Alternative Superconducting Drift Tube Linac R&D
(R&D Categories: Driver & Post-Accelerator Linacs)

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Summary
The low-energy section of the RIA driver linac uses superconducting cavities to accelerate beam from v/c = 0.025 to 0.40, and will constitute about one-quarter of RIA's total accelerating voltage. MSU has considered various alternative designs and optimization strategies, and has determined that a 10^{th} harmonic linac based on 80.5 MHz is an attractive solution. To minimize R&D and technical risk, the drift tube linac has a minimum number of cavity types and uses passive microphonics control. Three cavity types can cover this velocity range if they are two-gap structures. The cavity for the lowest velocity particles has the smallest accelerating gaps, and thus has the most severe issues with control of microphonics. Therefore, an 80.5 MHz β=0.041 quarter wave resonator (QWR) very similar to that already developed for INFN-Legnaro's heavy ion linac is used. Microphonics are controlled with a passive mechanical damper whose effectiveness has been proven above 80 MHz, instead of active control with VCX or piezoelectric fast tuners. The second cavity type is an 80.5 MHz β=0.085 QWR that will have reduced microphonics due to the larger diameter. A prototype of this cavity is being fabricated, and tests are planned for Fall 2003. The final cavity type is a 322 MHz β=0.285 half-wave resonator (HWR). A prototype 322 MHz HWR was successfully tested in 2002, and significantly exceeded required quality factors and accelerating electric fields. The cryomodules, including tuners and superconducting solenoids, have been designed. Cryomodule construction and testing are planned for 2004 (assuming FY2004 funding of $875k). By the end of 2004 drift tube linac R&D will be complete, and driver linac designs and production plans can be finalized. The same QWRs and cryomodules can be used in the RIA post accelerator.

1. Alternative SC-DTL Design and Comparison

We propose a three year program (2002-2004) to prototype and test all non-elliptical cavity types necessary for the RIA driver superconducting drift tube linac. The superconducting drift tube linac (SC-DTL) segment is a key element of the RIA driver linac providing the low beta (β = v/c) beam acceleration from about β~0.025 (0.3 MeV/u) to β~0.4 (85 MeV/u)[1]. We have developed an acceleration lattice for the SC-DTL that reduces technical risk and increases operational reliability[2,3]. The scheme's simplicity allows demonstration of all cavity and cryomodule types within the limited

RIA R&D budget and short timescale before RIA construction, thereby significantly reducing the uncertainty and risk to the project schedule and cost.

Given the limited RIA R&D funds, it is of paramount importance that they be allocated to the most critical, long-lead items whose demonstration is required to confidently design and cost RIA. In this context, the 1999 Marx Committee recommended two key research areas one of which was the superconducting rf cavities and cryomodules for the driver linac[4]. This R&D area remains the most critical item, even more so today, with the reduced window of opportunity for definitive R&D before construction. A primary R&D element in this context is the development of SC-DTL cavities and cryomodules. Optimization of the SC-DTL design includes many tradeoffs regarding performance, reliability, simplicity, operational costs, and risks to the cost, schedule, and performance. Absent operational prototypes, including cryomodules, there will exist uncertainties that provide substantial risk to the RIA cost and schedule.

In 1999, a RIA driver linac with four types of SC-DTL structures was proposed by Argonne National Laboratory (ANL) and the judgment given that prototyping, including complete cryomodules, of these long lead items would take at least two years and be the critical path for the RIA construction schedule[5]. At ANL, over 2.2 M$ of RIA R&D funds in FY00-03 have resulted in one prototype and the proposed structure types continue to evolve most recently suggesting six designs to cover the same energy range[6,7]. To date no horizontal cryomodule has been built for testing in realistic operating conditions. This uncertainty justifies exploration of an alternate design that we believe is a simpler and better solution.

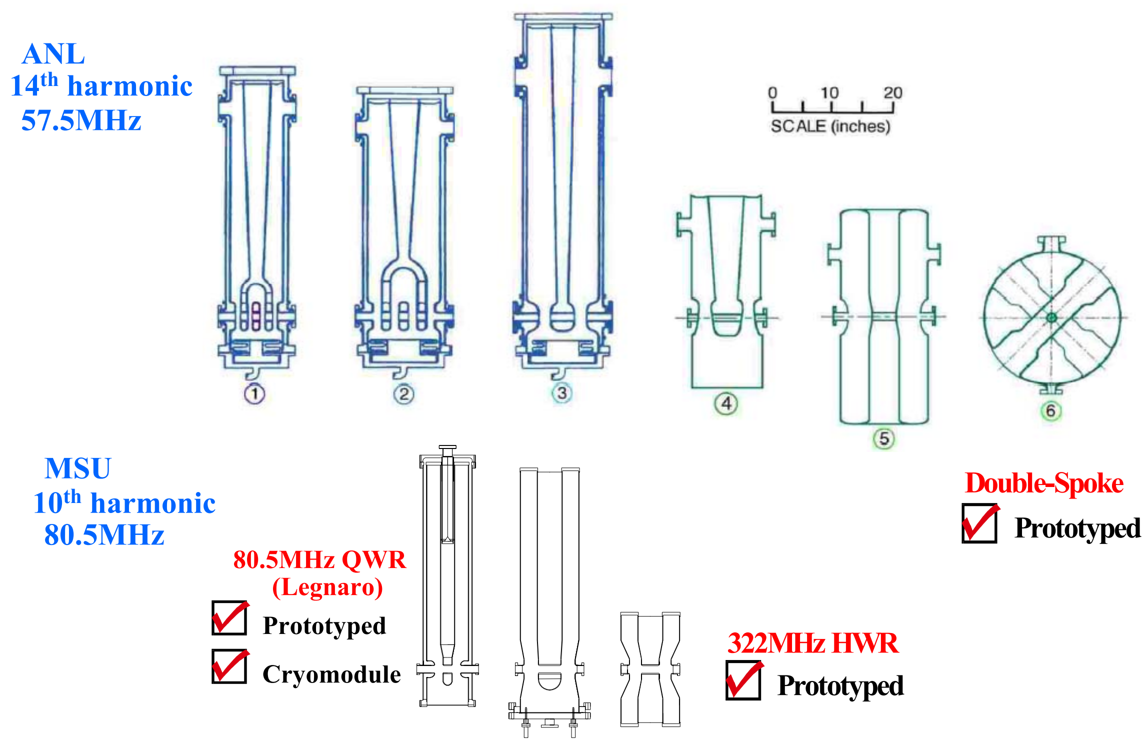

Figure 1. ANL[7] (top panel) and MSU (bottom panel) SC-DTL cavities for RIA driver linac.

ANL 14th (57.5 MHz) Harmonic							
βopt		0.024	0.031	0.061	0.150	0.252	0.393
f (MHz)	57.5	57.5	57.5	57.5	115	172.5	345
Type	RFQ	Fork	Fork	λ/4	λ/4	λ/2	Double-spoke

MSU 10th (80.5 MHz) Harmonic				
βopt		0.041	0.085	0.285
f (MHz)	80.5	80.5	80.5	322
Type	RFQ	λ/4	λ/4	λ/2

Table 1. Comparison of ANL (top) and MSU (bottom) SC-DTL properties.

Our design involves three changes compared to the ANL alternative. (See Figure 1 and Table 1 for details.)

1) Increase the starting frequency from 57.5 to 80.5 MHz.
2) Use a quarter-wave resonator (QWR) in place of the first two Forks.
3) Use a 322 MHz half-wave resonator (HWR) in place of a 172.5 MHz HWR and 345 MHz double spoke

All of the cavities have a 3 cm beam aperture and would allow isolation of the beam vacuum from the cryostat vacuum as is standard for elliptical cavities. Simulations have revealed no frequency specific performance issues between the two options. Beam dynamics calculations have shown that the RFQ acceptance and output emittance is similar for either frequency (57.5 or 80.5 MHz)[8]. Longitudinal and transverse beam dynamics simulations of the entire SC-DTL show similar performance for either lattice of Table 1[2,3,9].

The MSU lattice efficiently provides the required energy and velocity range with only three cavity types reducing the number of elements to be developed and the number of spare cavity types required to ensure reliable operation.

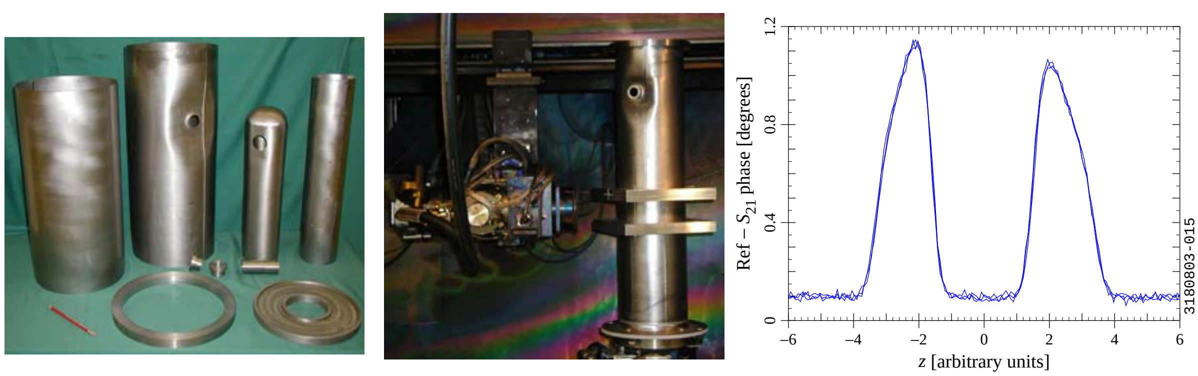

Figure 2. Fabrication of 80.5 MHz β=0.085 quarter-wave resonator. Components (left), final electron beam weld at Sciaky (middle), and bead pull of accelerating electric field (right).

MSU 10th harmonic			
Type	λ/4	λ/4	λ/2
β_{opt}	0.041	0.085	0.285
f (MHz)	80.5	80.5	322
V_{acc}(MV)	0.54	0.97	1.04
T(K)	4.2	4.2	4.2
Q_o	$2.5\text{x}10^8$	$2.5\text{x}10^8$	$2.5\text{x}10^8$
P_o(W)	2.74	9.1	21.8
U(J)	1.36	4.52	2.68
R/Q(Ω)	424	416	199
R_s(nΩ)	73	76	244
E_{peak}(MV/m)	16.2	16.5	16.5
B_{peak}(mT)	36	38.4	45.3

Table 2. Alternative SC-DTL design parameters

The first 80.5 MHz cavity of the MSU lattice is a very similar to an existing Legnaro QWR[10] that uses a passive mechanical damper to control microphonics instead of the voltage controlled reactance (VCX) tuner. The second cavity type, 80.5 MHz β=0.085 QWR, has larger diameter conductors and thus has even smaller mechanical vibrations that can be controlled with a passive damper. In short, the MSU SC-DTL lattice allows microphonic control with passive mechanical dampers and rf drive. This avoids the need for VCX tuners that have several disadvantages for operation in a large linac[11]. The MSU SC-DTL lattice requires smaller and simpler cavities that will be more easily and cheaply fabricated. Although the higher frequency lattice will require more units, it is anticipated that the overall system costs will be comparable for either SC-DTL.

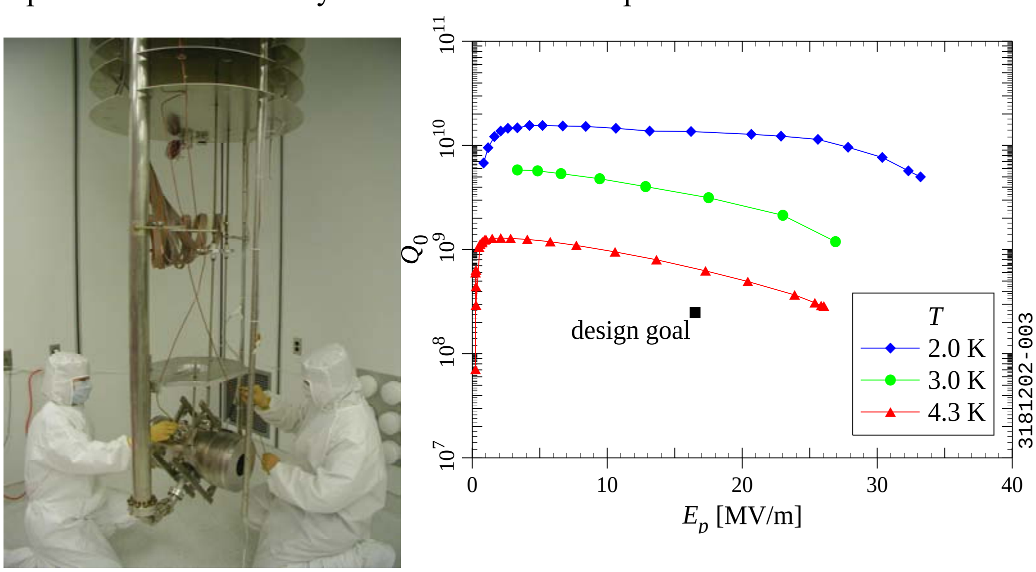

Figure 3. Test results of 322 MHz β=0.285 half-wave resonator.

One of the six Argonne SC-DTL cavity types is a double-spoke. While the spoke design has merit, only one multi-spoke has ever been prototyped and the proposed VCX tuner for microphonics control does not exist at the required 345 MHz frequency. Also, no multispoke cryomodule for testing under realistic operating conditions has ever been built.

2. Cavity and Cryomodule R&D

Since the first cavity type, β=0.041 QWR, of the MSU lattice is very similar to an existing Legnaro design, only two SC-DTL cavities with the same diameter inner and outer conductor need to be developed. The cavity design parameters are shown in Table 2. The second cavity type is an 80.5 MHz β=0.085 QWR that will have reduced microphonics due to the larger diameter. A prototype of this cavity is being fabricated, and tests are planned for Fall 2003 (see Figure 2). The final cavity type is a 322 MHz β=0.285 half-wave resonator (HWR). A prototype 322 MHz HWR was successfully tested in 2002 [12], and significantly exceeded required quality factors and accelerating electric fields (see Figure 3). Experimental results on the β=0.041 QWR and β=0.285 HWR justify increasing the design peak gradient from 16.5 to 20-25 MV/m, especially with the isolated vacuum. The cryomodules, including tuners and superconducting solenoids, have been designed and are based on the rectangular cryomodule for 805 MHz β=0.47 elliptical cavities [13]. Cryomodule construction and testing are planned for 2004 (assuming FY2004 funding of $875k). By the end of 2004 drift tube linac R&D will be complete, and driver linac designs and production plans can be finalized. The same QWRs and cryomodules can be used in the RIA post accelerator.

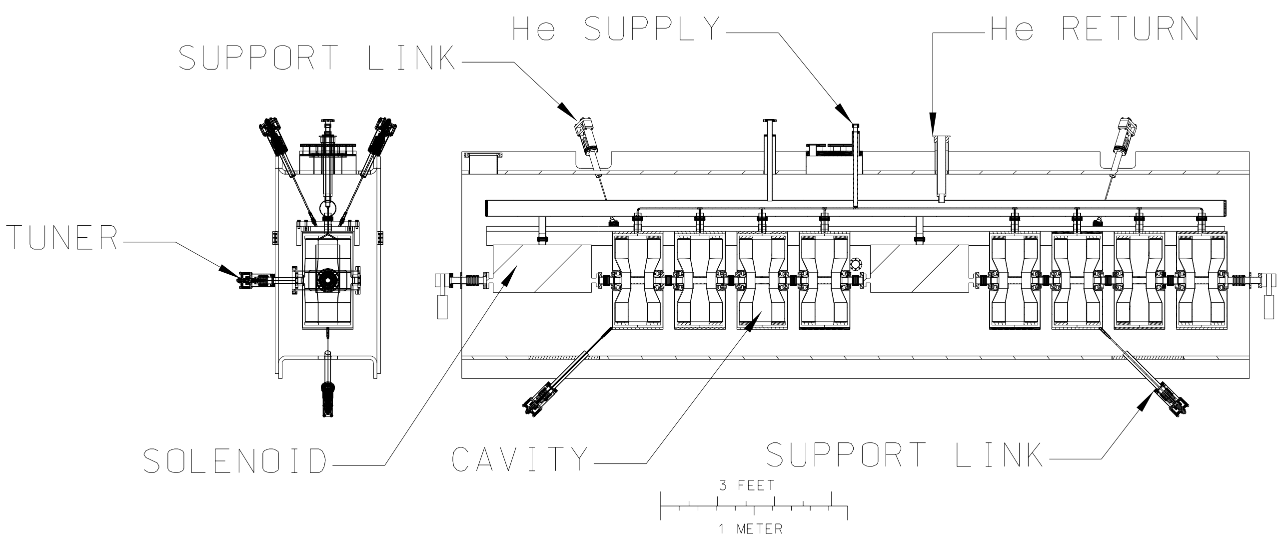

Figure 4. Horizontal cryomodule for the 322 MHz β=0.285 half-wave resonator.

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