FMCW compact reflectometer and future developments using DDS signal generation

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EUROfusion

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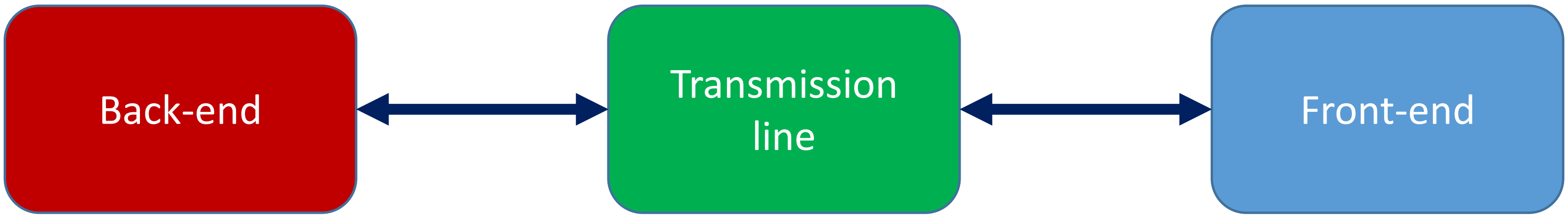
Reflectometer typical configuration



- Generate the probing signals.
- Detect the reflected signals.
- Sensitive to stray radiation.
- From tubes to solid state sources.
- From single ended to heterodyne detection.

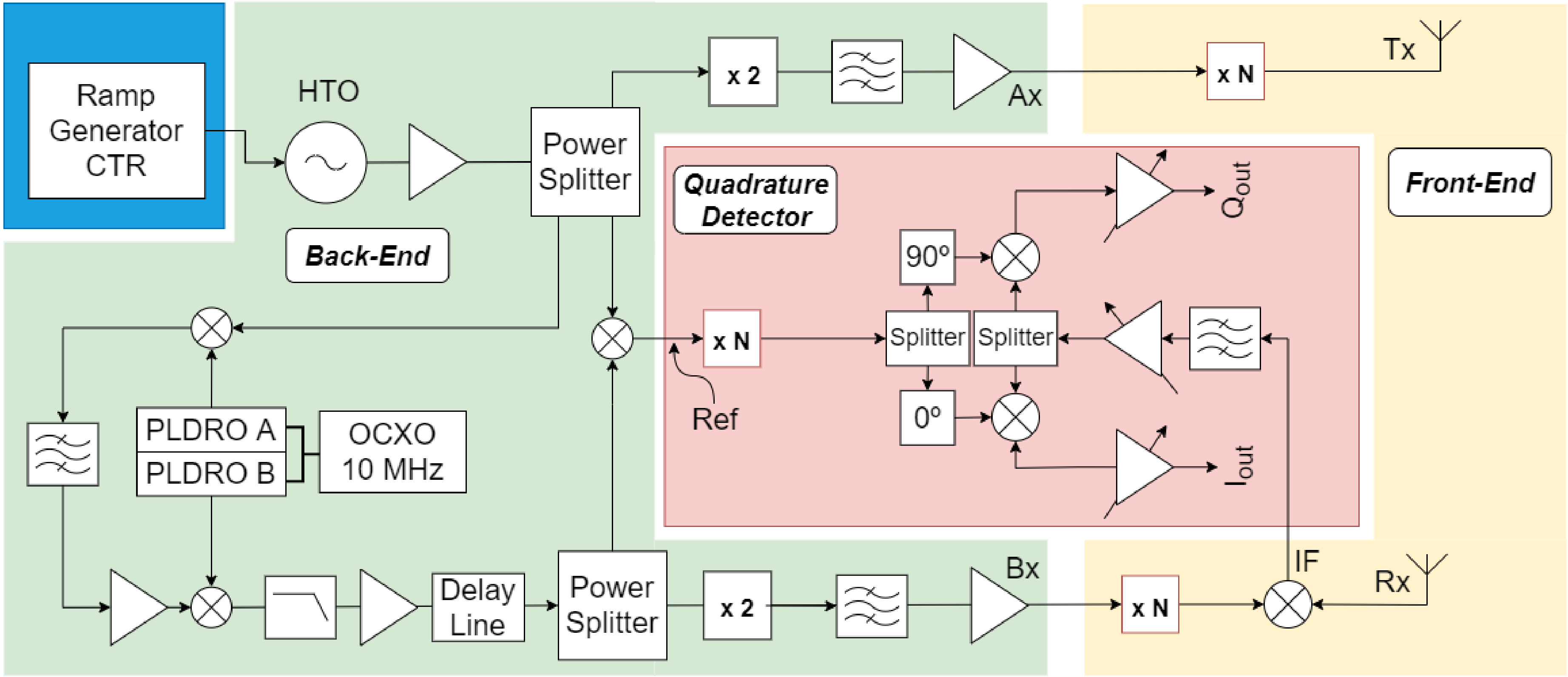
- Transmit the signals between back-end and front-end.
- Fundamental or oversized waveguides.
- Complicated routing, long lines, vacuum barriers, transition between different WG sizes.
- Low loss, large bandwidth.

- Send and receive the signals from the plasma.
- Antennas exposed to high neutron fluxes.
- Limited and non optimized plasma views.

Motivation

- Develop a compact coherent FMCW microwave reflectometer with applications in plasma diagnostics.
- Flexibility is one of the design goals for the back-end prototype, so that it can easily match the required frequency range:
  - Use commercial Monolithic Microwave Integrated Circuits (MMIC)
  - Improved stability as all components that share the same PCB.
  - Back-end covers directly 10 to 20 GHz
  - With full band frequency multipliers can be extended to 160 GHz
- For improved linearity, a key feature to guarantee high precision on an FMCW radar, analogue oscillators can be replaced by DDS generators.
- DDS benefits from the totally digital generation of the output signal, which allows full control of the signal's frequency and phase.
- Recent implementations feature automatic sweeping capability, thus allowing the DDS to generate very linear and agile frequency chirps, assuming a high quality and constant frequency reference clock source. Target sweeping time 1 µs.
- On the receiver side the IF and reference signals will be digitised allowing the use of high flexible data processing technics.

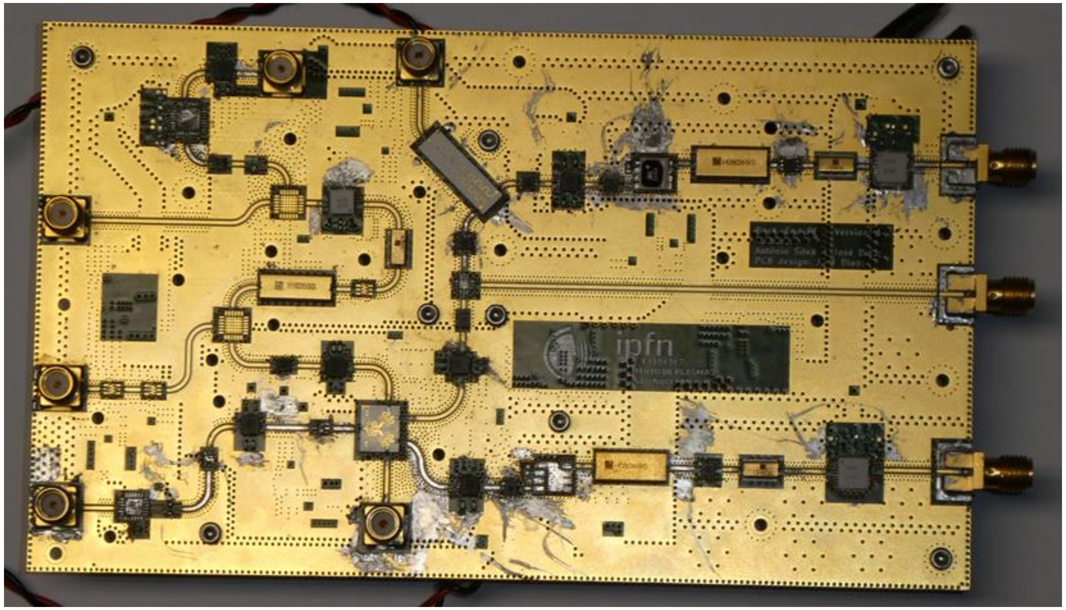
Compact reflectometer block diagram



- **Two prototype PCB boards were developed and build:**
  - ✓ **The back-end (green region)**
  - ✓ **The quadrature detector (pink region)**

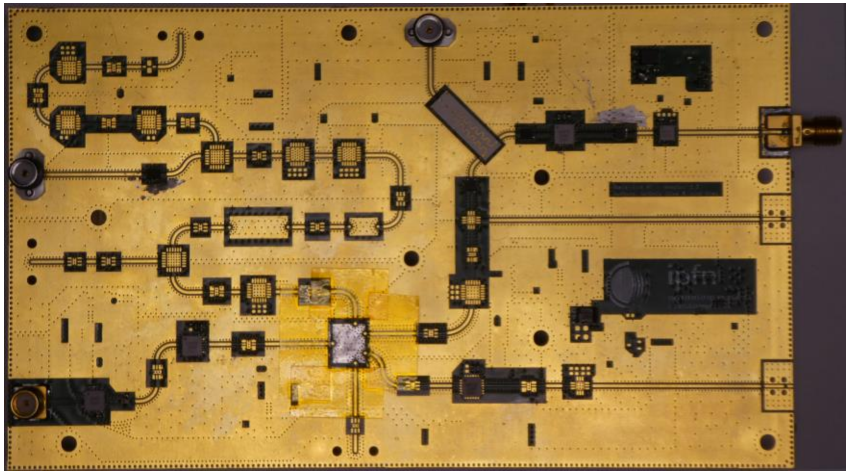
Back-end

- Using commercial MMIC', benefitting from recent telecommunications developments of RF silicon chips.
- Back-End generates the microwave signals (Ax, Bx, Ref).
- Ax is used to drive the frequency multipliers that generate the signals that probe the target.
- Bx drives the LO port of the front-end reception mixer, which receives the reflected signal (Rx) from a target, producing the IF signal.
- The IF signal contains the phase delay information that results from the propagation path to the target.
- The Bx is a coherent signal derived from Ax, however it is frequency translated.
- The frequency difference between the signal Ax and Bx is called a Coherent Reference (Ref).



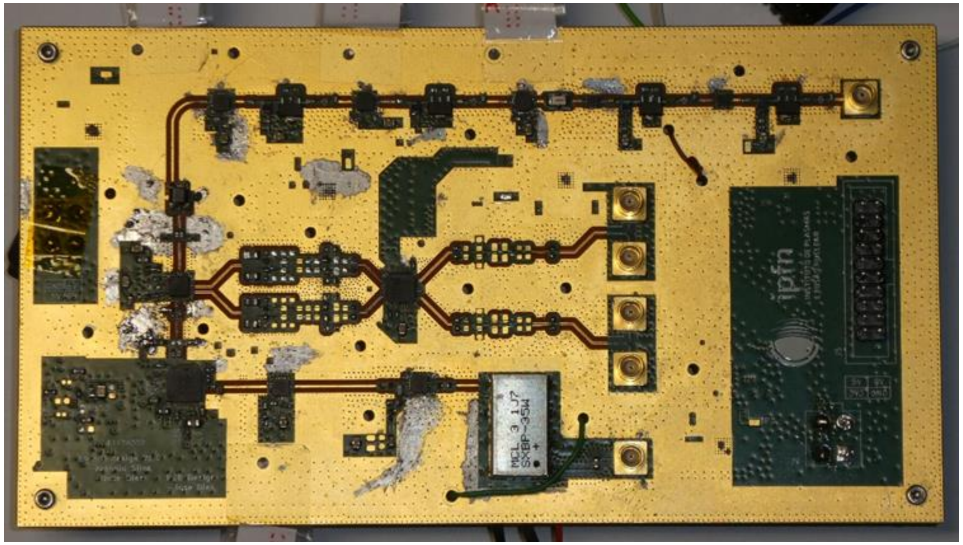
Back-end testing

- The back-end prototype can generate full band signals exciding 8 dBm, enough to drive external multipliers.
- Harmonics were too high, > -15 dBc at specific frequency ranges due to the amplifier chain’s saturation.
- The insertion of inline attenuators reduced the harmonics, now never exciding -20 dBc.
- The board layout was corrected and a new prototype was produced.



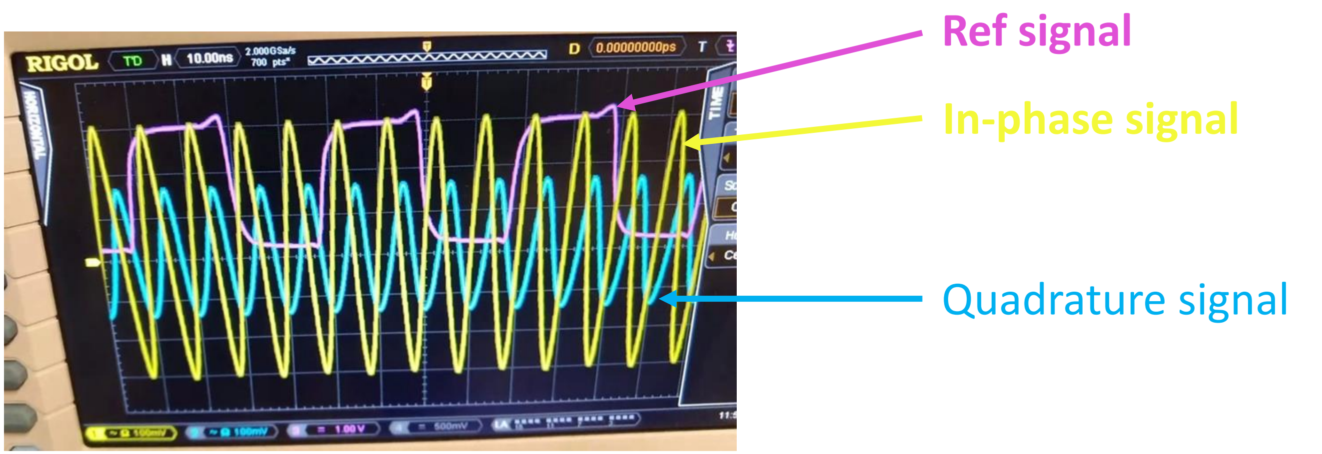
Quadrature Detector board

- The Quadrature Detector Board has the functionality of demodulate the IF signal to extract the targets phase delay.
- The IF frequency depends on the external multipliers present on the Front-End, it is therefore necessary to program the on-board Ref signal multiplier, to match the required carrier.



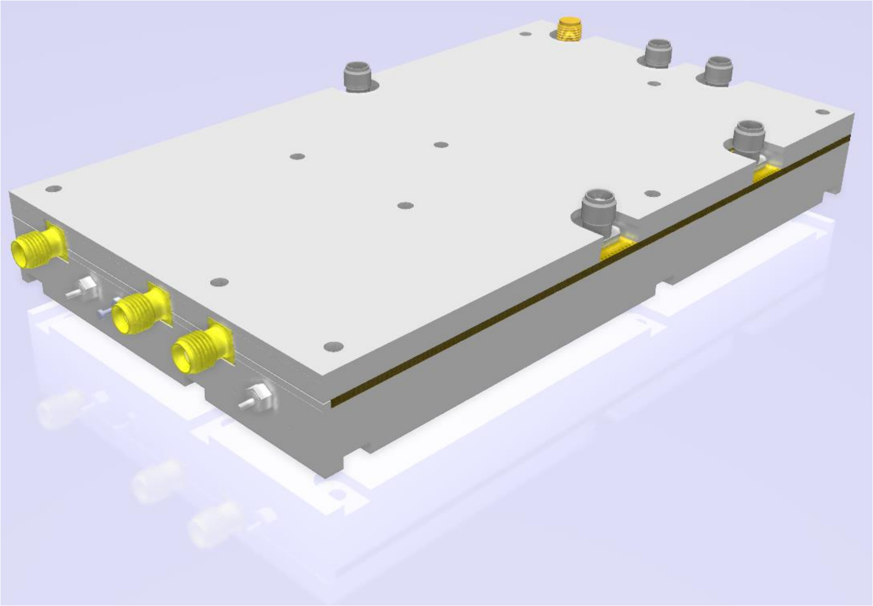
Quadrature detection board testing

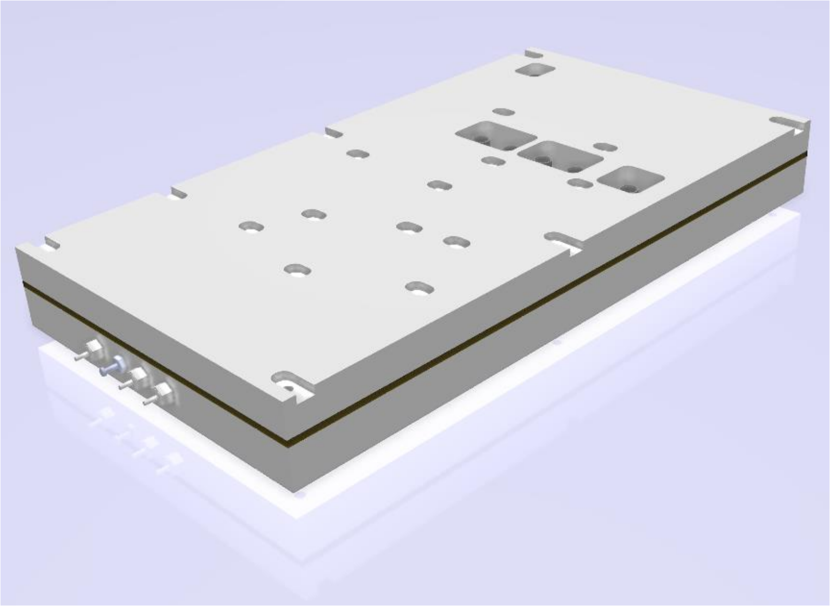
- The variable gain amplifiers, the Phased-Lock Loop (PLL) to control the Ref multiplier block and the variable gain amplifier with the filtering capabilities for the IQ signals were tested.
- The Ref multiplier block was able to produce all necessary frequencies, from 50 to 2000 MHz.
- The IF signal can range from -20 dBm to -120 dBm.
- The demodulation tests were only conducted in the lowest IF frequency (50, 100 MHz).



Final assembly

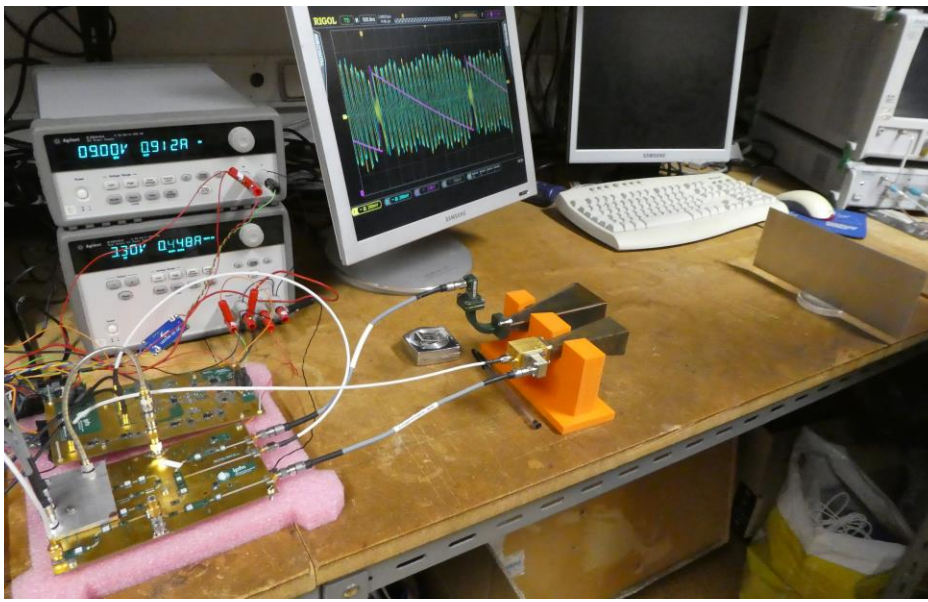
- The back-end and the IQ boards were design for an easy installation on a standard 3U 19” rack.
- Each board will include electromagnetic shielding.

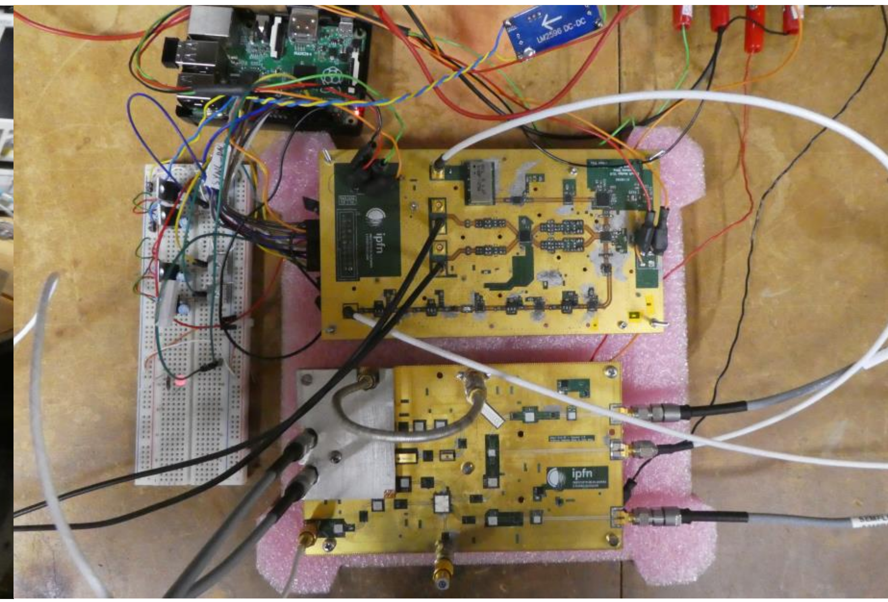




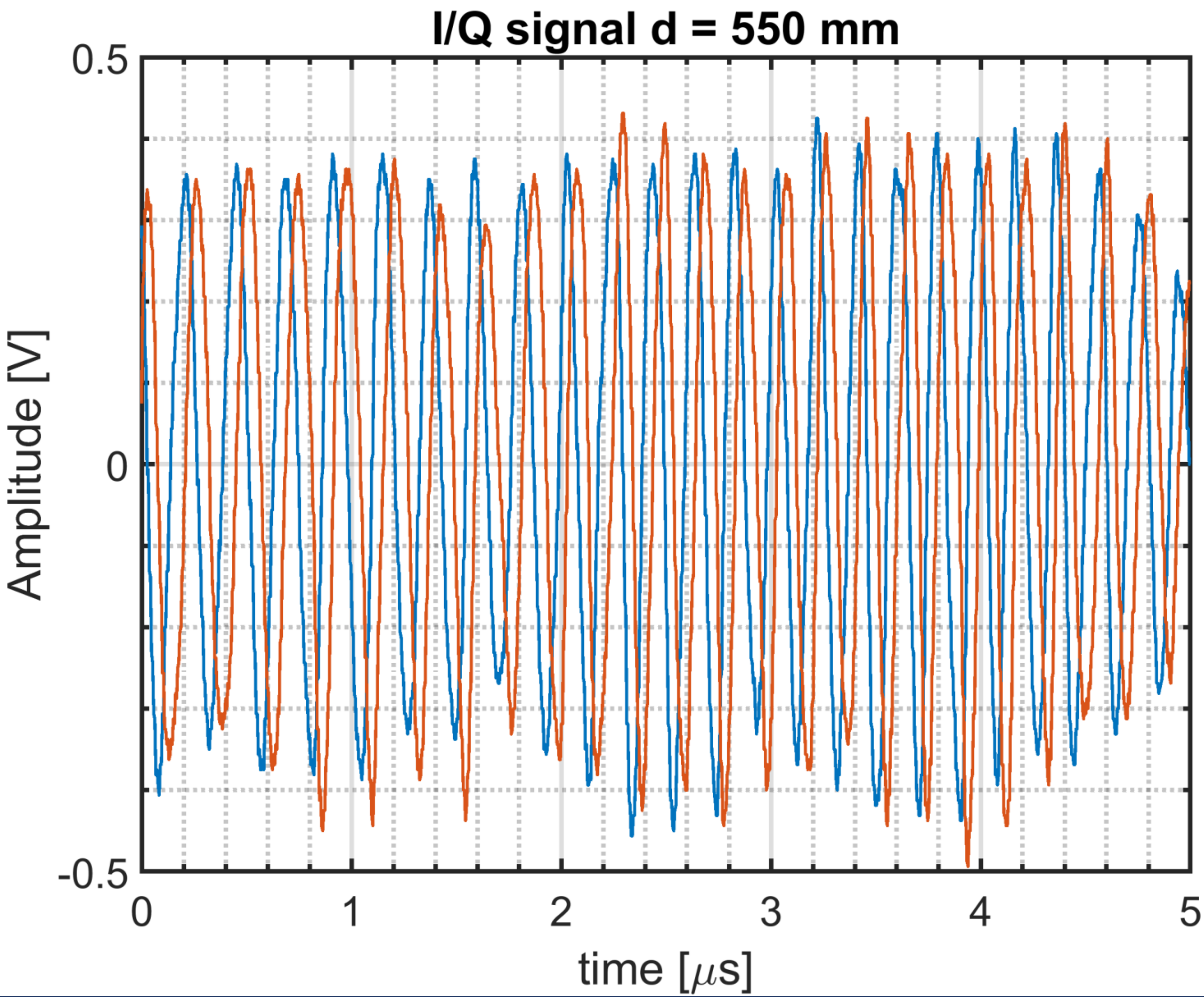
Reflectometer testing with a metallic mirror

- Bistatic setup.
- Operating frequency 15 to 20 GHz.
- Sweep rates 20 µs, 10 µs, 5 µs.
- Pre-linearization of the sweeping ramp (AWG).



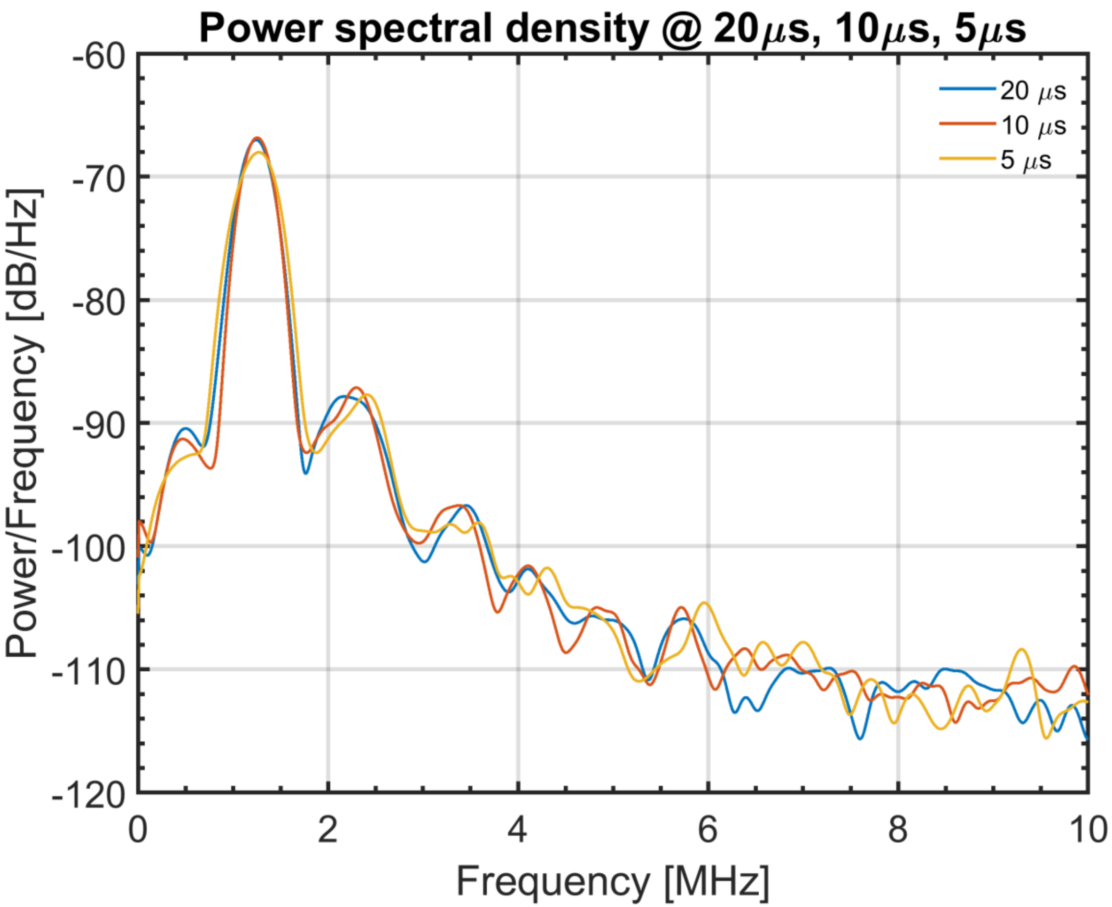


I/Q Signal



Sweep rate effects

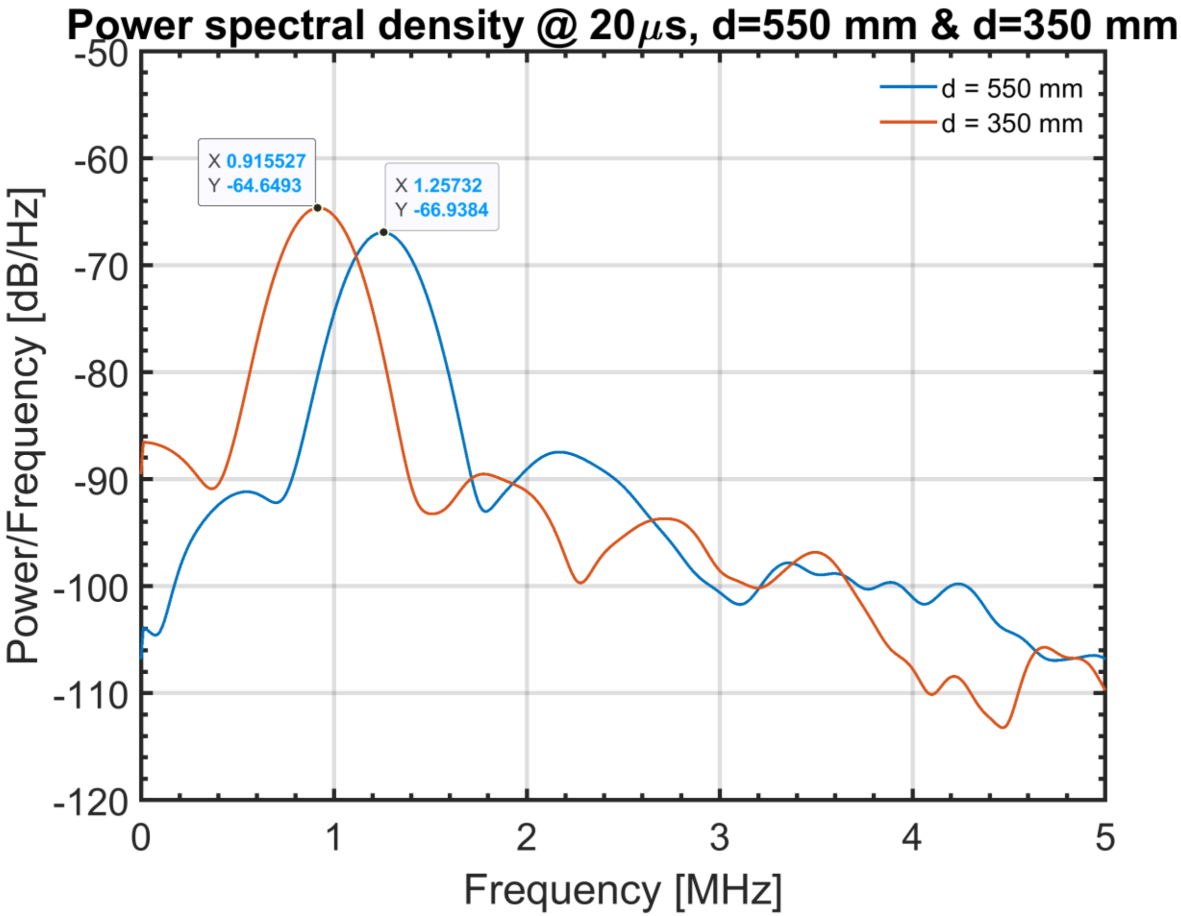
- Mirror distance 550 mm
- Sweep rate 20 µs, 10 µs, 5 µs



Accuracy

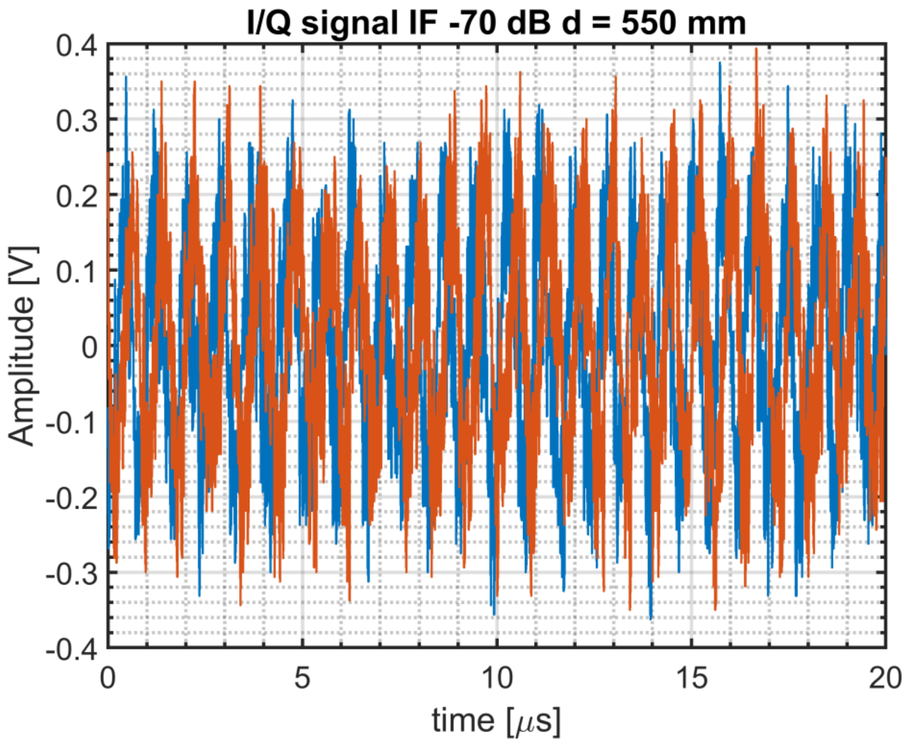
- $\tau_{tot} = \tau_\mu + \tau_{mirror}$, $\tau_\mu = 1.36\,ns$
- The accuracy for different mirror distances and sweep rates is ± 5 mm.

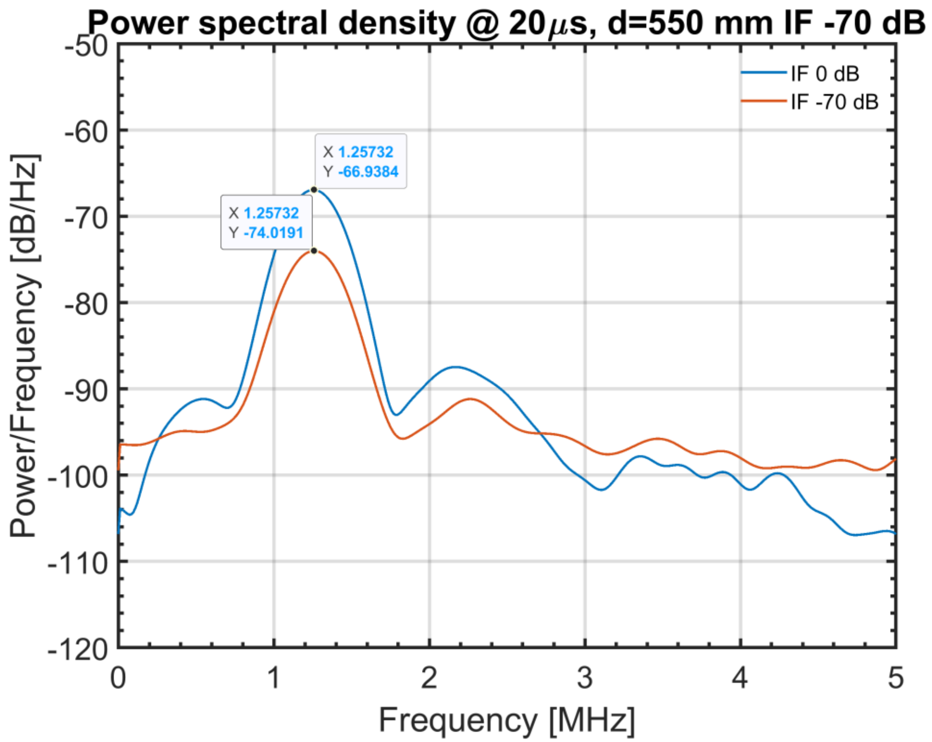
$$\Delta d = 204.9 \text{ mm}$$



IF attenuated by 70 dB

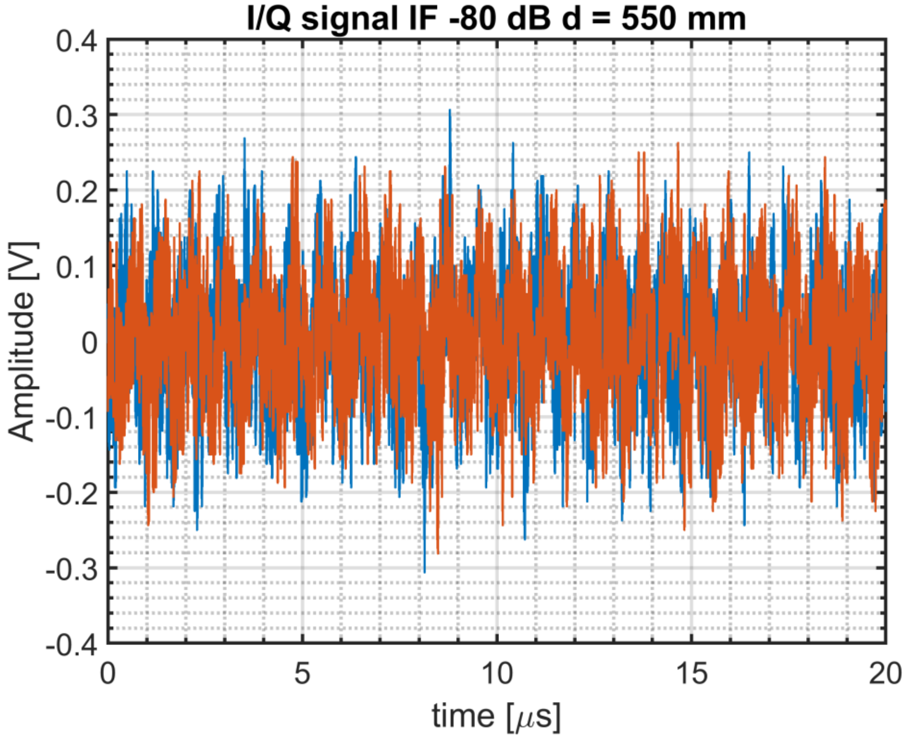
- Error of 0 mm

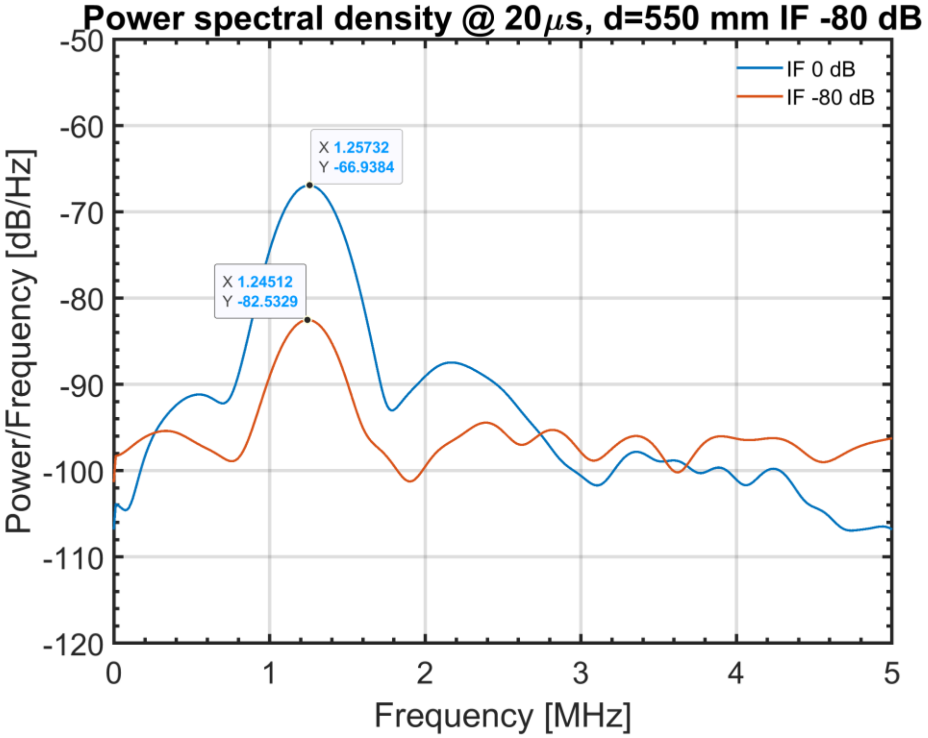




IF attenuated by 80 dB

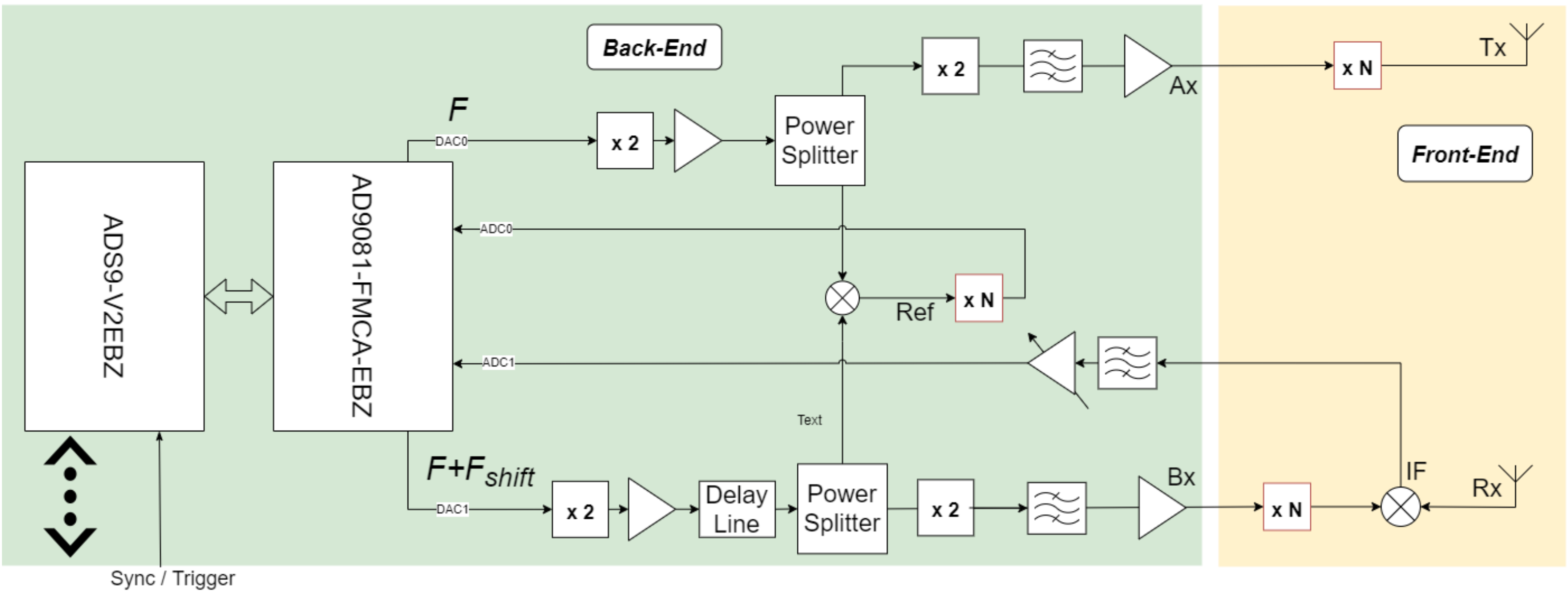
- Error of 7 mm





DDS signal generation

- The analogue oscillator will be replaced by a fast RF DAC.
- Frequency translation with PLDRO will be replaced by a second RF DAC.
- The Reference (Ref) and IF signals will be acquired by fast ADCs.
- Amplitude and phase will be numerically calculated.
- The AD9081 Demo board include 4 RF DACs (12 GSPS, analogue BW 8 GHz) and 2 fast ADCs (4 GSPS, analogue BW 7.5 GHz).
- ADS9-V2EBZ works as a data capture/transmit board. Designed to support the highest speed JESD204B/C data converters, the FPGA on the ADS9-V2EBZ acts as the data receiver for high-speed ADCs, and as the transmitter for high-speed DACs.



Conclusions

- A compact reflectometer system has been developed with possible applications on fusion plasma diagnostic, demonstrating that it possible to implement a reflectometer in a single PCB, for easy integration.
- The system was tested with a metallic mirror at different distances and the accuracy is ± 5 mm.
- The system proved to be able to cope with low-level signals.
- The use of DDS for signal generation will allow very linear and agile frequency chirps.
- Direct digitalization of the IF signals will allow the use of high flexible data processing technics.
- The DDS testing will start as soon the necessary parts are procured and purchased.