Differences between VLBI2010 and S/X Hardware

Brian Corey (MIT Haystack Observatory)

Synopsis –

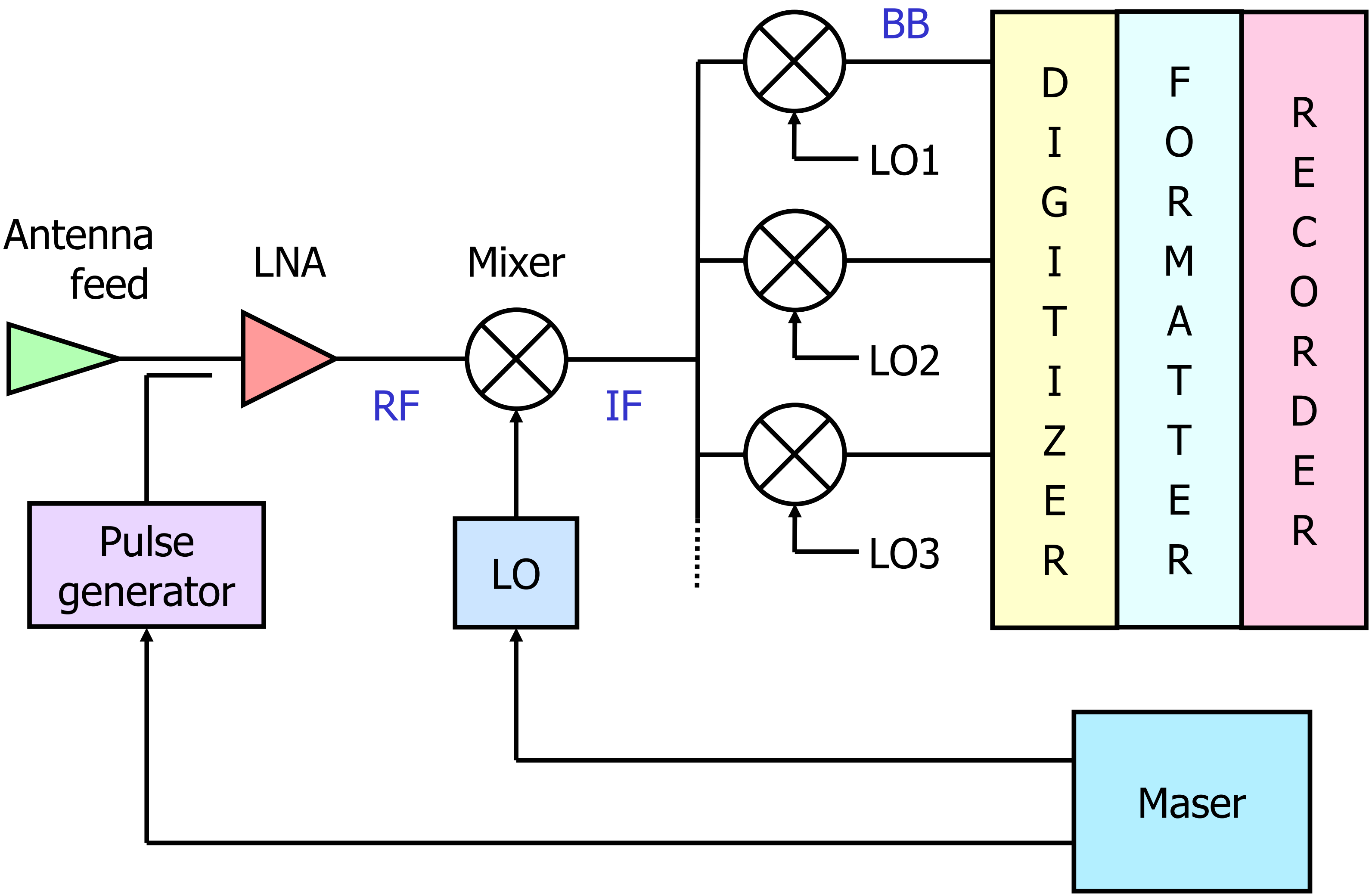
- Primary drivers behind hardware differences
- (Greatly) simplified block diagrams of S/X and VLBI2010 hardware
- Details about differences in various sub-systems
  - Antenna feed
  - Low-noise amplifier
  - Frequency downconversion from RF to IF
  - Frequency downconversion from IF to baseband
  - Phase calibration

Primary drivers behind hardware differences

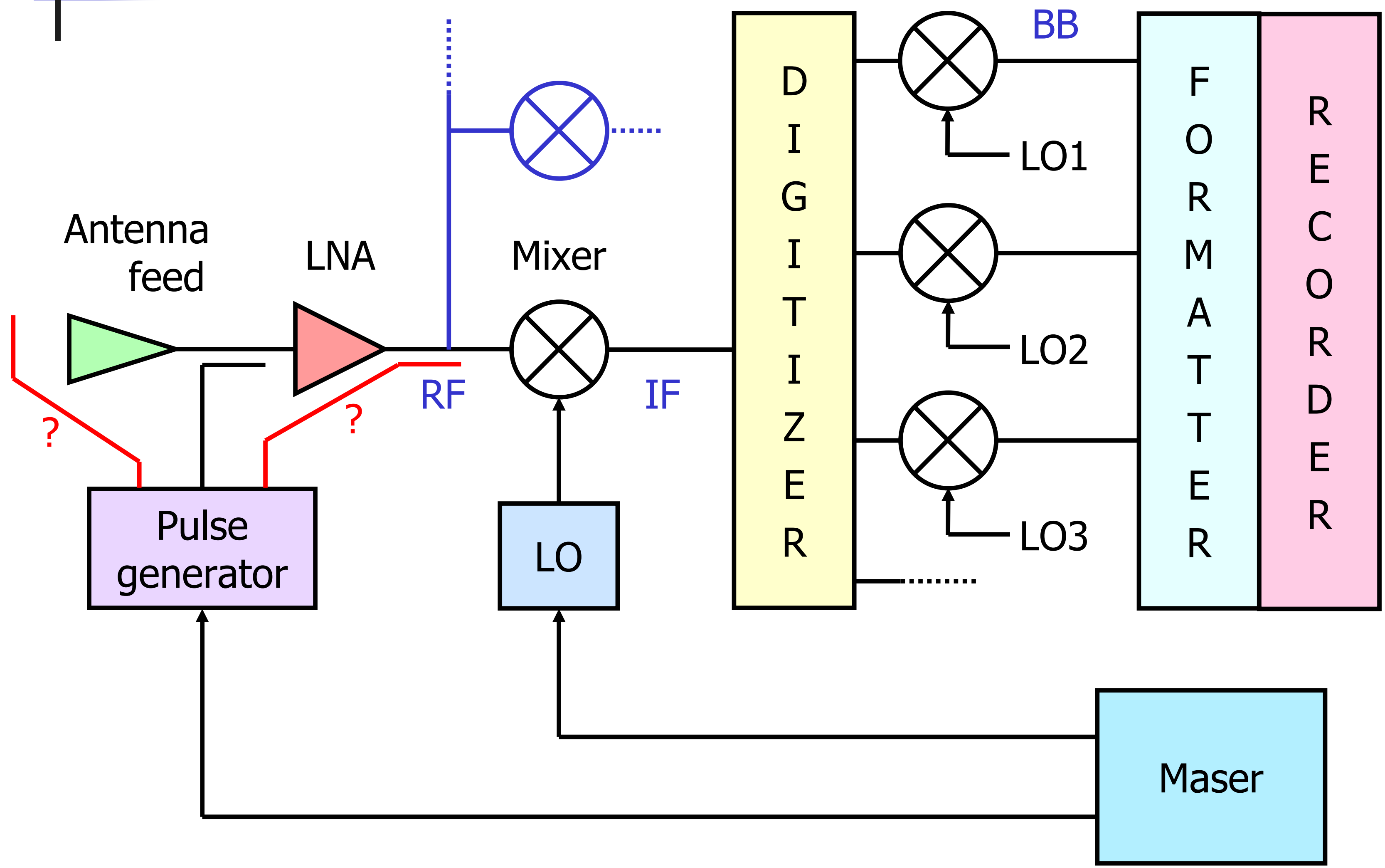
Compared with S/X, VLBI2010…

- Utilizes a much wider RF frequency range
  - Corollary: VLBI2010 is more likely to “see” RFI
- Records data from tunable frequency “bands” (500-1000 MHz wide) that may change from session to session
- Requires higher delay precision per observation

Simplified block diagram of S- or X-band electronics

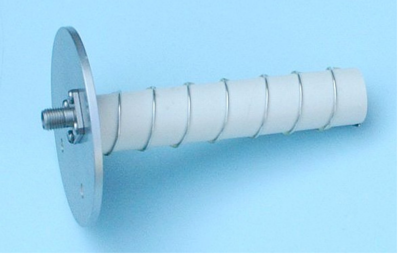


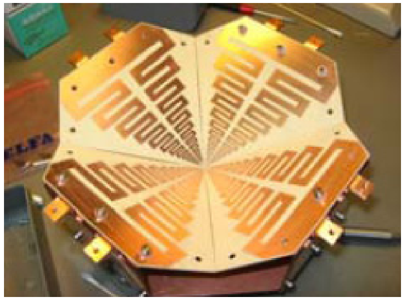
Simplified block diagram of VLBI2010 electronics

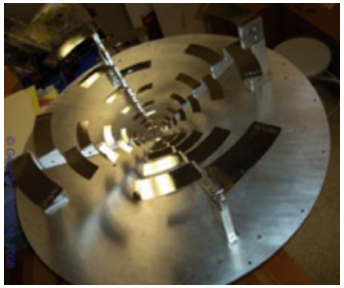


Antenna feed

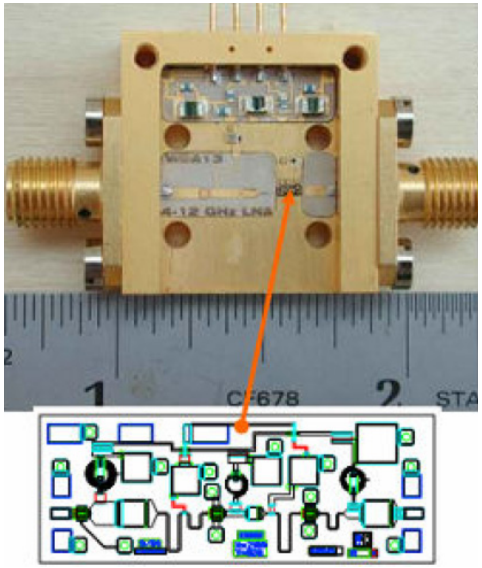
- Advantage of receiving circular polarization is insensitivity of fringe amplitude from parallel-hand correlation to relative feed orientation at 2 stations, which can vary by 180° over a day.
- Low-loss, circular-pol feeds are easy to build with fractional BW ~10%, as for S/X systems.
- Almost all wideband (2-14 GHz) feeds intrinsically receive linear pol.
- Options for "circularizing" wideband feeds:
  - Add a wideband 90° hybrid after the feed to create circular from two linears.
  - After signal digitization, generate circular from two linears in FPGA.
  - Correlate four linear parallel- and cross-hands, and create circular visibilities from four linear cross-products.







Low-noise amplifier

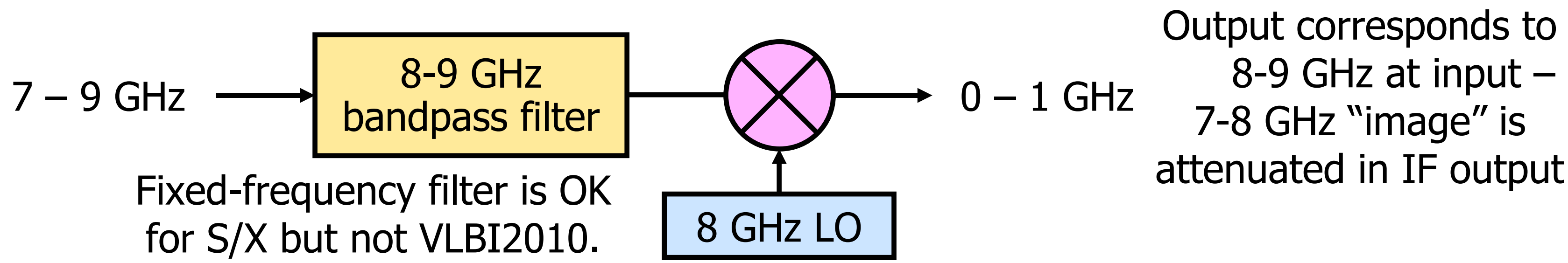


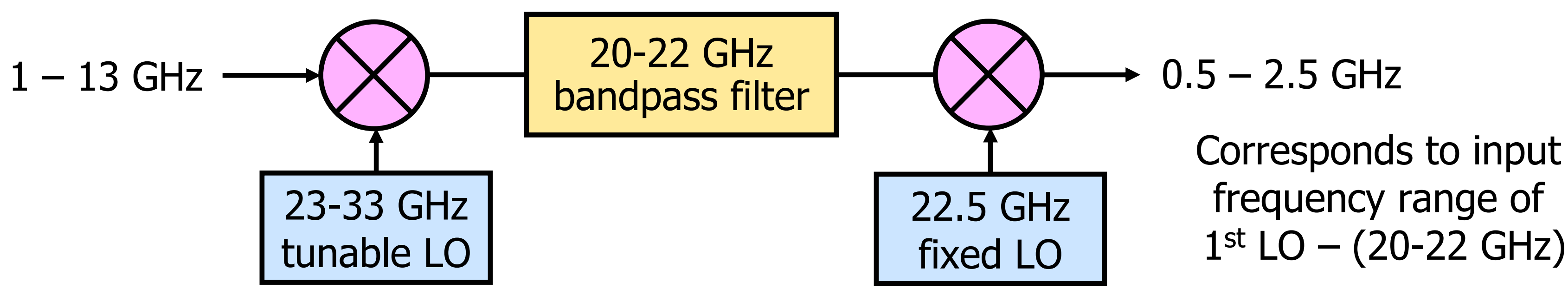
- No major performance differences between S/X and VLBI2010 LNAs.
  - 5-20 K noise temperature
  - ~35 dB gain
  - cryogenic operation
- Most broadband feeds require more than 1 LNA per polarization, unlike S/X.
- Wide BW of VLBI2010 makes it more likely RFI will fall in LNA freq range.
  - Electronics (LNA and post-LNA) need enough headroom not to saturate from RFI.
    - RFI outside observation band will still degrade sensitivity.
  - Notch filters can attenuate severe, fixed-frequency RFI.
  - It may not be possible to insert filters ahead of the LNA.

Frequency downconversion from RF to IF

Function: Translate down in frequency without contaminating output with undesired input frequencies

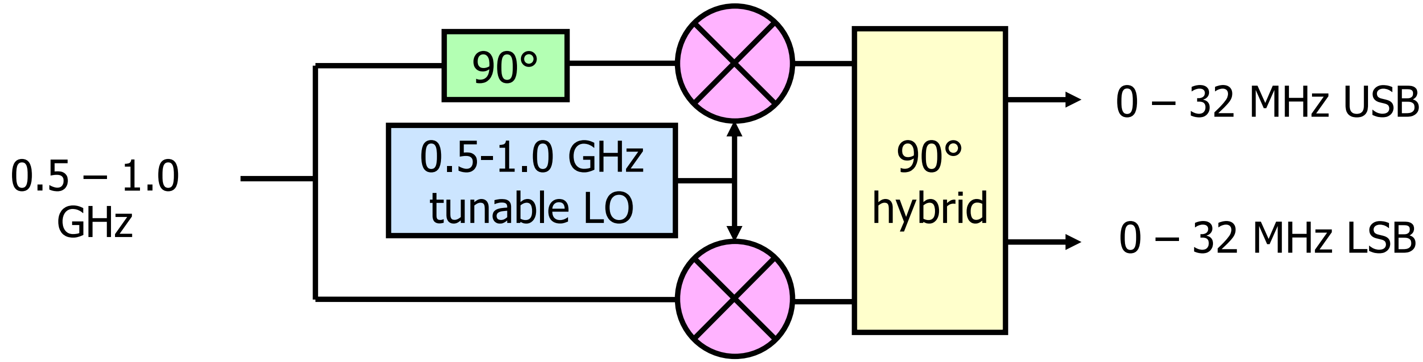
Implementation examples:





Frequency downconversion from IF to baseband

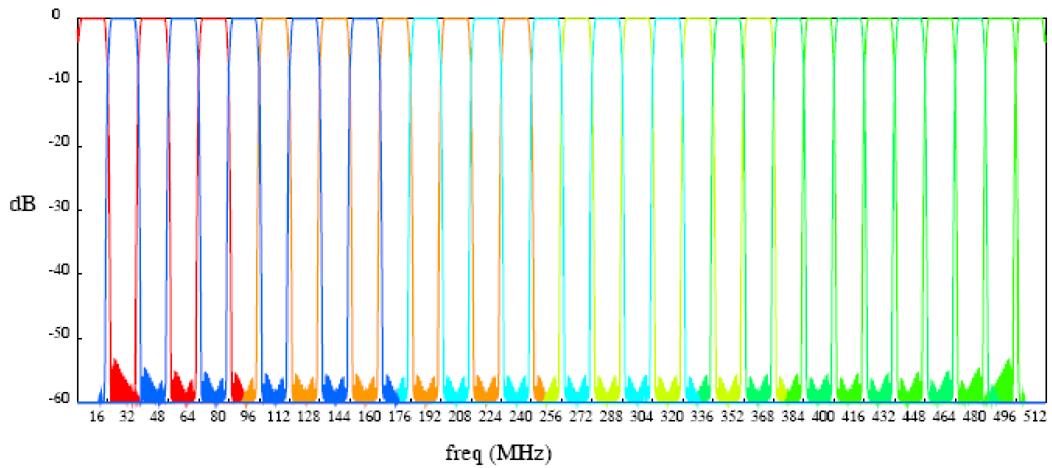
- Until recent years, all S/X systems used analog video/baseband converters to downconvert from IF to baseband.
- Each BBC employs an image-reject mixer to provide separate outputs corresponding to input frequencies above (USB) and below (LSB) the LO.



- In principle, VLBI2010 could use analog BBCs, but digital backends provide an alternative that is much more
  - flexible
  - stable electrically (phase and gain)
  - affordable

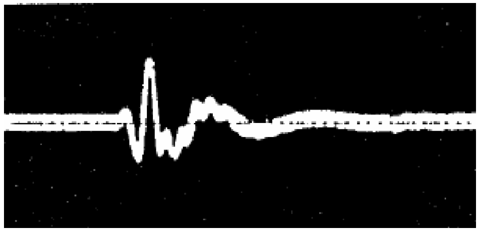
Frequency downconversion from IF to baseband – cont'd

- Digital backend firmware comes in two flavors:
  - Digital downconverter (DDC or DBBC)
    - Functions the same as analog BBC, with a tunable LO to downconvert an arbitrary slice of the input frequency range.
    - Multiple DDCs needed to provide multiple baseband channels for recording. (One FPGA can accommodate multiple DDCs.)
  - Polyphase filterbank (PFB)
    - Splits the input into 2^N channels, which are downconverted.
    - Limited flexibility in choosing input-to-output frequency mapping.



Phase calibration

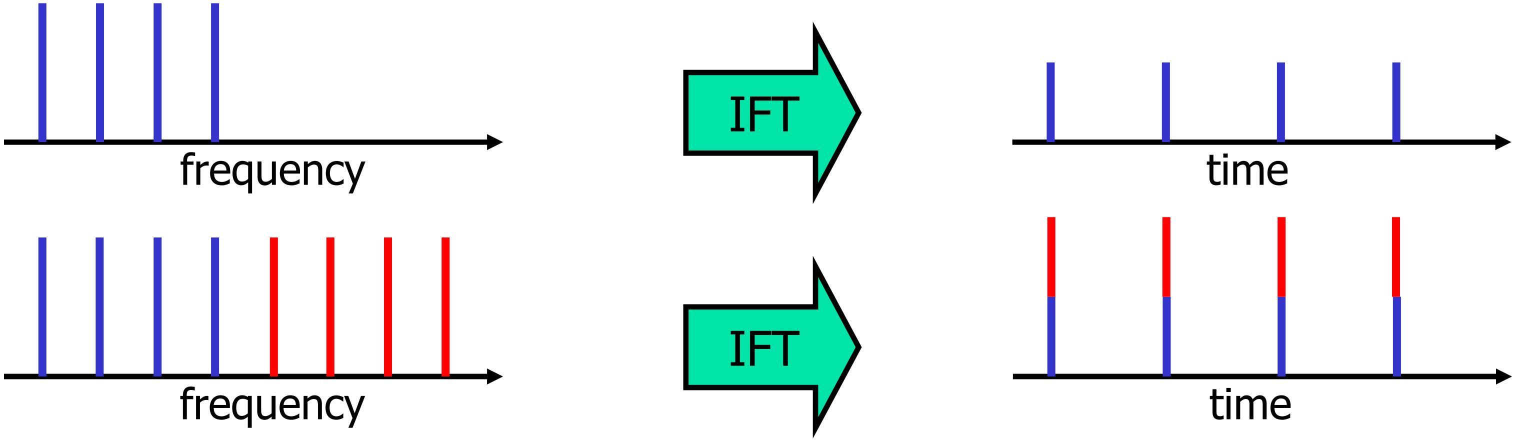
- Phase cal enables correction for
  - Relative LO phases between analog BBCs within a band (e.g., S or X)
    - Not needed with super-stable DBEs in VLBI2010!
  - Relative LO phases between VLBI2010 bands, to compute bbdelay
    - Not needed for S/X multiband delay estimation!
  - Phase/delay drifts in RF/IF electronics
- New "digital" pulse generator has temperature sensitivity < 1 ps/°C.
- As RF bandwidth increases, pulse intensifies.
  - Typically, peak pulse voltage » rms noise.



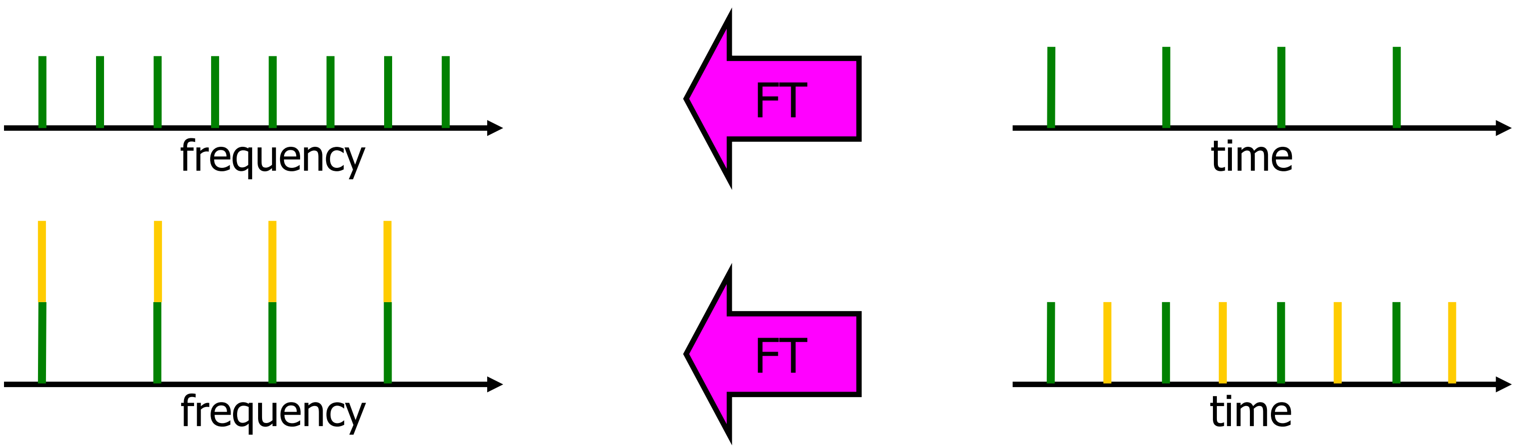
- Options to avoid driving electronics into saturation:
  - Reduce pulse strength
    - Phase cal SNR reduced → noisier phase extraction
    - More prone to contamination by spurious signals
  - Reduce pulse strength *and* increase pulse repetition rate to 5 or 10 MHz
    - Fewer tones spaced 5 or 10 MHz apart

Effects on phase cal of changing bandwidth or pulse rate

Pulse voltage scales with frequency bandwidth –



Amplitude and spacing of frequency tones scales with pulse rate –



Other differences – odds and ends

- RF/IF downconversion hardware location
  - S/X: in receiver
  - VLBI2010: in control room
- Signal transmission from receiver to control room
  - S/X: analog ~1 GHz IF over coaxial cable
  - VLBI2010: analog 2-14 GHz RF over optical fiber
- Signal digitization
  - S/X: 32-64 MS/s at baseband
  - VLBI2010: 1024-2048 MS/s at IF