuner

Gunn osc

100.000 GHz

f = f₀ + α(ΔV)

to SIS mixer

V₀

correction voltage

ΔV = A sinφ

Loop gain

Lowpass

50 MHz reference (from lab)

50 MHz

'mphaselock IF'

Mixer

50 MHz

'phaselock IF'

Amp

Coupler

Phaselock mixer generates harmonics of YIG freq – e.g. 89.955, 99.950, ...

YIG osc

9.995 GHz

Sin(ωt + φ)

Cos(ωt)
mm reference frequency comes from YIG (Xband) phaselock

YIG osc

f = f_0 + \alpha(\Delta V)

V_0

correction voltage \Delta V

loop gain

lowpass

10 MHz reference (from lab)

mixer

10 MHz 'phaselock IF'

amp

mixer

harmonic generator

produces harmonics of ref freq – e.g. 8.8756, 9.9850, ...

1.109444 GHz ref from freq synthesizer in lab

tuning range 8.0-12.5 GHz

9.995 GHz

to mm phaselock

coupler
summary of phaselock system

• start with 10 MHz reference (from rubidium oscillator or H-maser or GPS receiver/time standard)

• send 3 signals to each telescope via underground fiberoptic cables:
  – 10 MHz
  – 50 MHz (actually, not exactly 50, for reasons to be discussed in a moment), ~10 MHz from DDS + 4 x 10 MHz
  – \( v_{\text{synth}} \) (1.1 – 1.26 GHz) generated by a frequency synthesizer phaselocked to 10 MHz

• on each telescope:
  – phaselock YIG osc (8-12.5 GHz) to \( v_{\text{synth}} \) with 10 MHz offset freq
  – phaselock Gunn osc (80-115 GHz for 3mm band, 70-90 GHz for 1mm band) with 50 MHz offset freq
  – for 1mm observations, send 70-90 GHz to a frequency tripler (another nonlinear device) to generate 210-270 GHz
Gunn oscillator \( f_{\text{Gunn}} = 85-113 \text{ GHz} \)

Freq. control

\( f_{\text{LO}} - N f_{\text{YIG}} = 50 \text{ MHz} \)

Gunn phase lock loop

\( f_{\text{REF}} = 50 \text{ MHz} \)
+ lobe rotation
+ phase switching

\( f_{\text{YIG}} = 8-12.5 \text{ GHz} \)

YIG oscillator

Freq. control

\( f_{\text{YIG}} - N f_{\text{IF}} = 10 \text{ MHz} \)

YIG phase lock loop

Mixer

\( f_{\text{REF}} = 10 \text{ MHz} \)

\( f_{\text{REF}} = 1.10-1.26 \text{ GHz} \)

Reference signals on fiber from control building

\( f_{\text{LO}} = 219-261 \text{ GHz} \)

Gunn oscillator

Feed horn

\( f_{\text{SKY}} = 210-270 \text{ GHz} \)

Sky

Feed horn

SIS Mixer

\( f_{\text{IF}} = 1.9 \text{ GHz} \)

Dewar

post-amplifier module (PAM)

Laser transmitter

Fiber 1550 nm

To control building

1-mm Rx
fiber optic transmission

- Input voltage modulates laser power.
- Photodiode output voltage is proportional to laser power, hence reproduces the input waveform.
- Very low loss through the fiber (80% transmission for 2 miles of fiber).
complication #1: temperature variations of the fiberoptic cables

- temperature coefficient of delay is \( \sim 10^{-5}/C \)
- most fiber is buried underground (thermally stable) but a \( \sim65\)-foot length (100 nsec delay) runs up each antenna
- if this length changes temperature by 1 C:
  - delay changes by 1 picosecond (10\(^{-12}\) sec)
  - phase of \( \sim1\) GHz reference signal changes by 0.35°
  - LO phase at 230 GHz changes by 80°

how do we deal with this?
- observe phase calibrator every \( \sim30\) min to track instrumental phase
- linelength system continuously monitors the delay through the fiber; stored in data header; during data reduction, use linecal, then uvcat, to apply to your data
Fiberoptic linelength system measures roundtrip phase at the reference frequency

- No electronics at the antenna, just a fiber coupler
- Fiber 1 and fiber 2 are in the same gel-filled tube; their temperatures track very closely
Fiberoptic linelength system

3-m fiber patchcord in lab

delay uncertainty ~ ±10 femtoseconds

- 1 degree of phase at 230 GHz
- $\Delta T = 1$ C for 8 inches of fiber (or 0.1 milliKelvin for 7000 ft of fiber!)
linephase example

shows effect of air conditioner cycling in rcvr cabin or base
linephase correction example
1mm phase wraps in A-array (due to Doppler tracking through very different fiber lengths)
complication #2: lobe rotation

suppose $B = 10$ meters

velocity of ant 2 relative to ant 1

$v = 2\pi B/\text{day}$

$= \frac{2\pi(10\text{m})}{86400 \text{ sec}}$

$= 0.72 \text{ mm/sec}$

Doppler shift of signals at ant 2 relative to ant 1 due to Earth’s rotation

$= \frac{0.072 \text{ cm/sec}}{3 \times 10^{10} \text{ cm/sec}} \cdot 100 \times 10^9 \text{ Hz} = 0.24 \text{ Hz}$

$\rightarrow$ fringes ‘wash out’ in a 4 second integration
lobe rotation (= fringe tracking)

- wait! how does a 10 m single dish work if signals from the 2 edges arrive at the receiver with different frequencies? answer: the dish moves to track the source, cancelling the Doppler shifts

- same here: our telescopes are part of a large synthetic telescope; adjusting local oscillator frequencies is part of ‘tracking’ the source
offsetting the LO frequencies

• in our example, we must operate the LOs at:
  – ant 1: 100,000,000,000.00 Hz
  – ant 2: 100,000,000,000.24 Hz
• to do this, send a slightly different phaselock reference signal to each antenna:
  – ant 1: 50 MHz exactly
  – ant 2: 50 MHz + 0.24 Hz
• the phaselock reference signal for each antenna is generated by DDS (direct digital synthesis) in the lobe rotator chassis (in the fiber entry room), then is sent to the receiver via optical fiber
lobe rotation in the correlator

- each frequency within the passband has a slightly different Doppler shift; tracking LO1 only corrects the average phase
- the remaining phase variations change more slowly, can be removed in the correlator pipeline software
complication #3: sideband separation

shifting LO frequency shifts USB, LSB IF frequencies in opposite directions
sideband separation

• for an interferometer we do not need to change the freq, just the phase

• 90 degree phase switch on LO1 allows automatic separation of USB and LSB signals at the correlator

• note: we cannot separate USB, LSB noise; only signals that are common to a pair of antennas can be separated

• send out phase switch pattern on 50 MHz phaselock reference