Design of RF Controls for Precision CW SRF Light Sources

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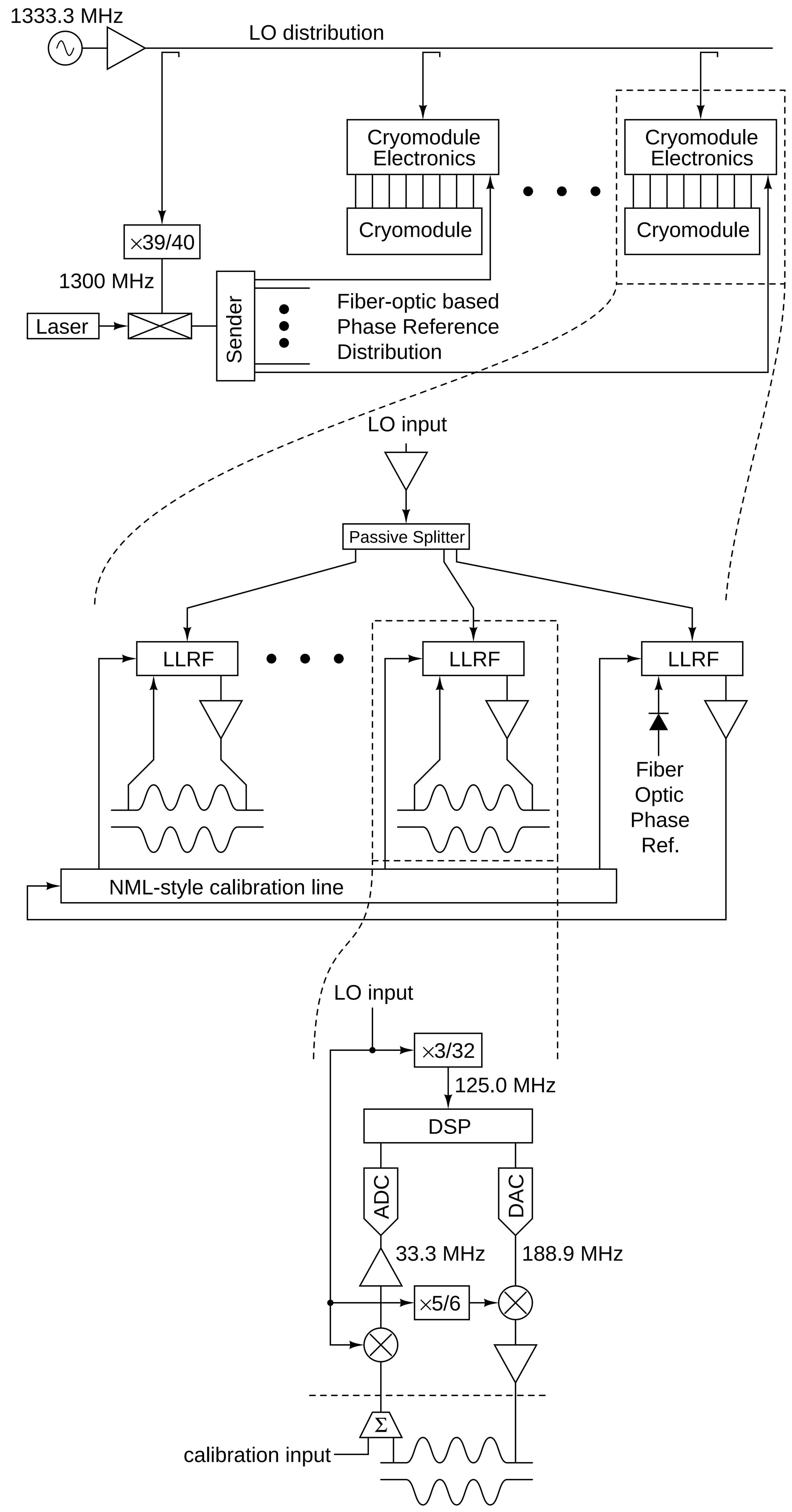
Abstract

A hierarchical and modular RF system is proposed to meet the stringent precision and stability needs of upcoming SRF linac-based light sources. It combines modern digital controls with proven techniques for phase and timing distribution, and eliminates artificial jitter caused by incoherent clocks. It is designed for systems with one cavity per RF source, as is normally chosen to give good operability for high-Q_L SRF cavities with occasional unpredictable performance limits. Particular attention is paid to system integration issues.

Hierarchy

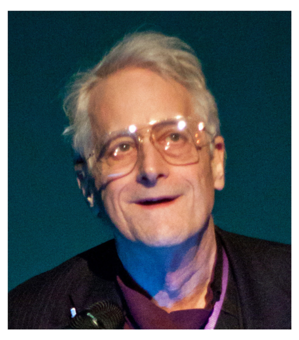


Local Feedback Latency Accounting

50 ns	input analog BPF
60 ns	ADC pipe (7.5 cycles at 125 MHz)
180 ns	DSP, including PI control (22 cycles at 125 MHz)
530 ns	bandpass filter in DSP (300 kHz)
70 ns	notch filter in DSP (800 kHz for TTF $8\pi/9$ mode)
100 ns	compute amplitude with CORDIC (12 cycles at 125 MHz)
100 ns	PWM generation (dual 2.6 MHz)
280 ns	class S modulator analog
100 ns	high-power RF cavity filter (1.6 MHz bandwidth)
50 ns	cables and waveguides
80 ns	contingency
1600 ns	total

Philosophy

I am a design chauvinist. I believe that good design is magical and not to be lightly tinkered with. The difference between a great design and a lousy one is in the meshing of the thousand details that either fit or don't, and the spirit of the passionate intellect that has tied them together, or tried. That's why programming (or buying software) on the basis of "lists of features" is a doomed and misguided effort. The features can be thrown together, as in a garbage can, or carefully laid together and interwoven in elegant unification, as in APL, or the Forth language, or the game of chess.



–Ted Nelson

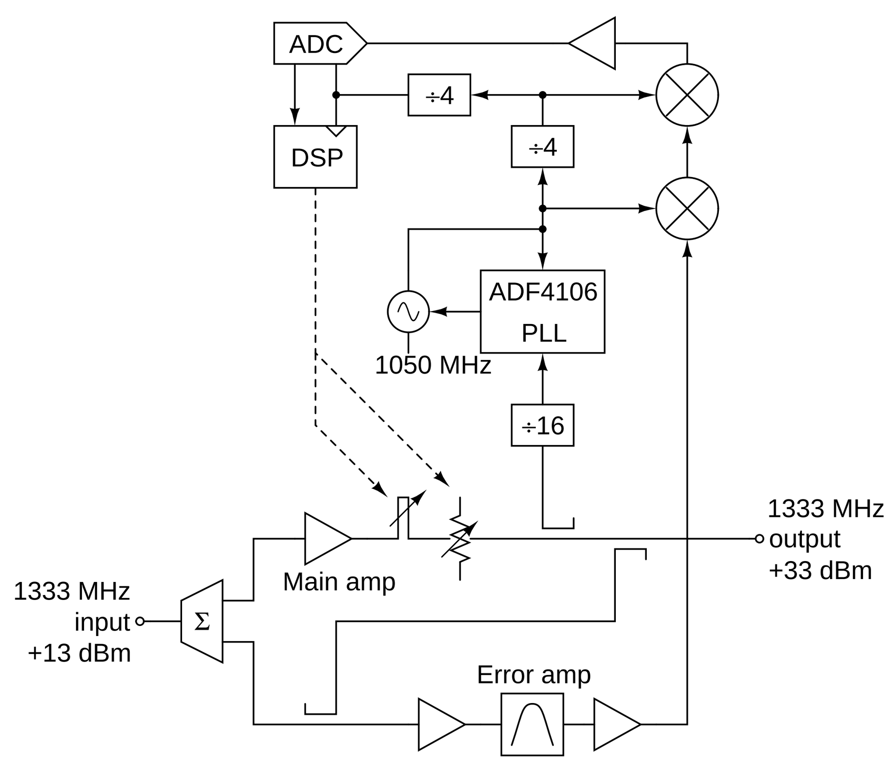
Component Technology

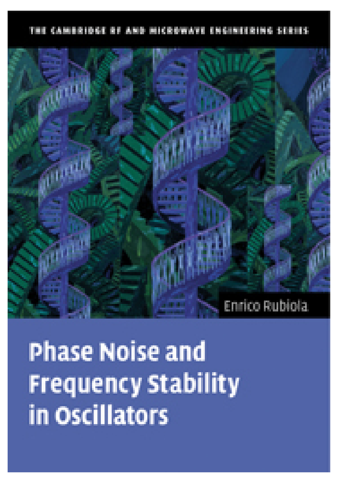
Key enabling technologies to hold -155 dBc/Hz across the site, state reproducible across power cycles, minimizing drift and $1/f$ noise

- Modern "16-bit" ADCs for 33 MHz IF
- Split-LO design to avoid measurements corrupted by IF drive signals
- Optical interferometer on phase reference: ~10 fs stability over 500 m
- NML-style drift-compensated line over ~12 m modules
- Distortion Compensating Gateware
- RF interferometer-based LO distribution amplifiers
- Direct LLRF control of SRF piezoelectric tuner
- White Rabbit: ~0.1 ns absolute syntonization over 500 m

Enables and reduces workload on final beam-based feedback based on fiber-optic communication.

Minimizing Additive Noise in LO Distribution Amp





Rubiola, 2008

$1/f$ noise much better understood than it used to be!

White noise is easy, just keep signal level - Noise Figure > -15 dBm

Per-cavity hardware