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Development & test of X-band LLRF for CLARA

Conor Jenkins

RF Engineer
ASTeC, STFC Daresbury Laboratory

CLARA

Test facility for Free Electron Laser research and other applications at STFC's Daresbury Laboratory

Front end (Gun + Linac) delivered 35 MeV in 2018/19

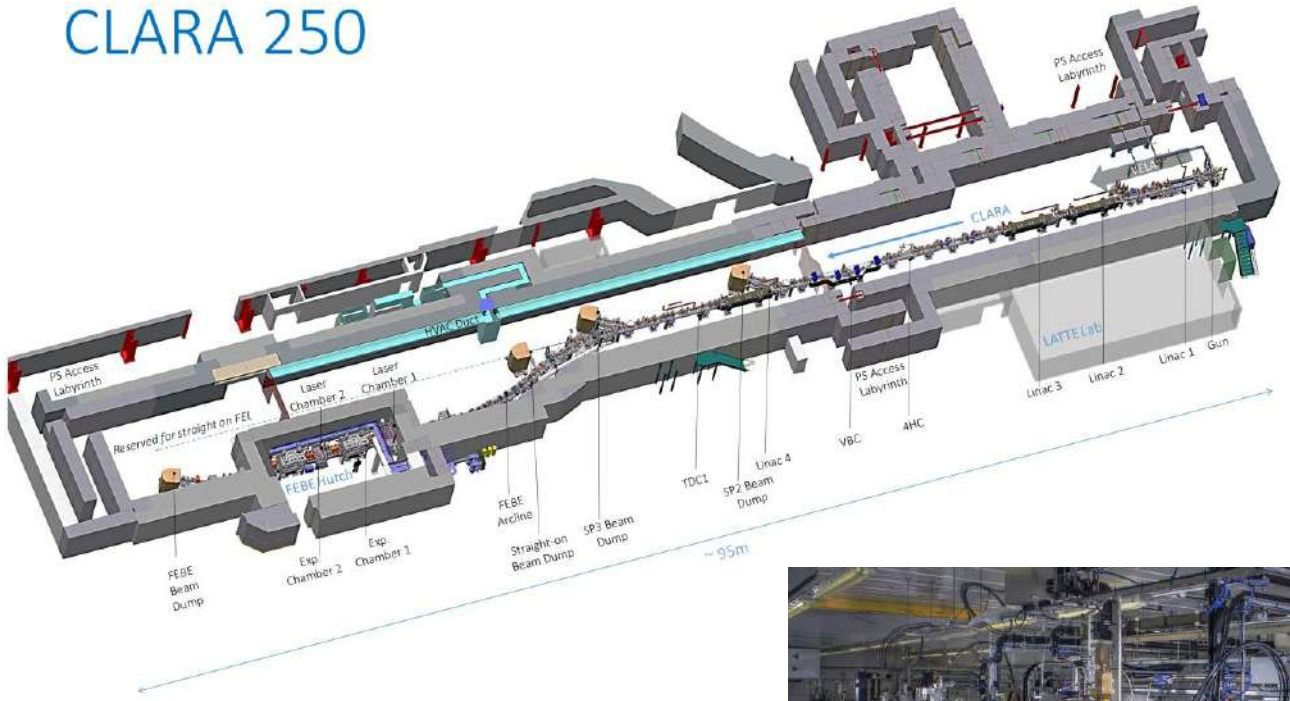
Commissioning work in progress to extend energy to 250 MeV and include additional FEBE experimental area

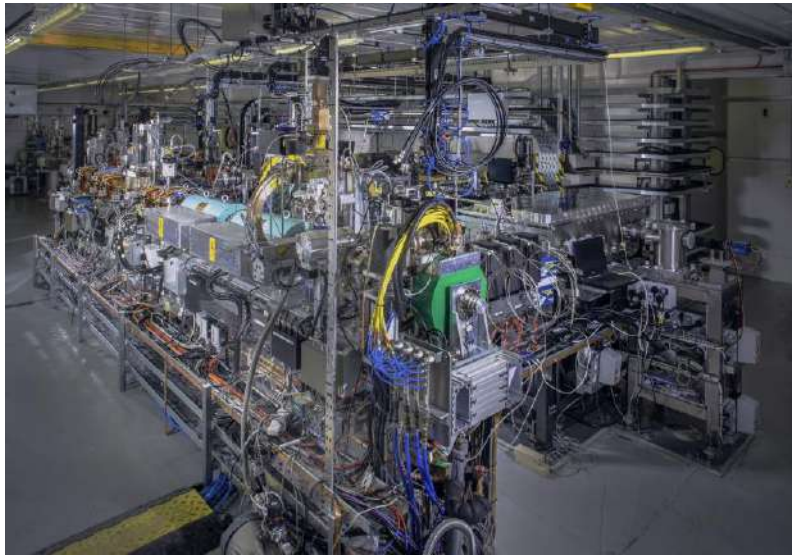
7 RF stations:

- Six at 2.9985 GHz S-band

(Gun, Linacs, TDC)

- One 4th harmonic at 11.994 GHz





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X-band cavity

- CERN/PSI travelling wave X-band linearising cavity
- For 30 MV/m 16.3 MW required
- Design frequency 11992 MHz with 10 MHz tuning range; operated at 11994 MHz
- Includes wakefield alignment monitors
- Will operate with ~120 ns pulse – 100 ns to fill cavity, 20 ns for beam

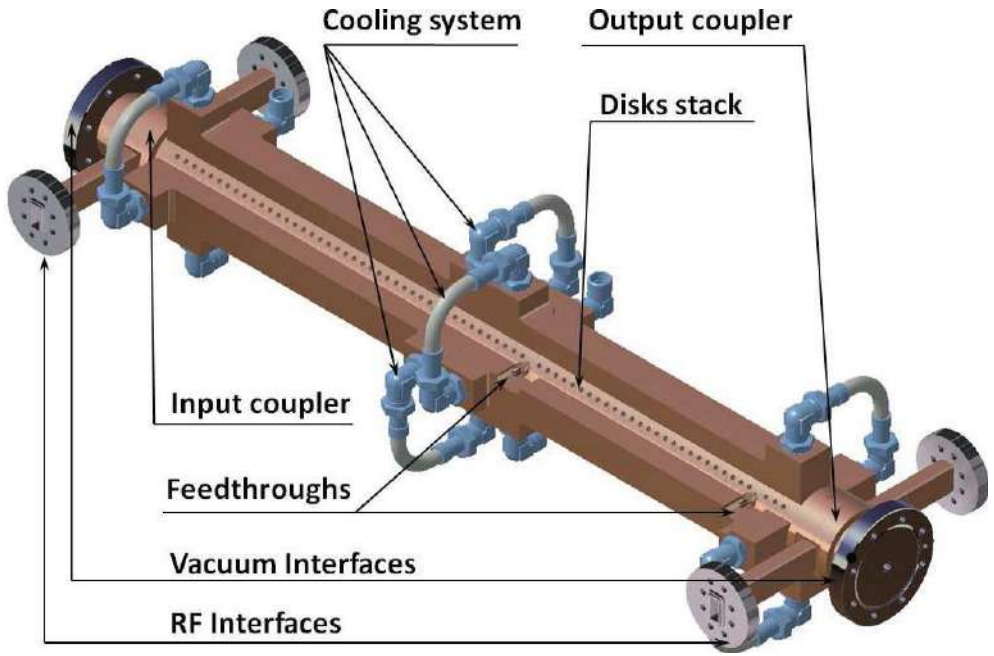

Image: M. Dehler, paper ref: WEBL3

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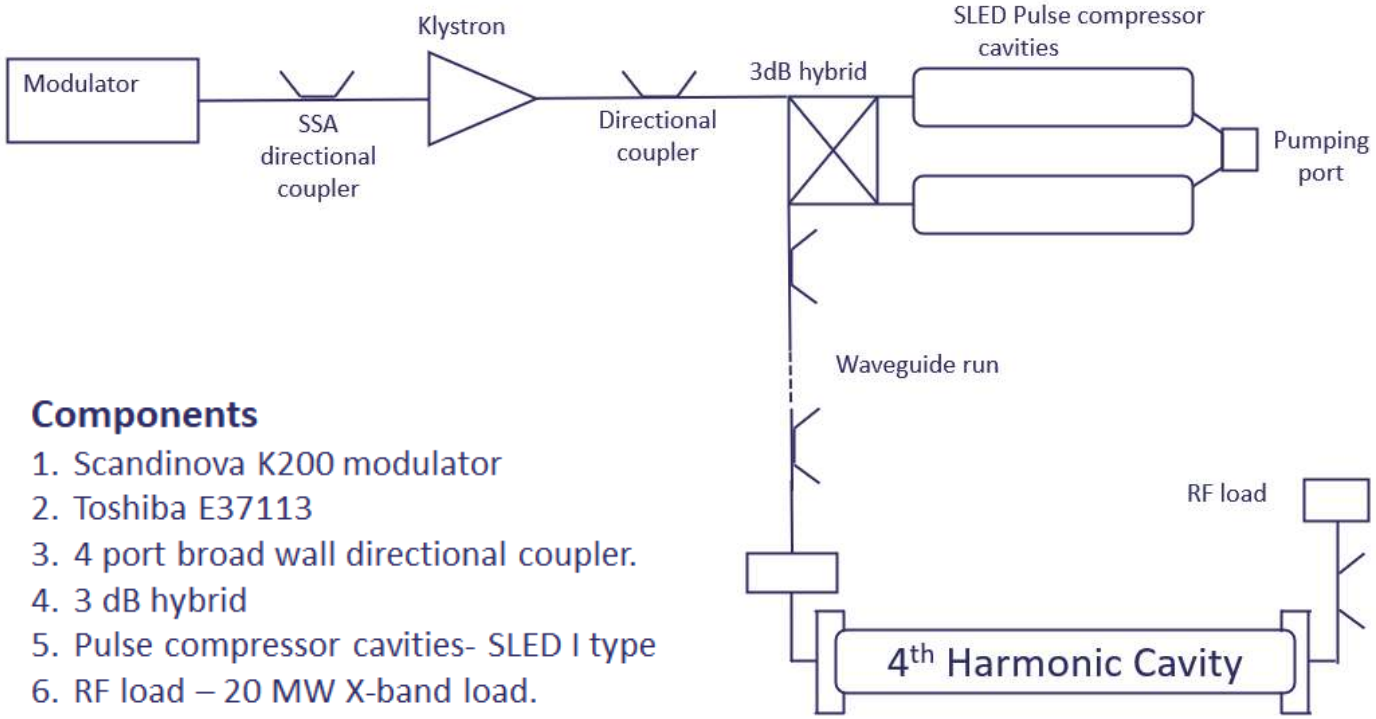
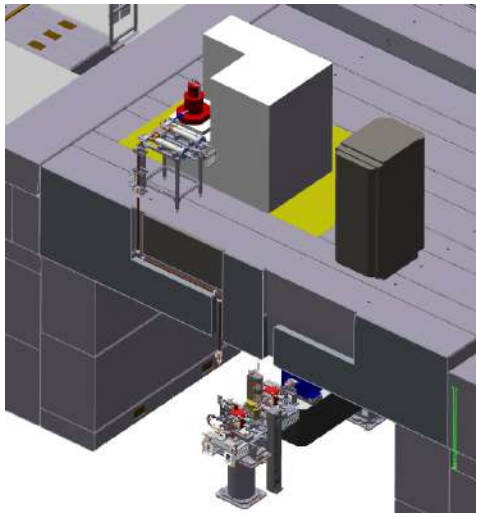
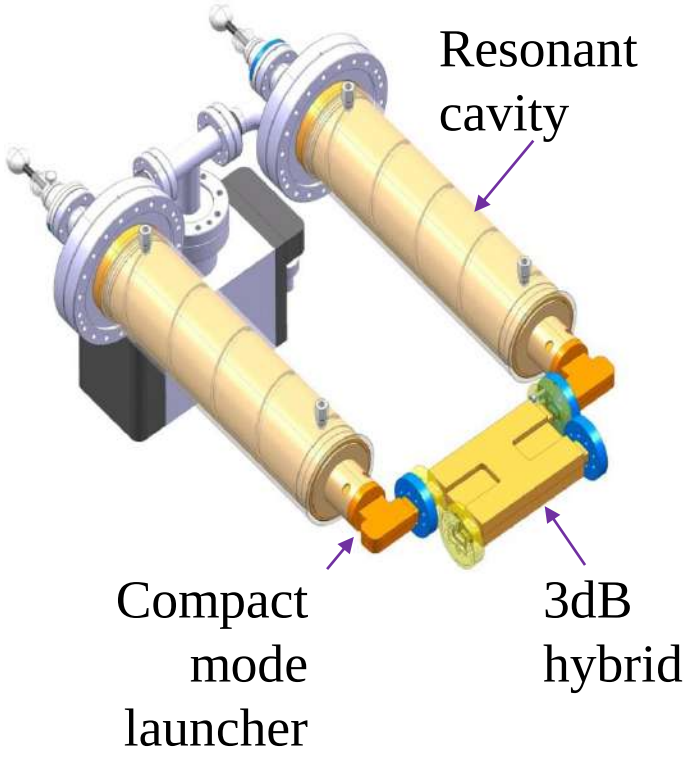
X-band RF system



Components

1. Scandinova K200 modulator
2. Toshiba E37113
3. 4 port broad wall directional coupler.
4. 3 dB hybrid
5. Pulse compressor cavities- SLED I type
6. RF load – 20 MW X-band load.





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X-band LLRF

All S-band RF stations use Libera LLRF:

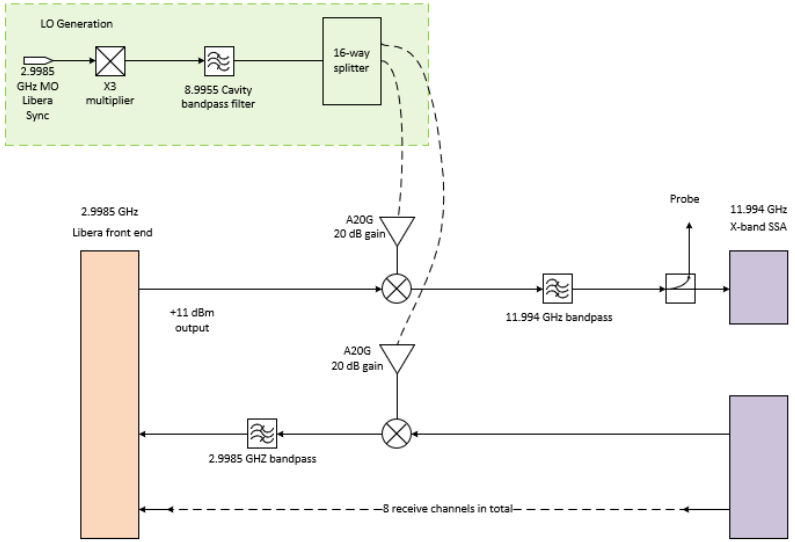
- 2.9985 GHz vector modulator, Max + 11 dBm
- 2.9985 GHz front end, Max +20 dBm

Down converted to IF = 41.6 MHz

- Clocked at 111.05 MHz – 9 ns resolution

X-band LLRF performance spec:

- Frontend - Maximize Libera signal levels
- Drive able to flip phase on ns timescale
- Input able to resolve ~120ns pulses



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X-band front-end: design

High linearity mixers

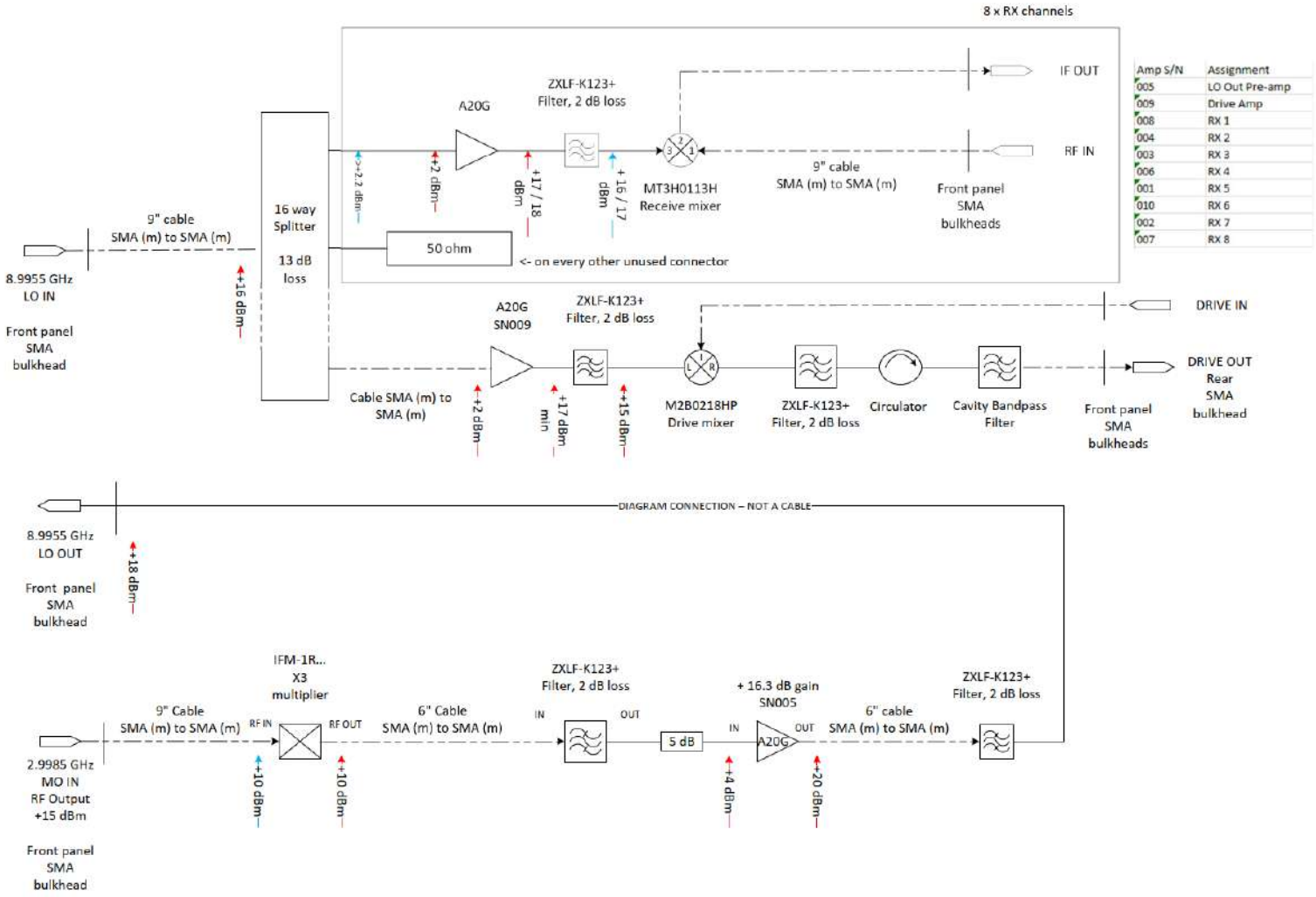
Ensure VM can be driven at maximum gain without compressing drive signal

Maximize dynamic range for receive signals – maximize signal level going into Libera

Each mixer requires a strong LO signal

Minimise channel-to-channel Rx crosstalk

Reflectionless filters remove unwanted harmonics without introducing mismatch on amplifier outputs



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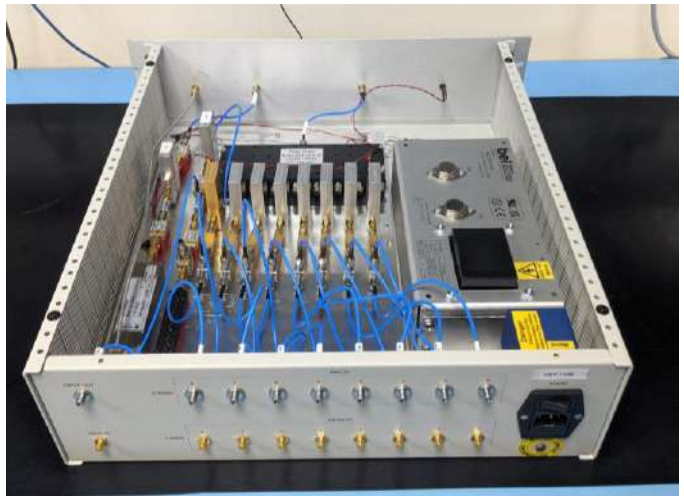
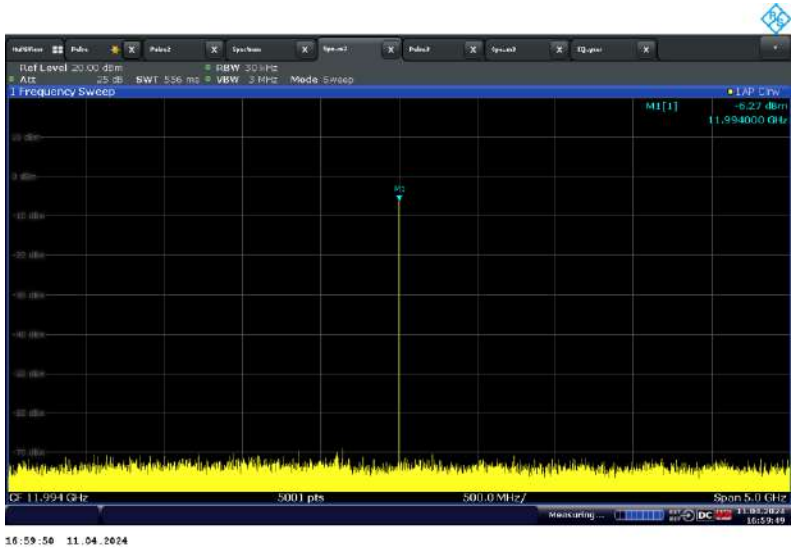
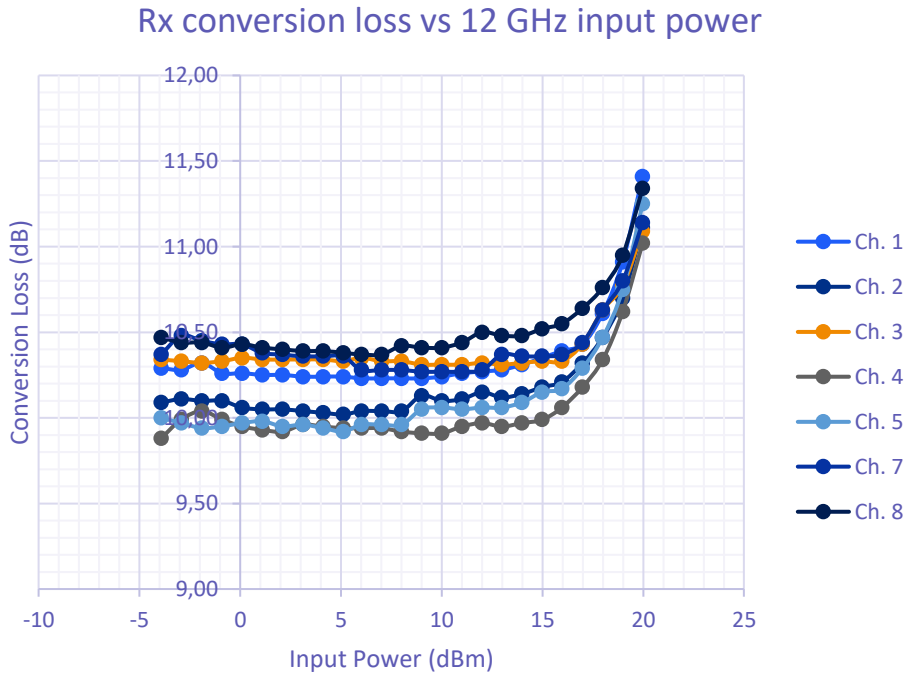
X-band front-end: benchtop tests







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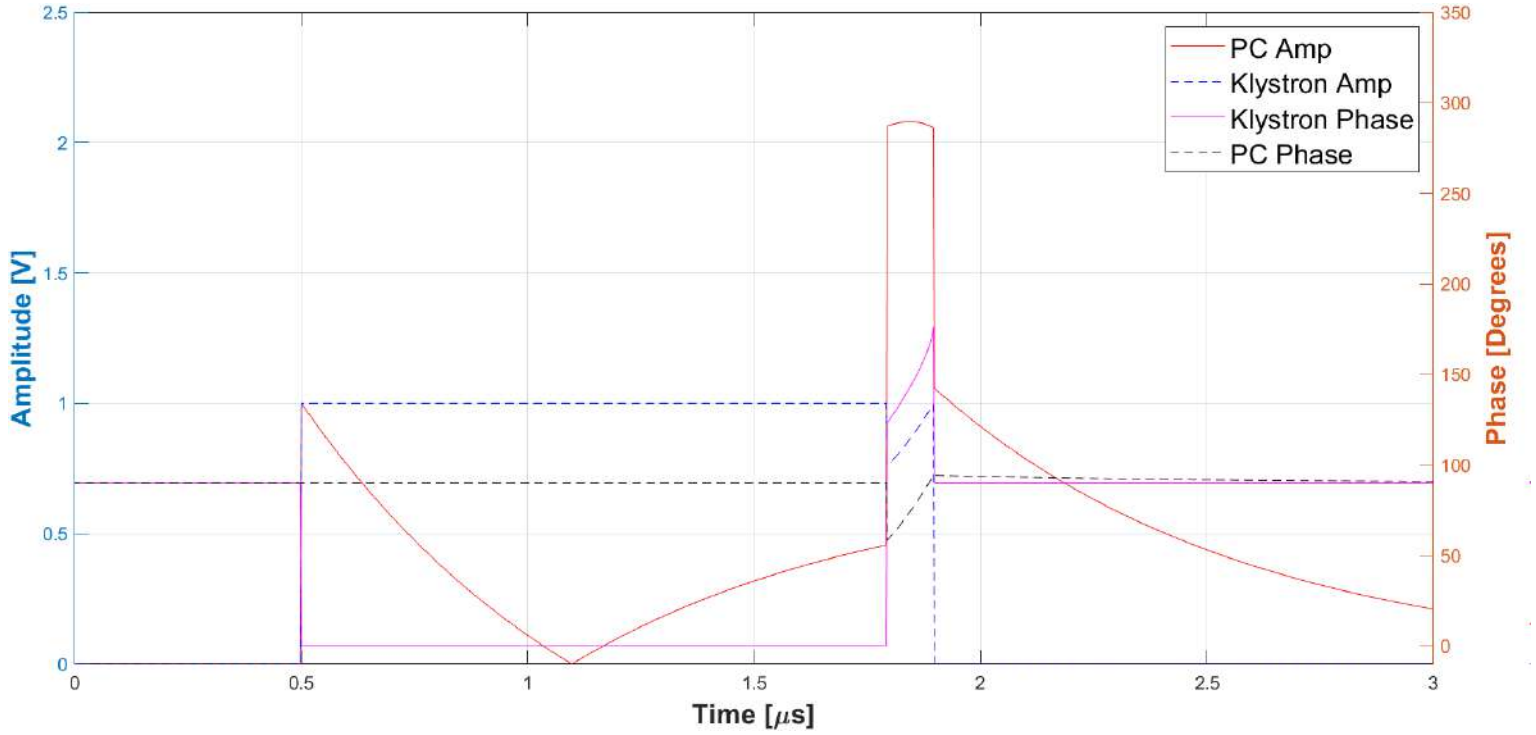
Libera: phase flip

Pulse compressor:

1.5 us input to ~100 ns output

Phase flip occurs about 200 ns from end of pulse

Amplitude and phase ramps used on the input pulse shape to achieve flat output amplitude



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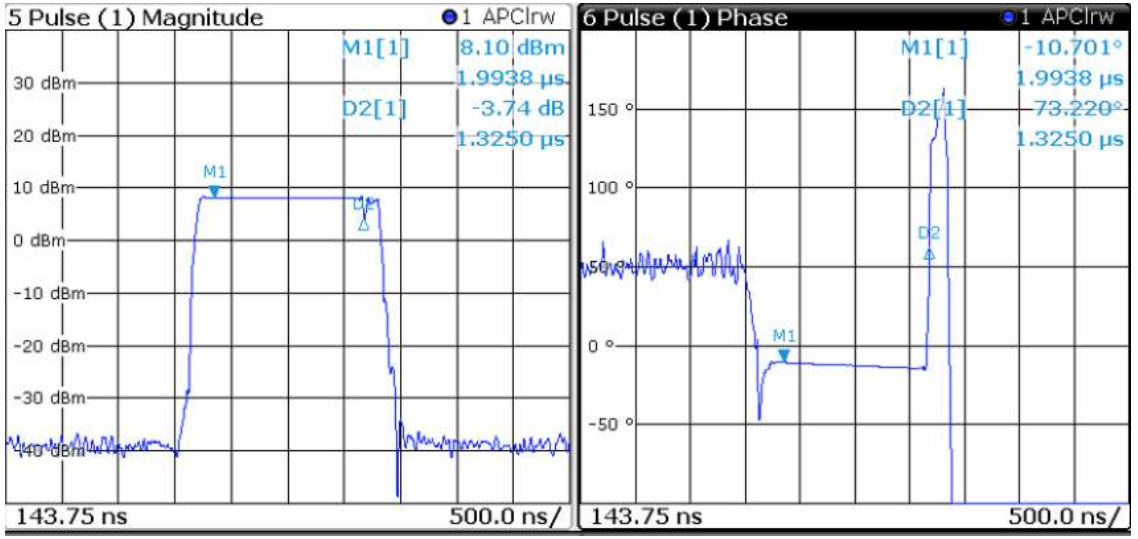
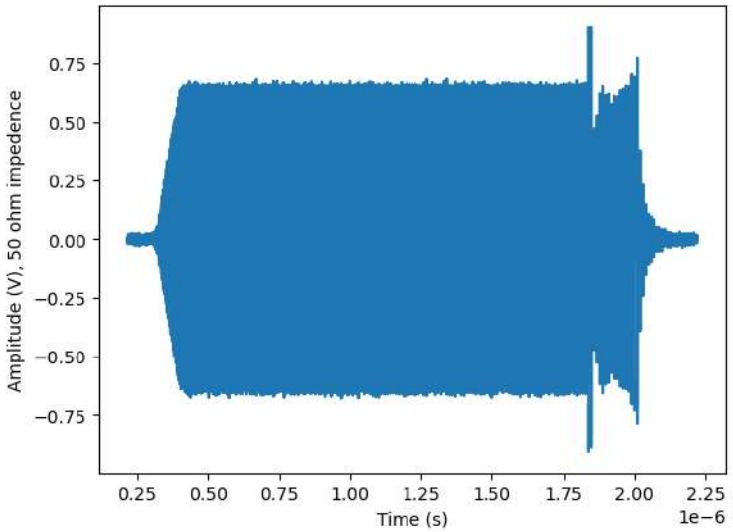
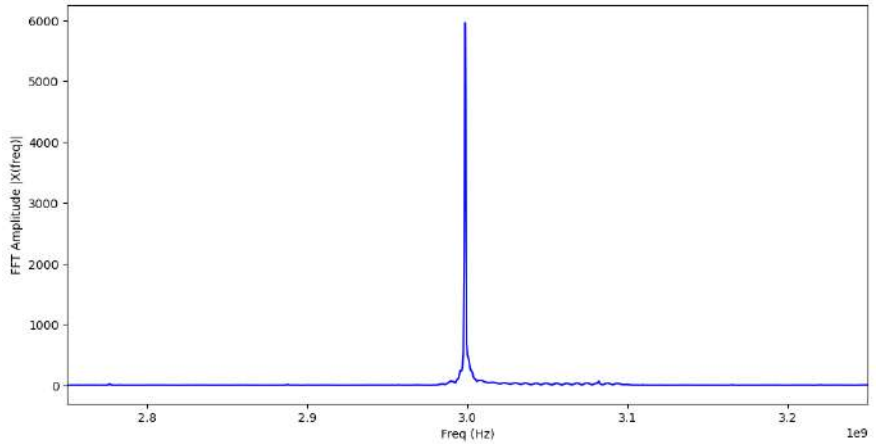
Libera: phase flip



Analysing the output of the Libera VM with the chosen pulse design:

- Amplitude envelope and phase look good
- Time domain characteristics need further understanding – what is the amplitude spike at the phase flip?
- Frequency analysis of pulse shows no unwanted sidebands





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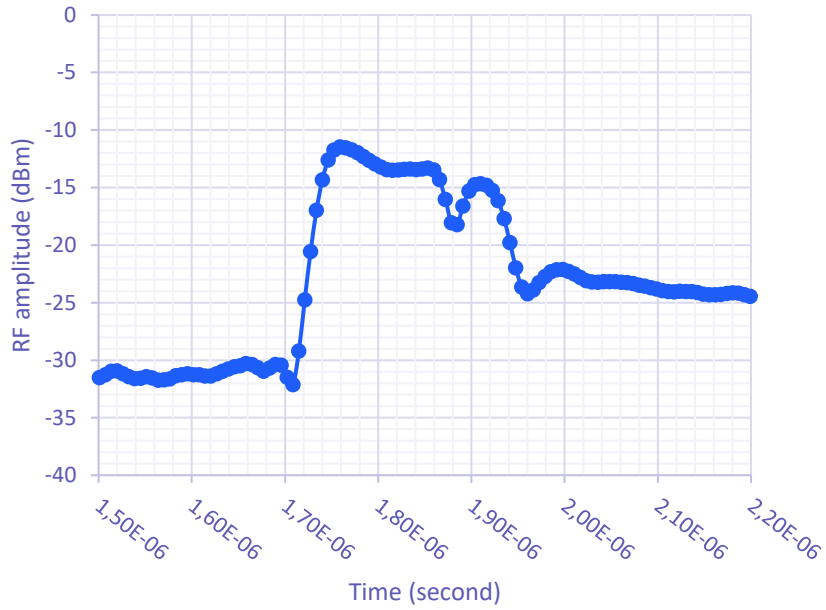
What's next?

- We have not engaged with i-tech to collaborate over this, but are interested
  - More flexible pulse-shaping features
  - Increased sample rate for both VM and ADC
- Complete system tests with pulse compressor at low power
  - We have some initial data which is promising but points to further optimisation of the pulse shape
- Additional gain stage after down-conversion to S-band
  - Will allow us to use the full scale of Libera inputs, but additional noise implications need to be considered carefully
- Investigate use of analogue phase shifter (piezo-type) on X-band output
  - In addition to using Libera VM; would allow us to use fast feedback to optimise the pulse shape



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Thank you

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