A Novel Magnetron Phase Locking Method

Introduction - Some Unique Features of Magnetron

- Magnetron is Cross field RF oscillator
  - High power (kW~ MW), high frequency(1GHz ~10GHz, or higher), high efficiency (~80%).
  - Compact size, simple in design and construction.
  - Cheap RF source, $7000 for NLM915 L-band 915MHz industrial magnetron, 100kW CW output power.
  - Application areas: RF heating, medical linac, RF power transmission, radar, communication systems.
  - Difficult to be phase locked.
- Can we use magnetron as accelerator RF source? – We need to synchronize magnetron oscillation with an RF reference.
- Even radar and communication systems require some control over frequency, phase and noise emitted by the source.

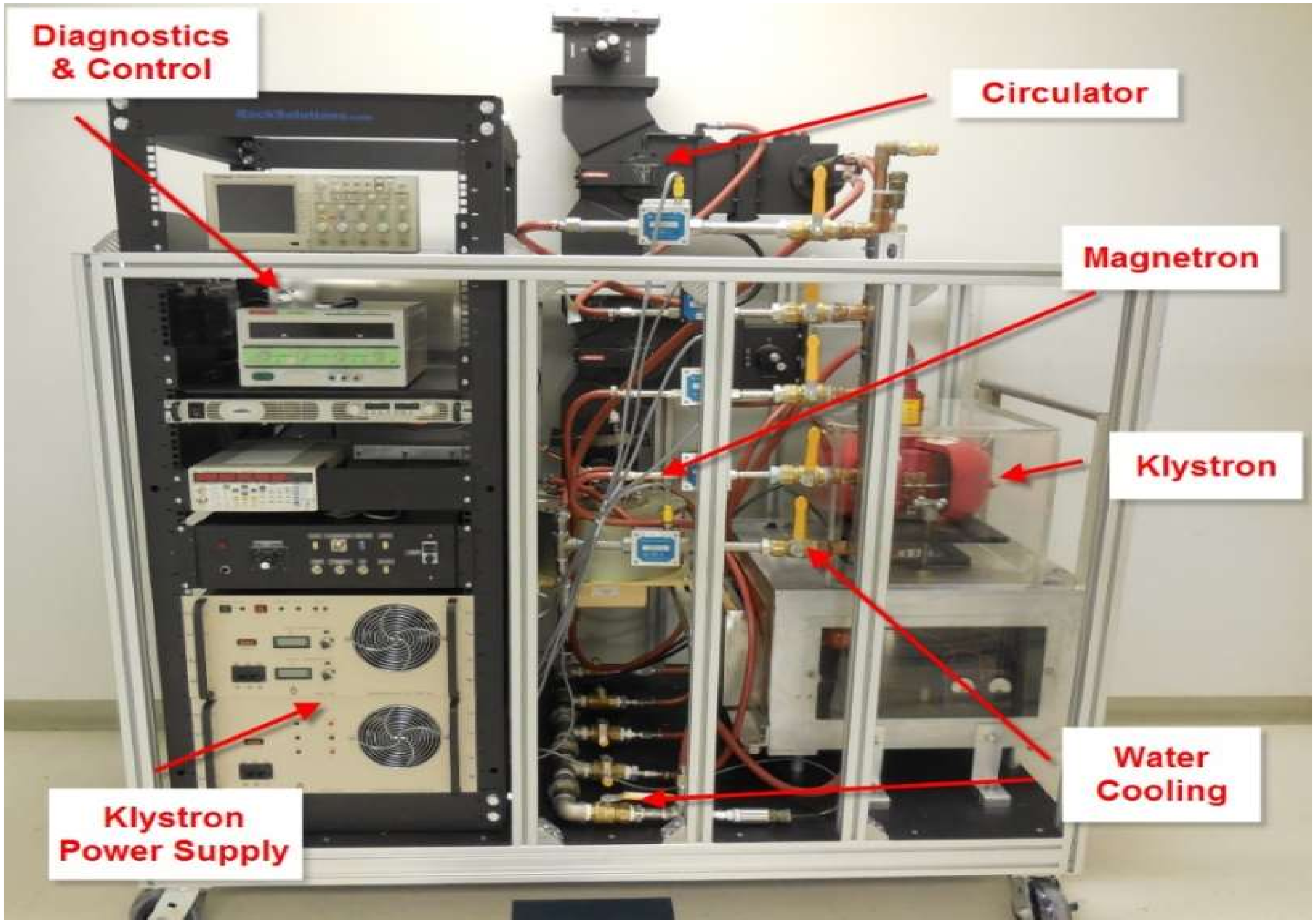
Current Status of Magnetron Phase Locking

- There are a few publications on magnetron phase locking. Authors includes researchers from Fermi Lab, Jefferson Lab, Lancaster university, etc.

- One popular way is to inject RF signal into magnetron through its RF output port to lock the magnetron oscillation to a reference.
  - The method involves another RF tube, e.g., a TWT, or a solid state amplifier to lock the magnetron;
  - The locking signal generator must be protected from the magnetron output power by a circulator.
  - The ability of the magnetron to follow sudden changes in injected frequency or phase is proportional to the injected power level.
  - The total range of frequency locking is also dependent on the injected power.
  - The overall system is complicated, expensive and less efficient.

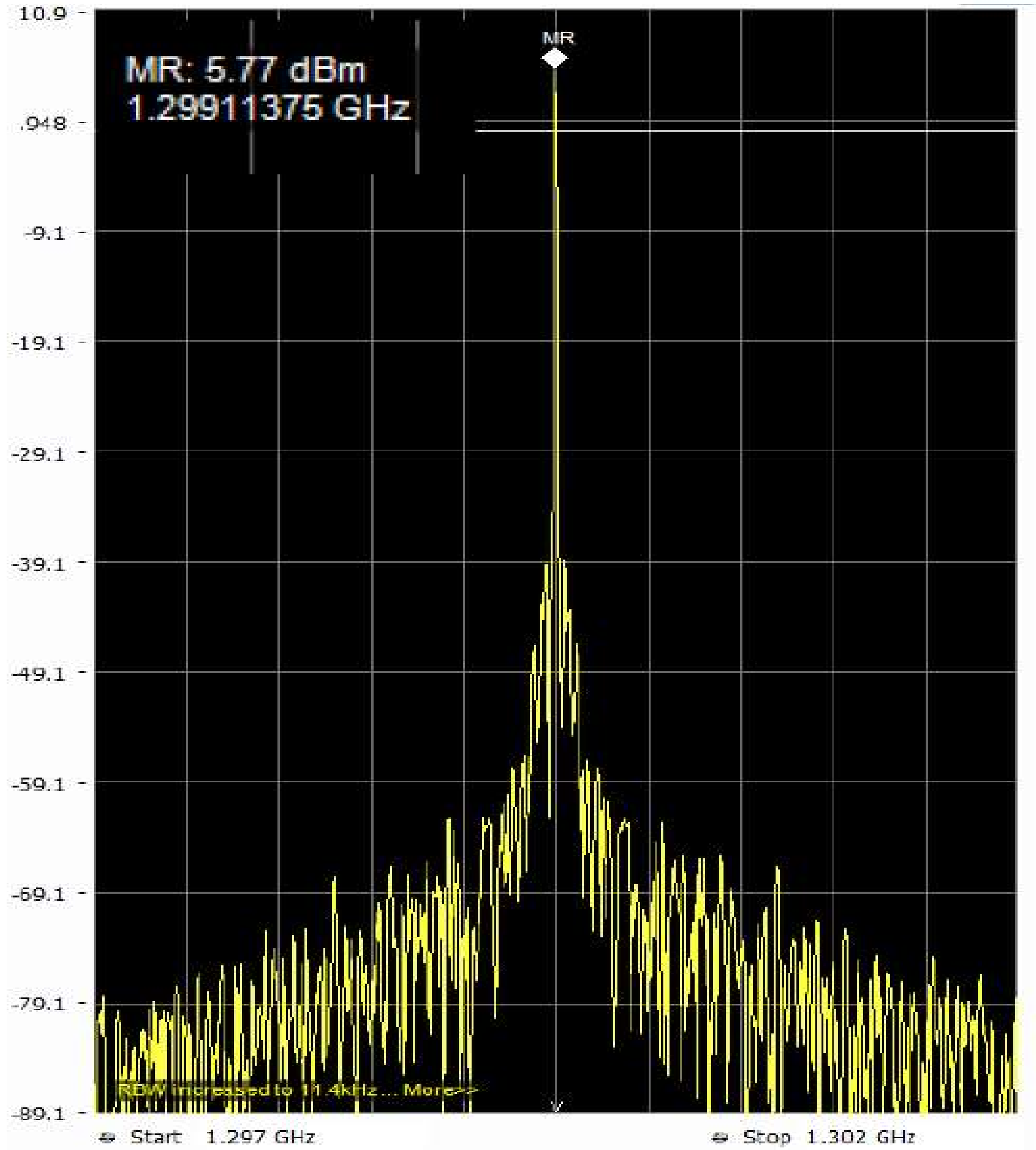
- Fermi Lab and Calabaza Creek Research developed a phase locked, 100kW peak, 10 kW average 1.3 GHz magnetron-based RF system for driving accelerators.

Calabaza Creek Research & Fermi Lab 1.3GHz Magnetron RF System



[Ref]: M. Read, B. Chase, "A100kW 1.3GHz Phase Locked Magnetron for Accelerators", 2018 IEEE International Vacuum Electronics Conference (IVEC)

Calabaza Creek Research & Fermi Lab 1.3GHz Magnetron RF System



Need 300Watts to drive 100kW!

Fig. Spectrum of the magnetron with a drive power -24.8dB below the magnetron power at the natural frequency of the magnetron

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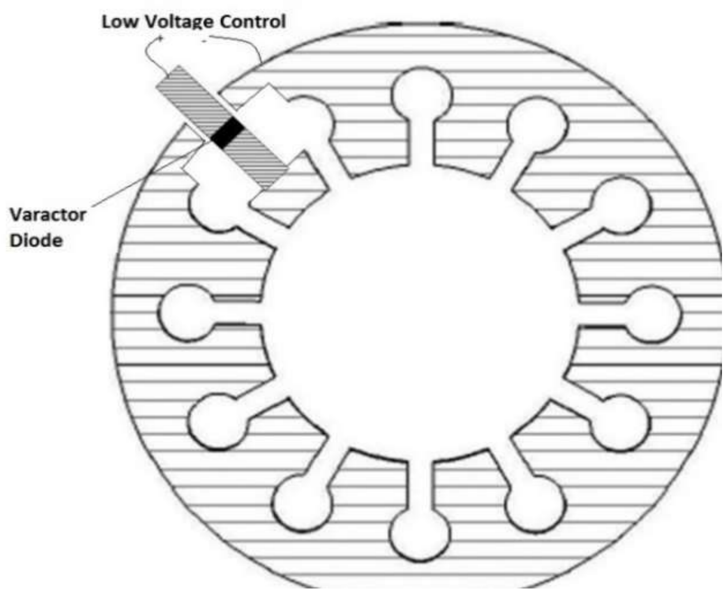
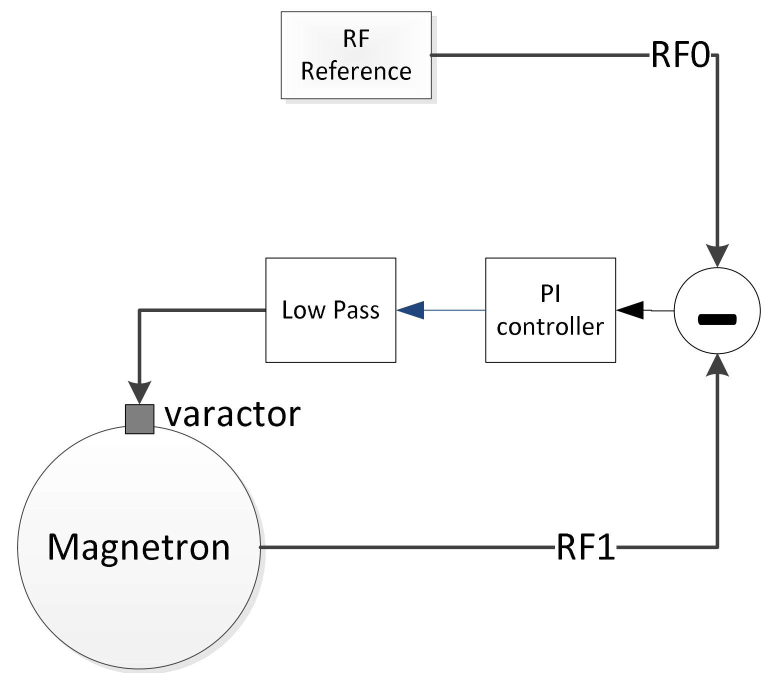
A novel Magnetron Phase Locking Method

- Use varactor diode to tune magnetron oscillation frequency.
- Feed back loop to lock magnetron oscillation to RF reference.
- Want to know magnetron phase noise measured from 10Hz to MHz. – didn’t find any from existing publications.

Algorithm of Magnetron Phase locking with a Varactor Diode



Tune magnetron oscillation by varactor



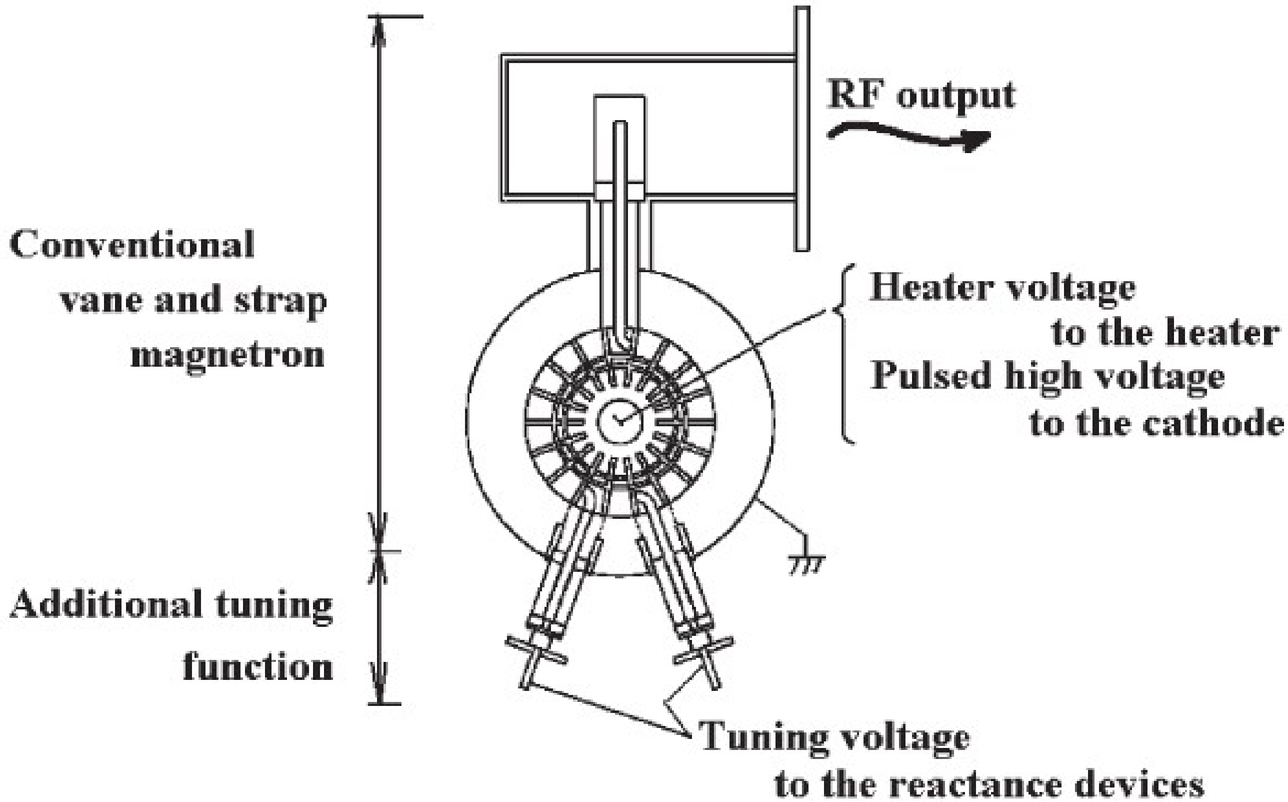
Lock magnetron oscillation to RF reference by phase lock loop

- This method is based on two established technologies.
  - Tuning of the magnetron frequency by introducing a capacitance from a varactor;
  - A laser-RF synchronization control system developed by SLAC.

Lock Magnetron Frequency/Phase with a Varactor Diode

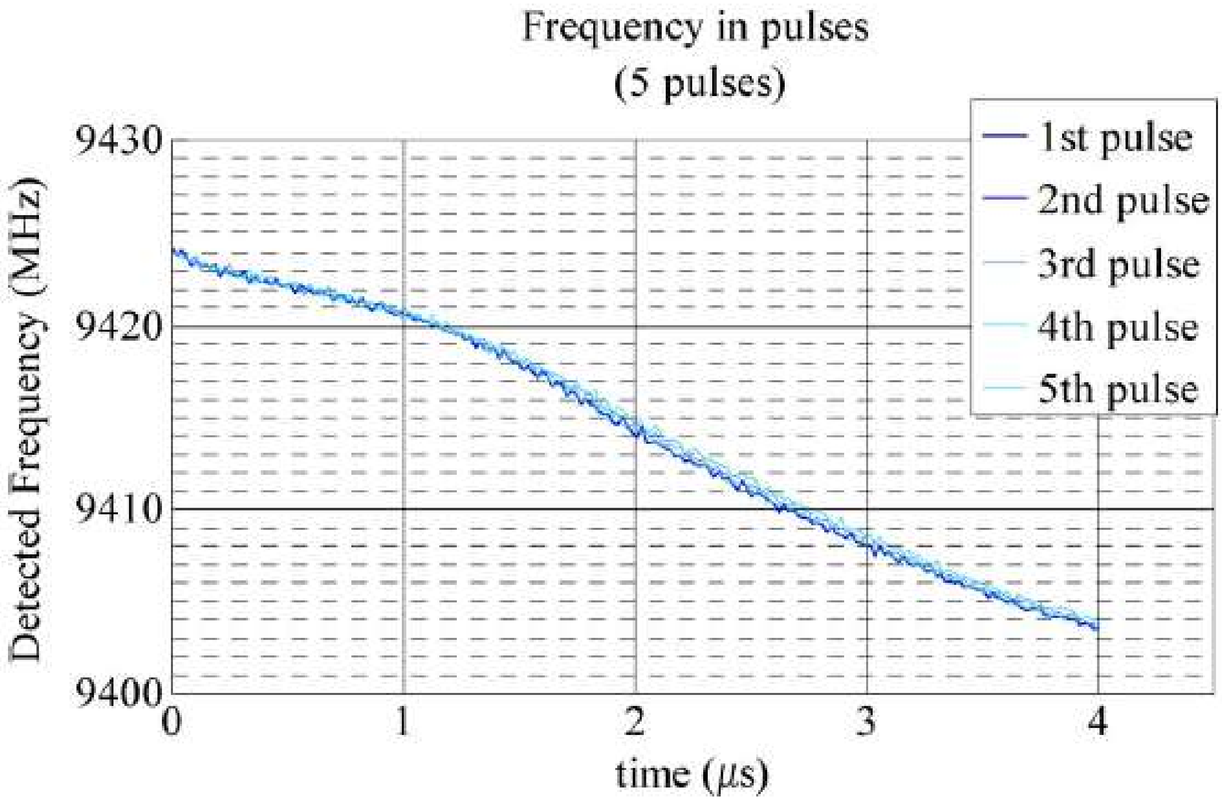
- In laser phase control system, we use Piezo actuator to tune laser cavity length therefore tune the laser pulse rep rate. Can we do the same to magnetron as we did for laser?
- Insert reactance component into magnetron resonance structure, turn magnetron into a voltage controlled oscillator.
- Varactor diode has a much faster tuning speed than Piezo actuators, therefore magnetron phase lock loop should achieve a much larger bandwidth and lower phase noise. Compared to injection locking method.
- Find varactors that can stand high RF frequency, high RF power.
- Investigate tuning configuration that provides the control required within the power loading capability of the diodes.
- Simple overall hardware system, no RF power is required to lock magnetron oscillation, no circulator required. Dramatic reduction in size, weight and power efficiency.
- Use existing ATCA based laser locker control system.

Publication on X Band Pulsed Magnetron Frequency Tuning with Varactor Diode



[Ref]. H. Obata, "Electronic-Frequency-Tuning Magnetron", IEEE Transactions on Electron Devices, Vol. 59, No. 11, November 2012.

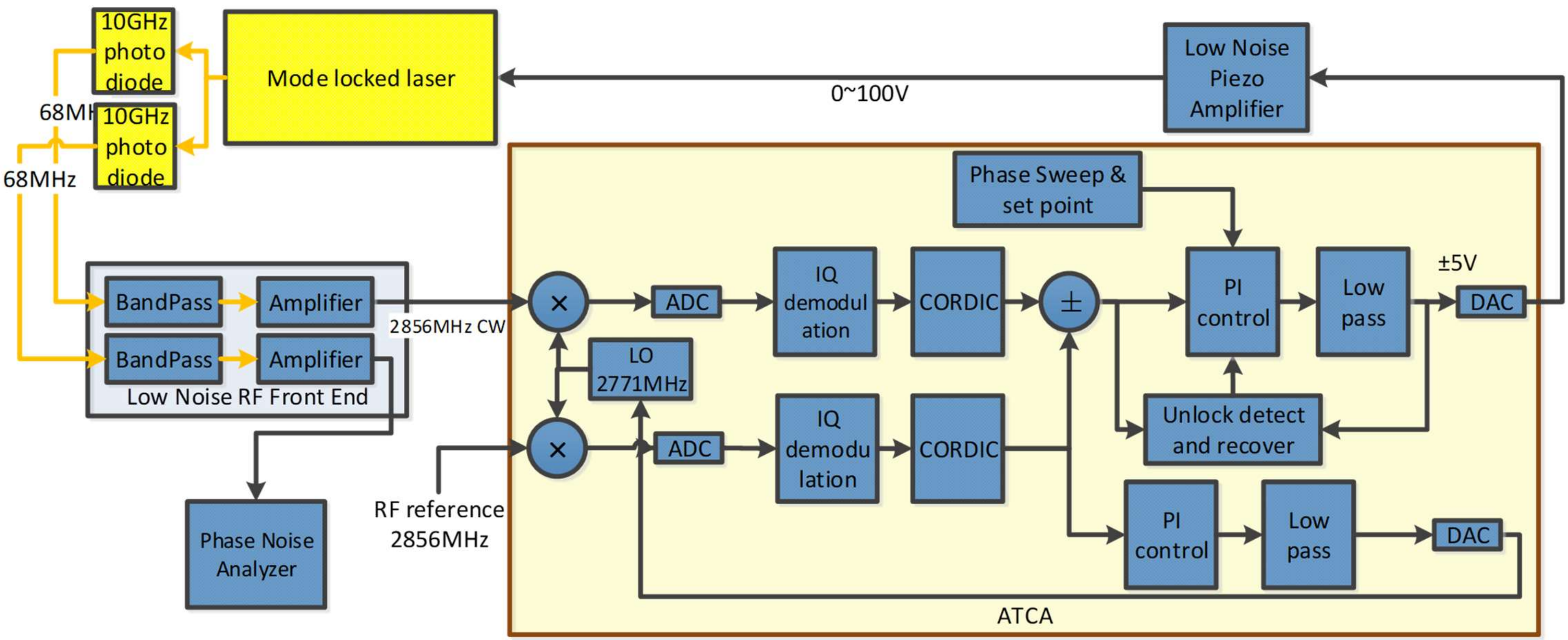
Publication on X Band Pulsed Magnetron Frequency Tuning with Varactor Diode - continued



Frequency Shifts 21MHz during 4us pulse length; Peak output power 12kW, duty cycle 0.001.

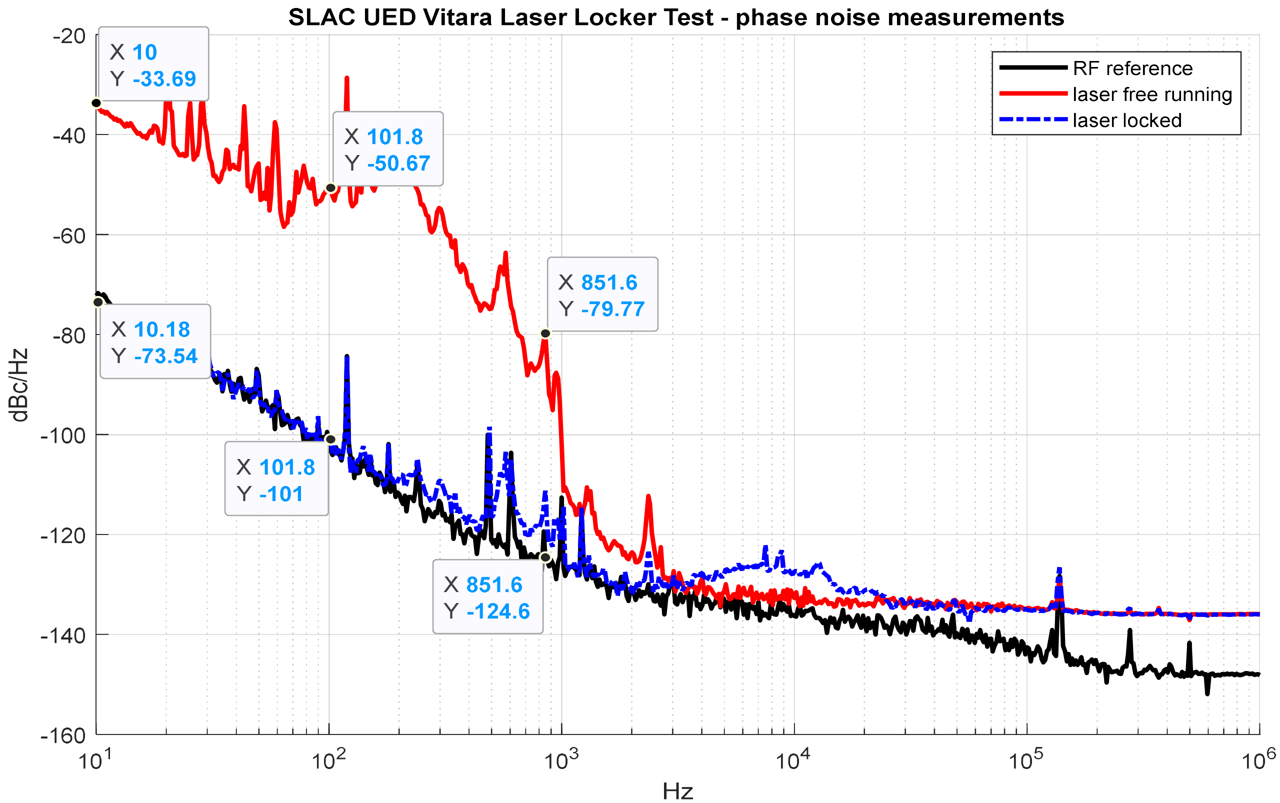
[Ref]. H. Obata, "Electronic-Frequency-Tuning Magnetron", IEEE Transactions on Electron Devices, Vol. 59, No. 11, November 2012.

SLAC Femtosecond Laser Locker System



ATCA based Femtosecond laser timing synchronization algorithm

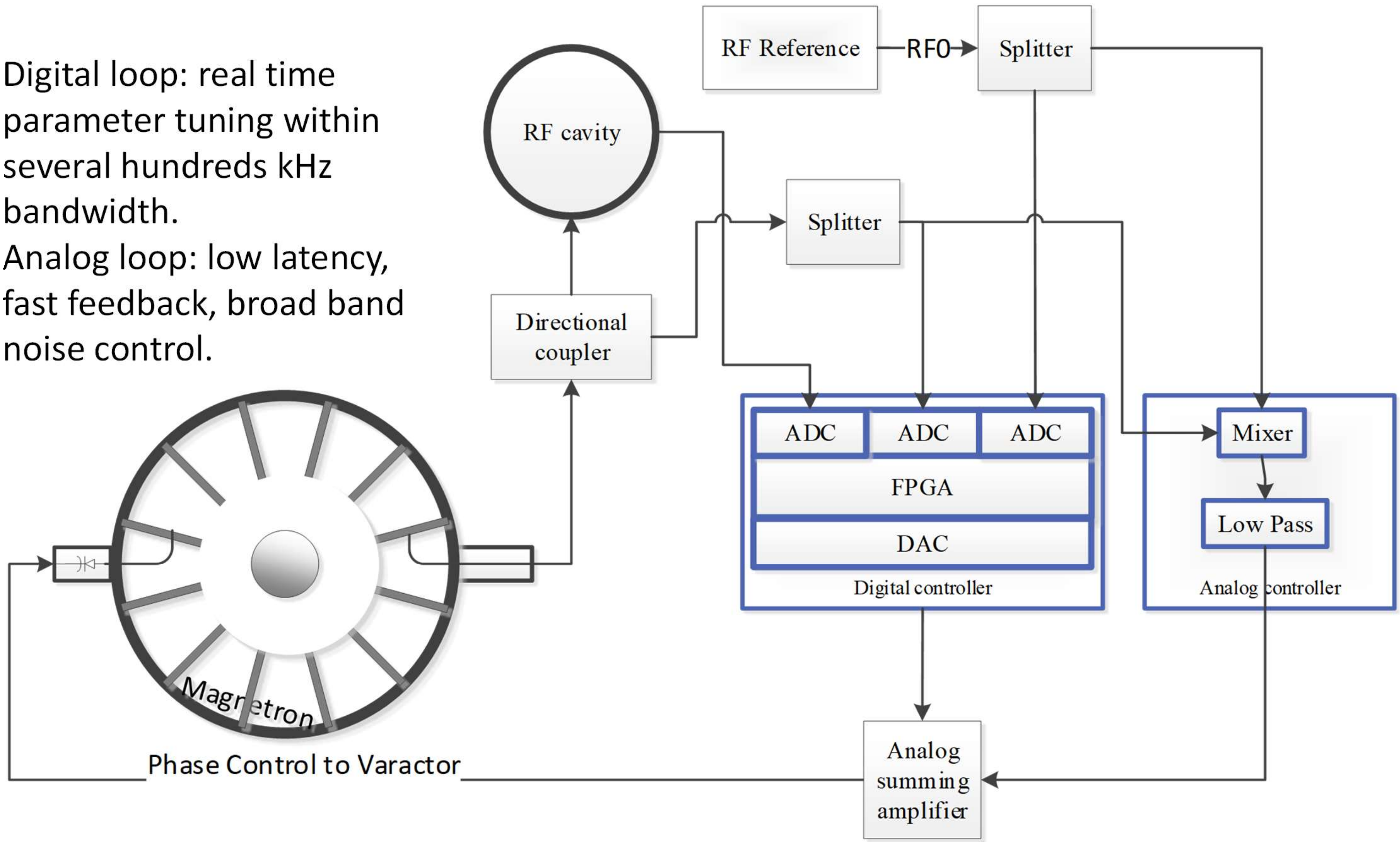
Phase Noise Measurements of UED Laser Oscillator



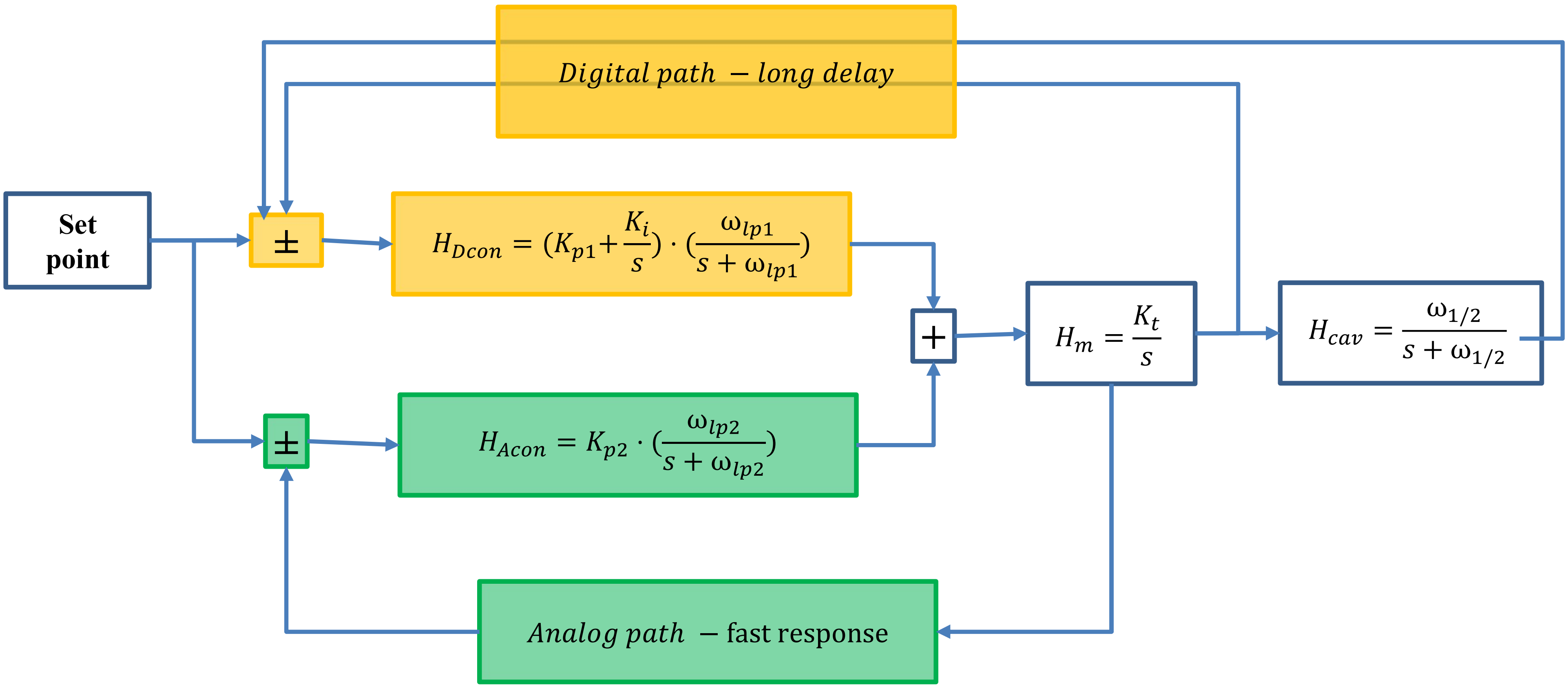
Red: free running laser phase noise; blue: closed loop laser phase noise; black: phase noise of RF reference.

LLRF Algorithm of Magnetron Driven RF System – Hybrid of Analog and Digital Loop

- Digital loop: real time parameter tuning within several hundreds kHz bandwidth.
- Analog loop: low latency, fast feedback, broad band noise control.



LLRF Algorithm of Magnetron Driven RF System – Hybrid of Analog and Digital Loop



$$H_{tot} = (H_{Dcon} + H_{Acon}) \cdot H_m \cdot H_{cav}$$

Current Status

- Have first applied for LDRD funding last year.
- Now submitted proposal to Navy STTR 2020 together with Calabaza Creek Research.

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