Online identification algorithm for mathematical model of RF cavity system based on FPGA

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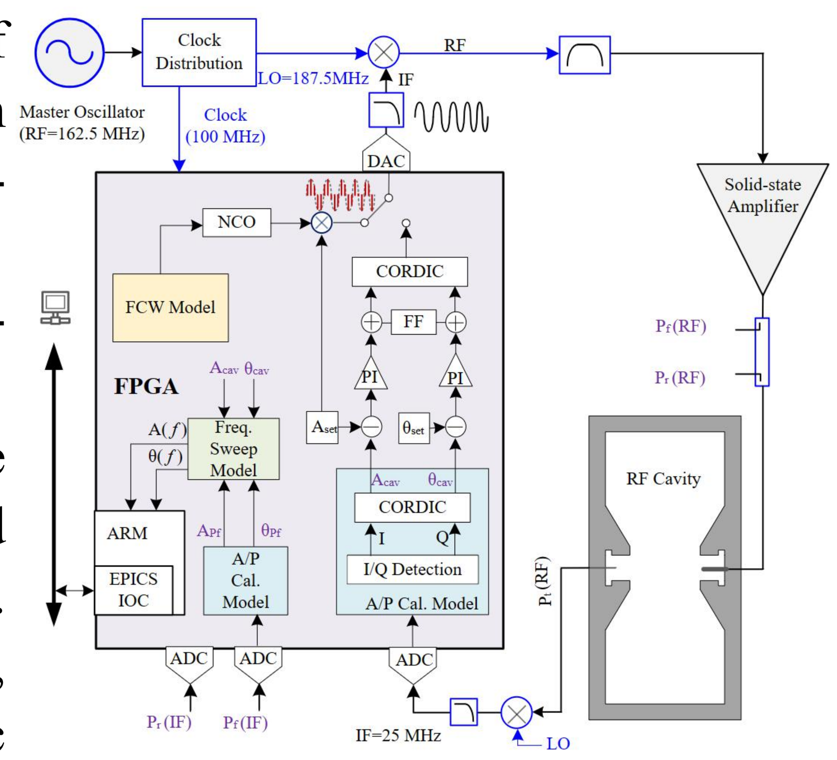
Abstract

The mathematical model of a RF system incorporates crucial characteristic parameters of the RF cavity, including cavity bandwidth, resonant frequency, and LFD factors. This mathematical model is crucial for cavity performance evaluation and optimization of control algorithms. The network analyzer is usually used for measuring the scattering parameters of the RF system and subsequently constructing mathematical models. However, its measurement steps are tedious and fail to identifythe system model online. Therefore, we have developed a sweeping algorithm in the LLRF system. This sweeping algorithm simulates the operational principles of a network analyzer, which can achieve the cavity system model online identification. The sweeping algorithm has been verified on a superconducting cavity of the CAFe accelerators. The measurement result using the proposed sweeping algorithm is in accordance with those obtained via a network analyzer. Furthermore, this algorithm successfully measures the distortion curve of cavity frequency response caused by Lorentz force detuning. Finally, we discuss the influence of LFD variation on the measurement of the critical cavity parameters.

1. Introduction

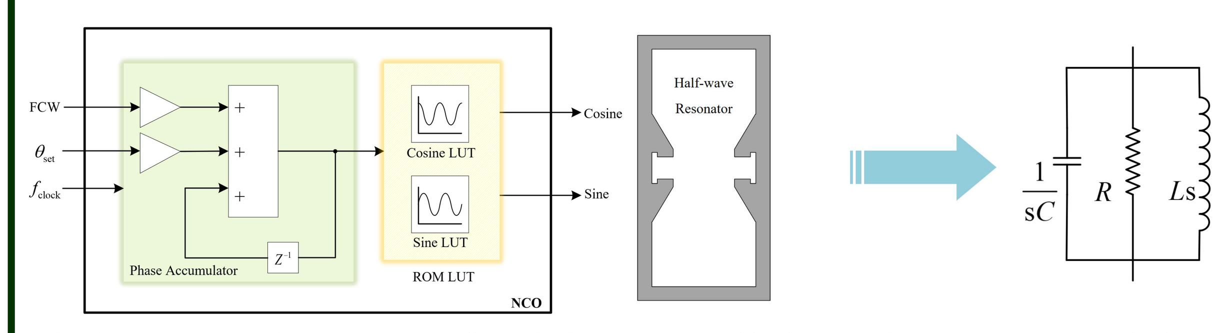
The Chinese ADS front-end demo (CAFe) linac is a supercond-ucting radio frequency linac, 23 HWRs were installed in its superconducting section. The mathematical model of the superconducting RF cavity system is essential for the measurement, design, and optimization of the RF system. The mathematical model of the RF cavity system contains many key parameters of the SC cavity, such as cavity band-width, Lorentz force detuning coefficient, loaded quality factor, etc. Currently, network analyzers are commonly used to measure the S-parameters of RF systems in order to obtain the transfer function of RF cavities. However, this measurement method requires turning off the RF, disconnecting the cavity from other RF components, and subsequently connecting it to a network analyzer for measurement. Moreover, only one superconduct-ing cavity can be measured at a time, which is inefficient and doesn't allow for real-time automatic parameter monitoring during the operation of the superconducting cavity. This approach not only involves a cumbersome operation but also consumes a significant amount of accelerator machine time.



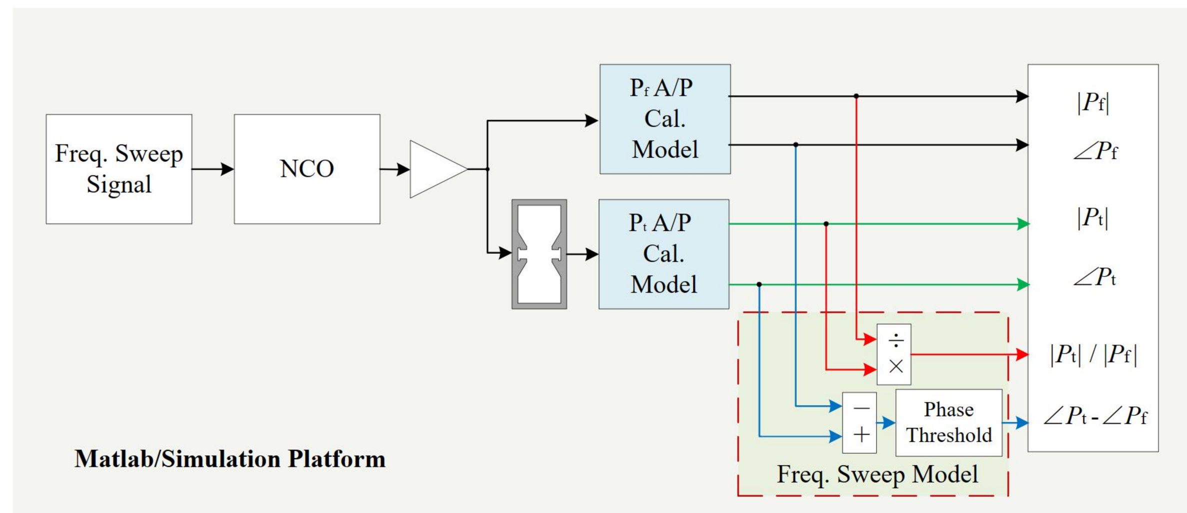
Schematic of LLRF in CAFe

We have developed an FPGA-based real-time identification algorithm. Its key components include a numerical control oscillator (NCO) and an auto-frequency sweeper. This innovative algorithm enables online measurement of the RF cavity's transfer function. This real-time algorithm can be used not only to measure the cavity model but also other RF-related models, such as the parasitic mode and mechanical mode of the multi-cell SRF cavity, as well as the mechanical mode of a piezo actuator. Thus online automatic monitoring of RF parameters during the operation of the superconducting cavity is a powerful function of the LLRF system.

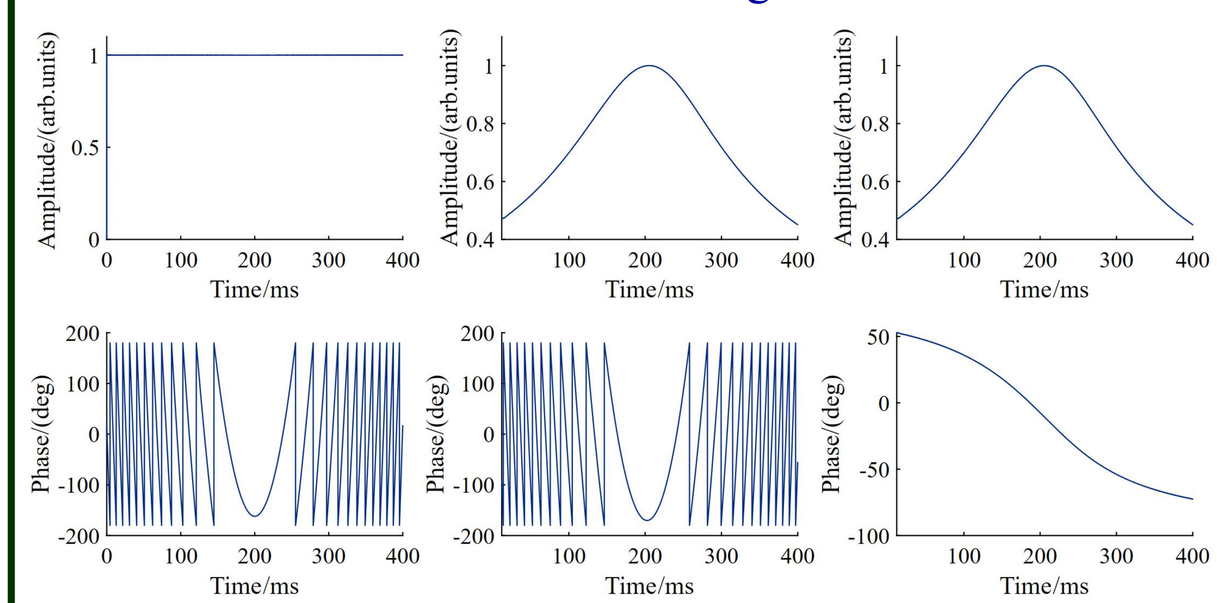
2. Simulation



Schematic diagram of NCO Parallel RLC circuit model

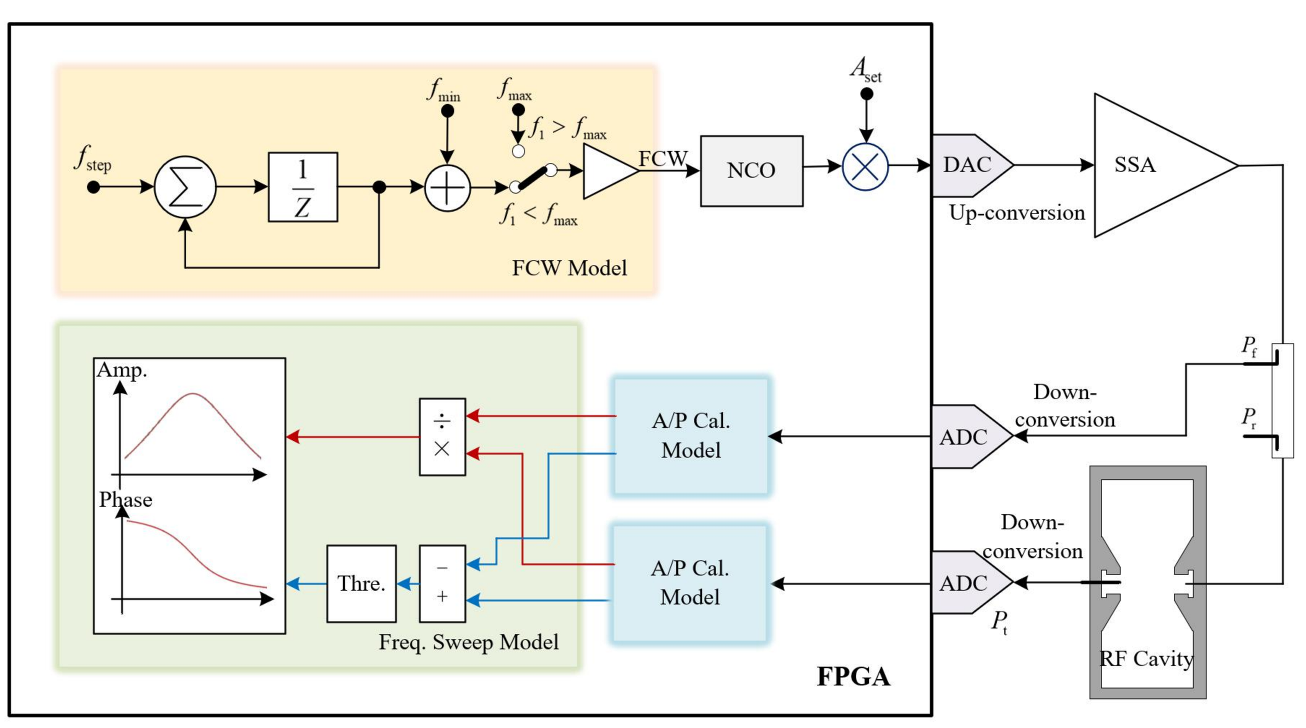


Simulation structure diagram

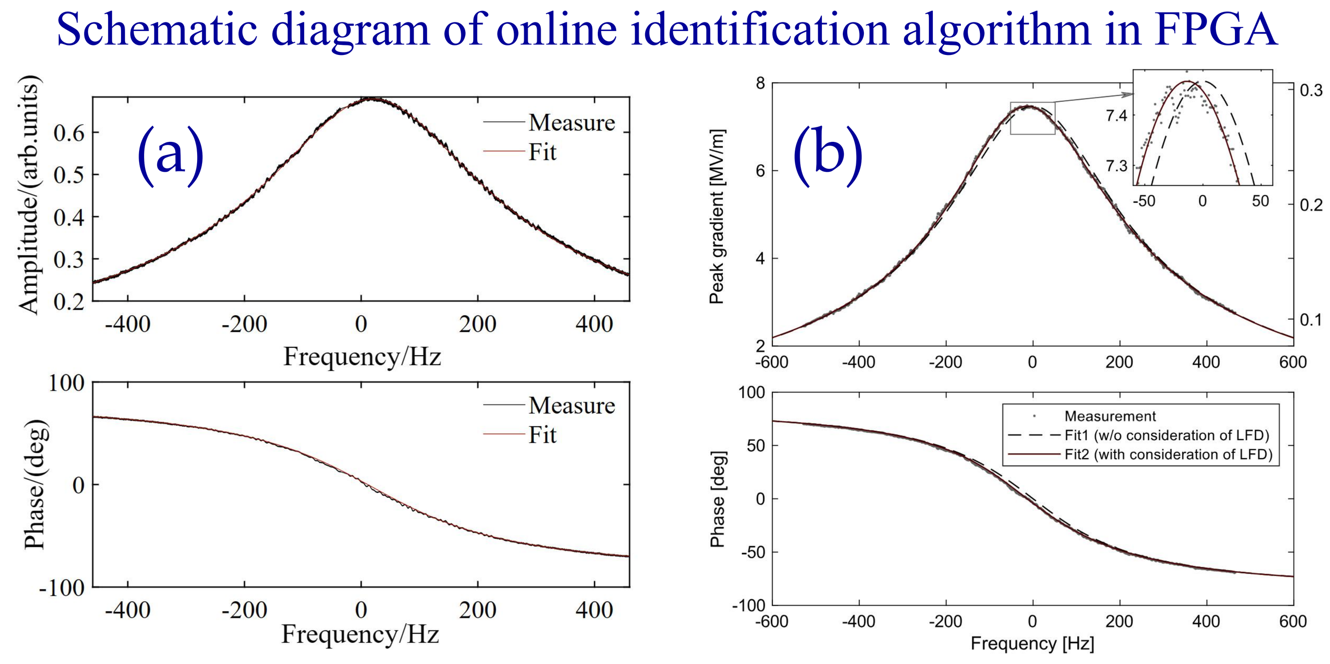


Simulation result of online identificatio algorithm

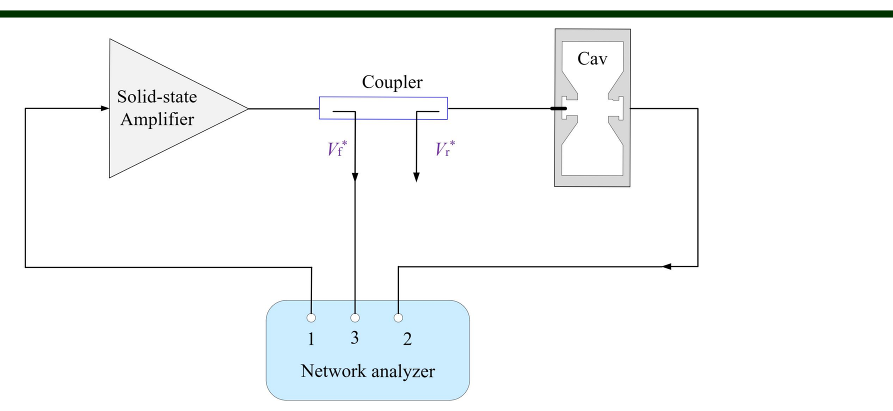
3. Online Identification



Schematic diagram of online identification algorithm in FPGA

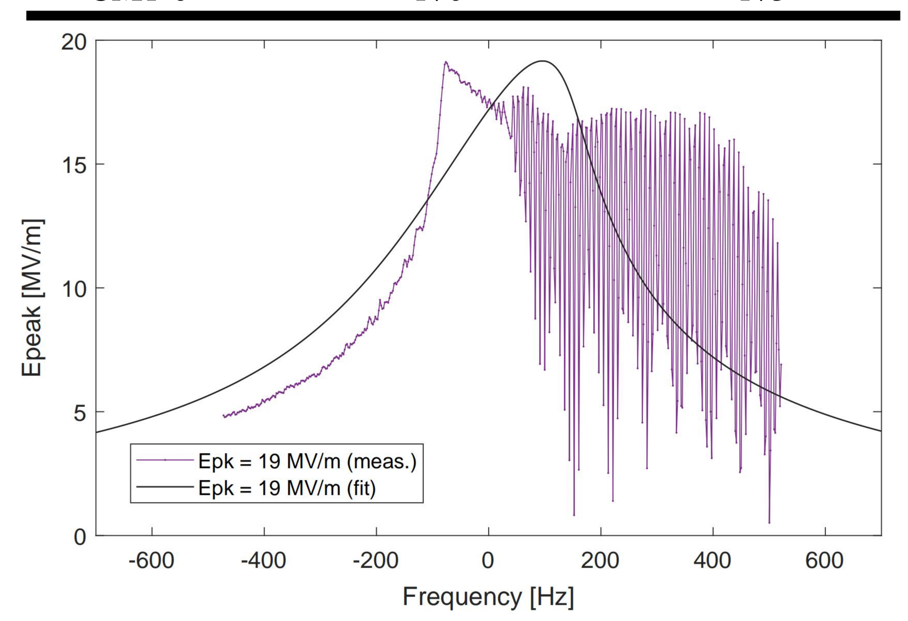


(a)-E_{peak}<3MV/m; (b)-E_{peak}=7.5MV/m
Amp. Freq. and Pha. Freq. response curves of Cavity

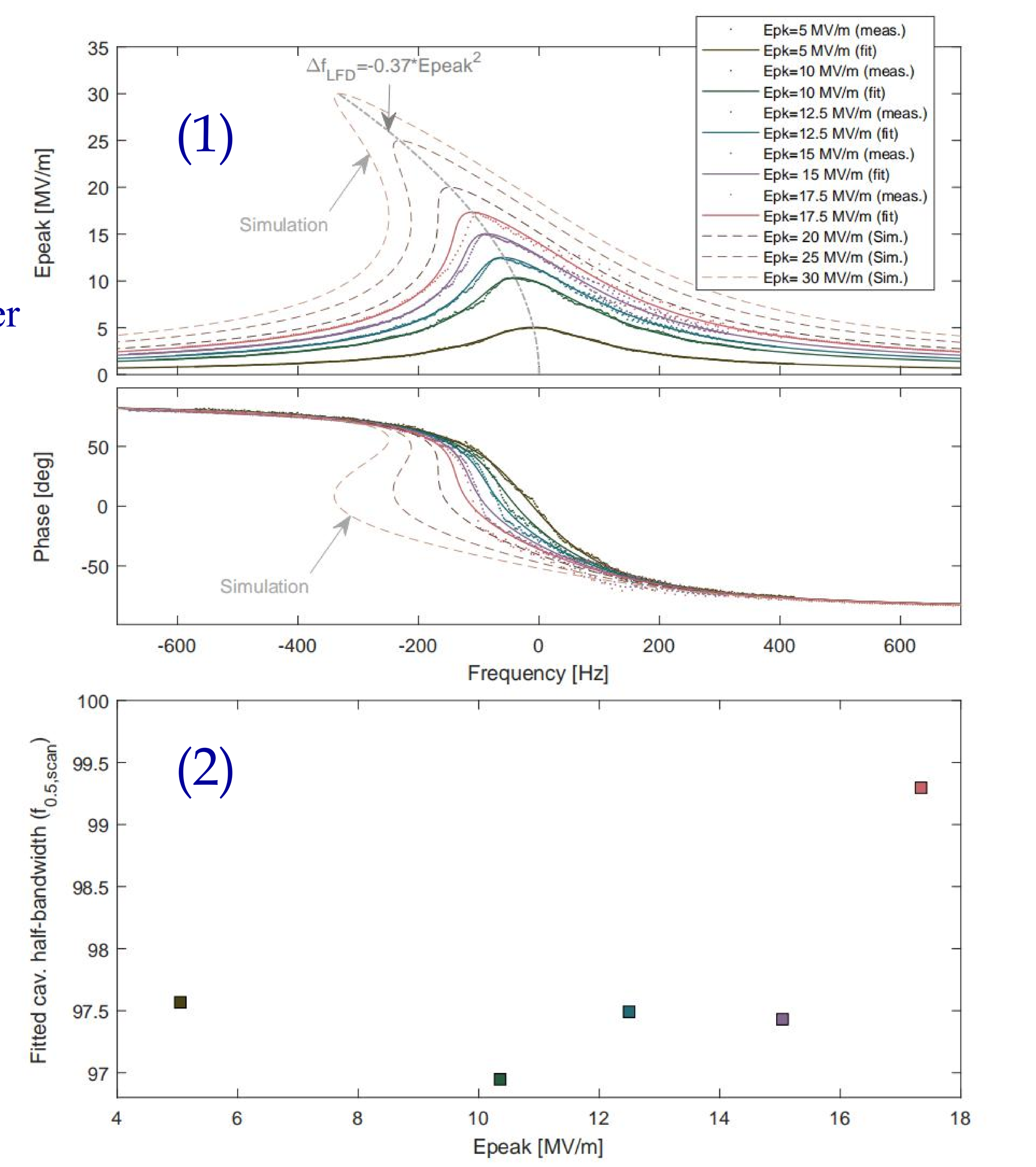


Schematic of measuring device by network analyzer

Cavity \ Meas.	Half-bandwidth (Hz)	
	Online identification algorithm	Network analyzer
CM1-1	115	112
CM1-2	208	213
CM1-3	155	153
CM1-4	168	167
CM1-5	172	175
CM1-6	176	173



On-line identification result of superconducting cavity at 19 MV/m



Frequency response distortion curve of RF superconducting cavity due to Lorentz force detuning(1) and cavity half bandwidth measured at different E_{peak}(2)

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