A Frequency Choice for the SCRF Proton Driver

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This note summarizes the considerations for either standardizing on TESLA-compatible (1300 MHz and 433 MHz) frequencies throughout the 8 GeV SCRF injector linac, or on the SNS-compatible (402.5 MHz, 805 MHz, and 1207 MHz) frequencies assumed in the Design Study. Figures 1-3 show block diagrams both options, for both 2 MW (ultimate) beam power and 0.5 MW (staged) beam power.

My conclusion after examining the trade-offs is that **the 1300 MHz TESLA frequencies are preferred**, both from the point of view of a fast start to the development program, and for the attractiveness of the final machine. The conclusion doesn't depend heavily on whether a warm (DTL) or a cold (SCRF Spoke Resonator) front-end linac is chosen.

The main implications for the development program for the 8 GeV Linac is to begin development of a set of TESLA-compatible beta<1 elliptical cavities, to focus the development of the fast ferrite tuners at 1300 MHz, and to drop consideration of an early replacement of the FNAL 805 MHz linac front end.

Advantages of using the TESLA-compatible frequencies:

1) There are only two klystron types (433 & 1300 MHz) in the final machine, rather than three klystron types (402,805, & 1207 MHz) in the SNS-compatible design.
2) No Klystron R&D program is needed. For the main 1300 MHz Multi-Beam Klystrons, TESLA has working prototypes and is in the process of qualifying three vendors (Thales, CPI, Hitachi). For the front-end 433 MHz linac, several MW pulsed klystrons (e.g. Thales TH2120) also exist. Development cost for a new Klystron design is ~$1M/vendor and takes 1-2 years. Cavity development is cheaper.
3) There are fewer overall klystrons, since one 10 MW TESLA Klystron replaces two 5 MW SNS klystrons. This is a savings of 5 klystrons in the 2 MW design, or 2 klystrons in the 0.5 MW staged design.
4) The long-term availability of the 5 MW SNS klystron is not clear, since the SNS upgrade plan is to replace the warm-copper CCL which uses the 5 MW klystrons with a SCRF section that does not use them.
5) We don't have an immediate need for an RF coupler R&D program, since the conductively cooled TESLA (TTF3) coupler is adequate in both price and performance. For 805 MHz, we would have to design and test a conductively cooled variant of the (vapor cooled) SNS coupler, as well as a separate 1207 MHz coupler. The TTF3 coupler is not perfect, and the longer term, we may wish to continue RF coupler development.
6) No immediate cryostat R&D is needed, since the beta<1 cavities will fit into the same TESLA cryomodules as the beta=1 cavities. For the larger 805 MHz cavities, a new cryostat design is necessary.

7) Ceiling height on the Klystron Gallery will be about 5 ft shorter. The TESLA Klystron height is 8.2 ft vs. 13 ft for SNS 805 MHz klystron. For an underground gallery the cost difference will be significant.
8) Waveguide components, circulators, loads, ferrite tuners etc.are smaller & cheaper at 1300 MHz than at 805 MHz.
9) There is some evidence that the larger 805 MHz cavities are harder to rinse than smaller TESLA cavities, and that this may be responsible for recent SNS cavity yield problems.
10) Frequency compatibility with A0 infrastructure may be an advantage for early tests

Advantages of the SNS-Compatible 402.5 MHz / 805 MHz / 1207 MHz solution

1) Successful models of three out of four cavity designs exist: the SNS beta=0.83,0.61, and the RIA beta=0.47. Only one new cavity design (1207.5 MHz beta=1) would need to be created.
2) Only three beta ranges (rather than four at 1300MHz) are required to cover the beta<1 region, since the 6-cell 805 MHz cavities have a wider velocity acceptance than the 9-cell 1300 MHz cavities. One fewer cryomodule type (plus spares) will be required.
3) Cost data exist for the 805 MHz components, althought they would still have to be extrapolated to 1207MHz in the back 7/8 of the linac.
4) Waveguide losses are lower for the larger 805 MHz waveguide.
5) Compatibility and parts interchange with SNS is possible for the first 1/8 of linac [but no parts exchange with anyone for the last 7/8 of the linac].
6) Frequency compatibility with existing FNAL linac front end. This would be useful only if the warm front end gets replaced off-project, or if we want to do early beam tests in the linac gallery or muon area.
7) Accelerator Physics are well documented for the 805 MHz SNS design. The 1300 MHz design will have a smaller RF bucket area and a smaller beam iris. Petr Ostromov's quick look at a point design did not uncover any problems, however.

Non-Issues

1) 53 MHz Main Injector frequency compatibility is irrelevant since the beam will either be asynchronously chopped, or adiabatically rebunched at 53 MHz in the MI.
2) Front end frequency compatibility with existing designs is also a wash. The 402.5 MHz SNS front end is not a useful starting point due to the high costs arising from its high duty factor. The AccSys RFQ/DTL runs at 425 MHz and would have to be frequency tweaked for either 402.5 or the TESLA-compatible 433 MHz. The SCRF spoke cavities for RIA would have to be tweaked in either case.

Comments on the Cavity Development Program

In the SNS-compatible approach, only one new cavity design (1207.5 MHz beta=1) would need to be created. However high-power testing of this cavity could not take place until the 1207.5 MHz klystron development is completed.

In the TESLA-compatible approach, four new beta<1 elliptical cavities must be developed. Informal discussions with JLAB personnel indicate that their development cost of these cavities would be in the range of $500k total. If this is even approximately true then it is much cheaper to develop new cavities than new Klystrons. It may be expedient and propitious to spread this design & prototype work among several labs.

Evaluation of the SCRF Spoke Resonator option for the front end can proceed at a more leisurely pace, since we already have an acceptable warm DTL alternative. The key developments are measurement of the of the gradients achievable in pulsed mode in cavities operating somewhare near 400 MHz, and the development of an economical pulsed RF system, possibly including the fast ferrite phase shifters.

It is conceivable that if the spoke resonators will end up attractive enough to bite into the lower beta ranges of the elliptical cavities, possibly reducing the number of new elliptical designs to three or even two. So, the elliptical cavity prototype program should start at the high-beta designs and work downwards. It will not be upsetting if we end up with overlapping ranges of prototypes in which either spokes or ellipticals are feasible.

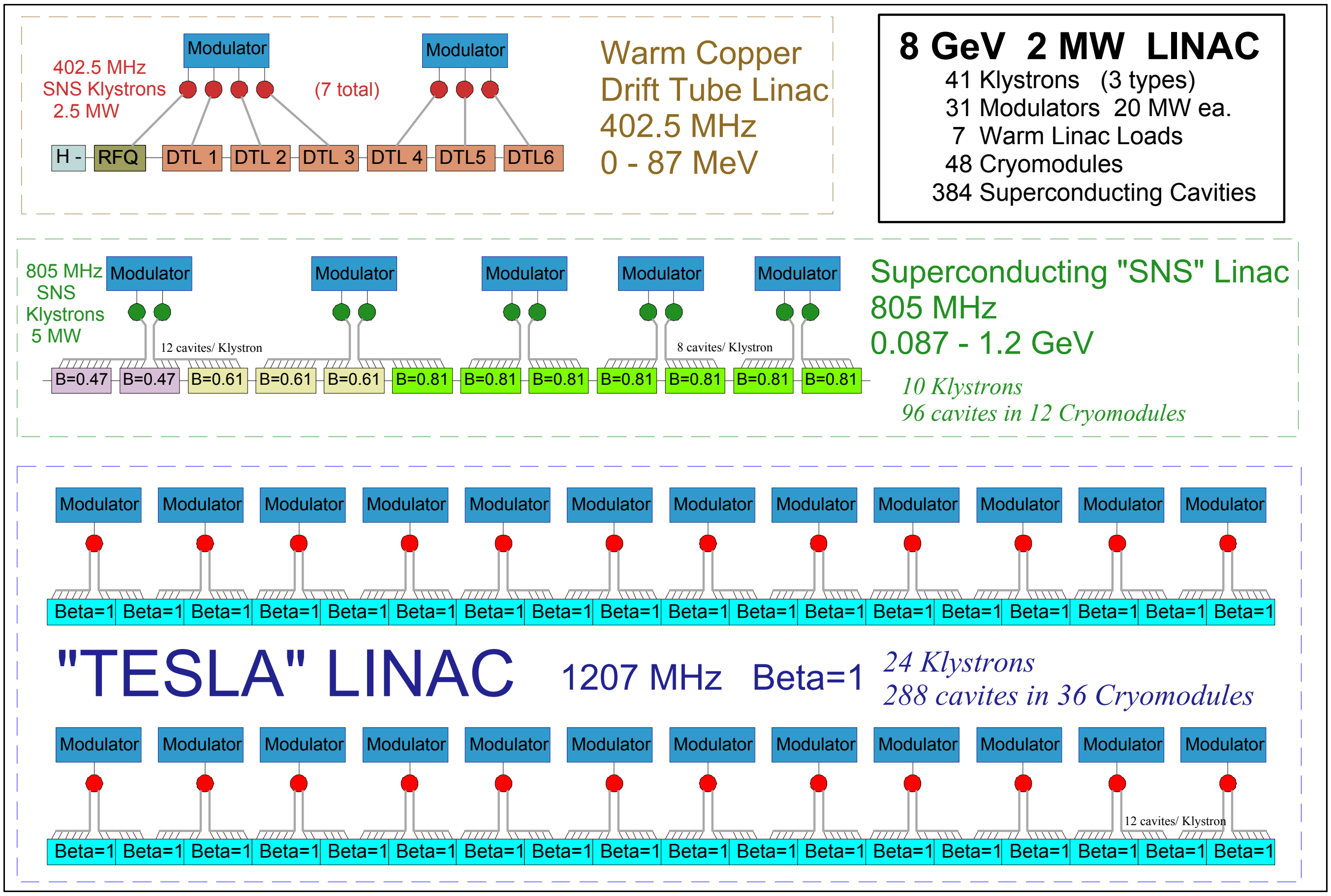

Fig. 1 - Design Study Baseline with 2 MW beam power and “SNS-compatible” 402.5 MHz, 805 MHz, and 1207.5 MHz klystrons and cavities. The 2 MW beam power represents the

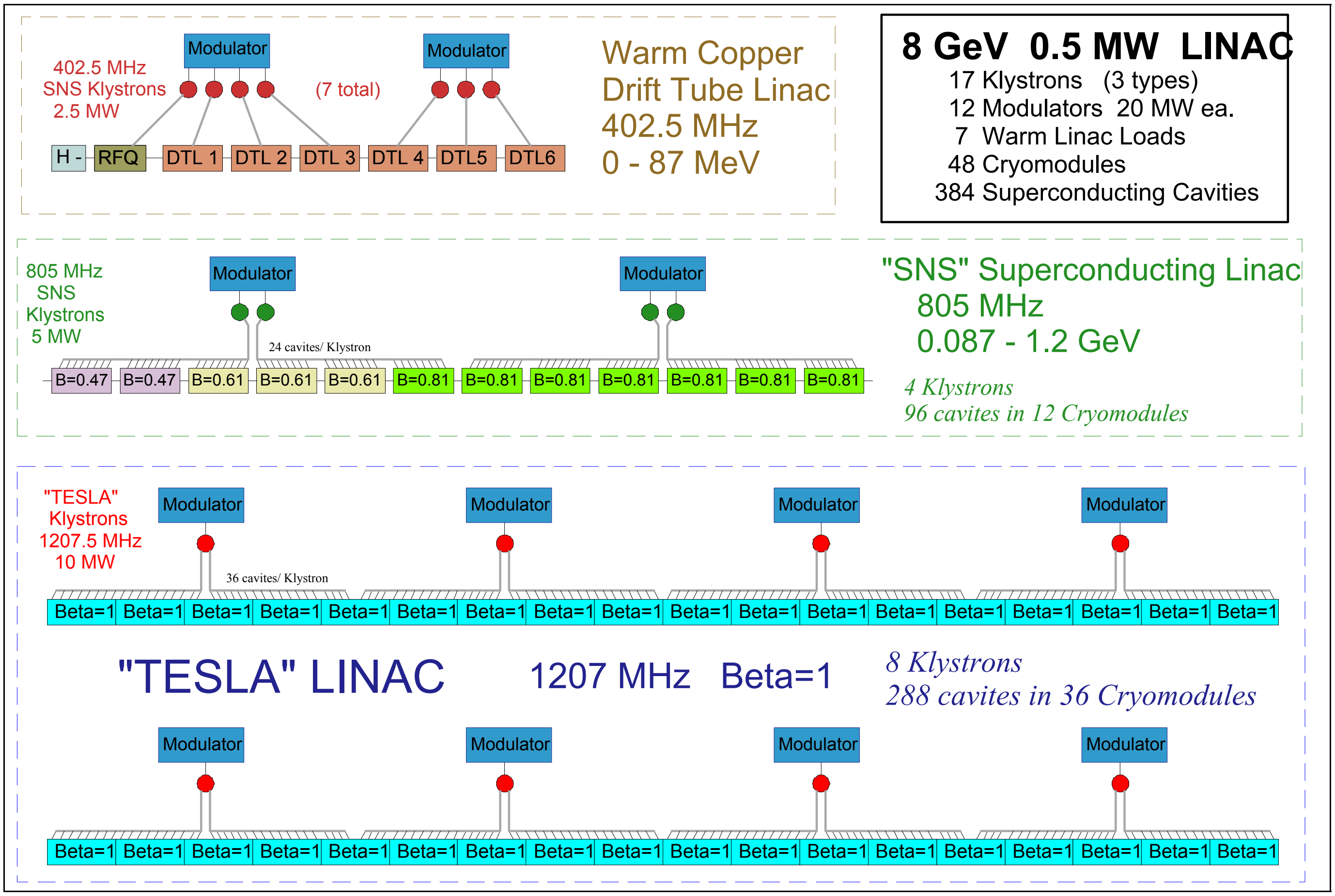

Fig. 2 - "SNS-compatible Staged RF Power Design" with 0.5 MW beam power (upgradeable to 2 MW) and 402.5 MHz, 805 MHz, and 1207.5 MHz klystrons and cavities. A superconducting front end linac (shown in Fig. 3) is also possible with these frequencies.

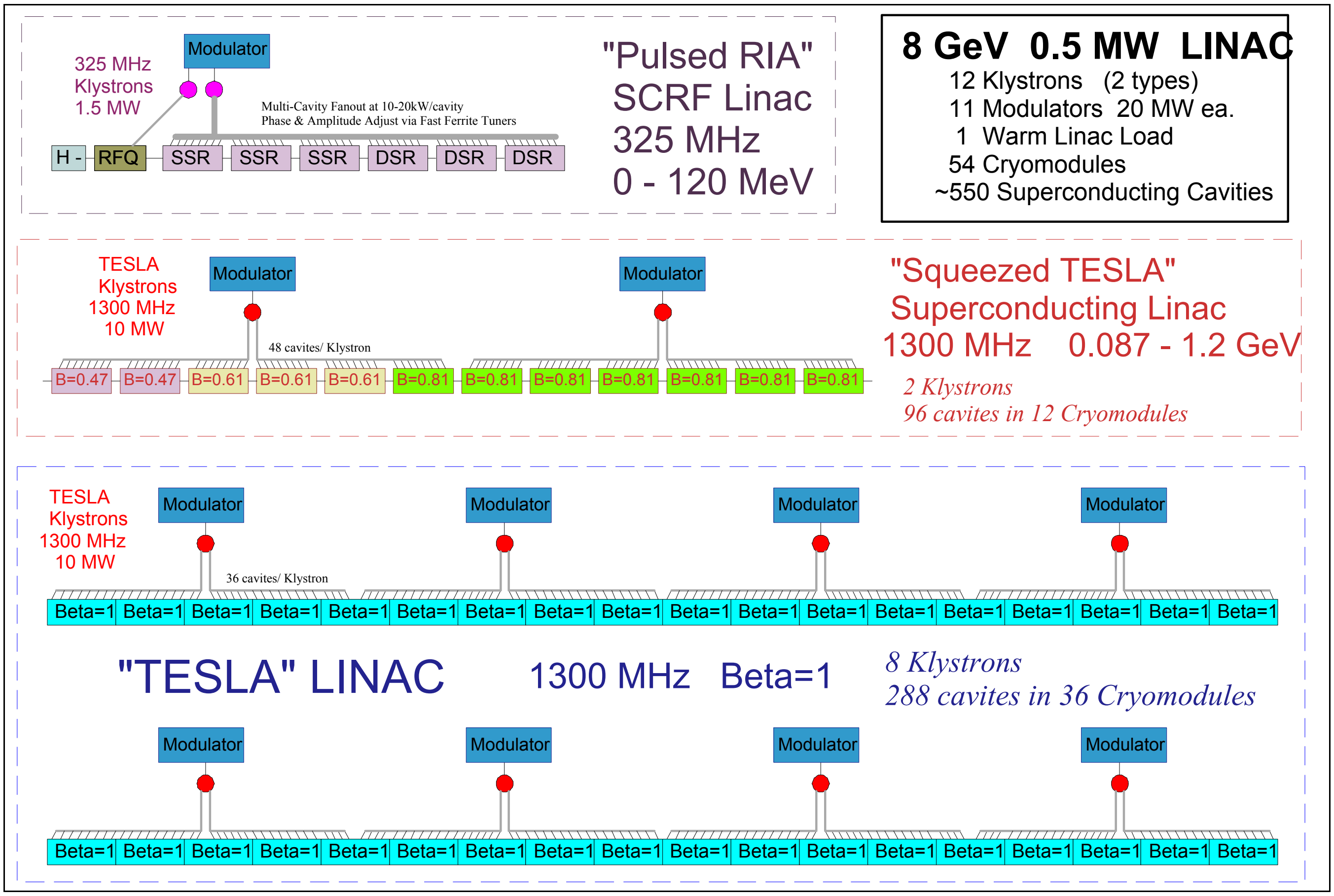

Fig. 3 - "TESLA-compatible Staged RF Power Design" with 0.5 MW beam power (upgradeable to 2 MW) and a spoke resonator front end. TESLA 1300 MHz multibeam klystrons drive elliptical cavities in both the beta<1 and beta=1 sections. The front end linac can operate at either 1300/4 = 325 MHz (shown), or else at 1300/3 = 433 MHz (which may be preferable due to the existence of commercially available Klystrons at that frequency).