# LINAC ACCELERATING STRUCTURES

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*Abstract*

The review of the cell geometries, of the coupling modes between cells in accelerating sections, of the sections combination relative to a common RF source shows new possibilities as strongly reentrant cell geometries, SW at the 3pi/4 coupling mode, TW with slot coupling backwardly for v/c near unity or forwaıdly for lower v/c values, new combinations in serie of sections.

## INTRODUCTION

The accelerating cell geometries, the modes used when they are coupled in accelerating sections, the section combinations seemingly have reached maturity [1-4]. Traditionally, iris waveguide at the TW 2pi/3 coupling mode as illustrated by SLAC and other large energy instruments are used for electrons, more efficient cell shapes in the SW pi/2 coupling mode as illustrated by Los Alamos side-coupled geometry are used for protons and electrons. These geometries are RF fed in parallel.

Interesting alternatives exist: we used over 30 years at CSF, Thomson CGR, General Electric France, SW 2pi/3 coupling [4], coupling mode change along section in SW for better capture in bunchers [6], SW cell added to TW section on a common coupler (unpub.), TW with 3pi/4 slot "backward" coupling for Trieste 1.5 GeV e-linac [5]. We proposed section combination in serie [10], TW proton acceleration [7] etc. The large body of other workers proposals is not properly covered here - except [9,11,12]. This paper discuss cell shape, attempt a classification, presents three new ideas: multigap cells in TW, SW in 3pi/4, 2:1 recombination of sections.

## CELL SHAPES

The cell shape compromises between the conflicting requirements of high efficiency (high Q and transit factor T), moderate field gradient (even if the limit is now relaxed to several times the Kilpatrick criterion value, see [13]), low perturbation of the dynamics (avoiding deflecting modes, reducing trailing field), thermal control.

Highest Q being achieved for spherical shape (highest volume to surface ratio) asks for comparable diameter and cell lengths. Using all the available space near axis, spheres becomes cylinders and the optimal cell length becomes less than the diameter or about half the free space wavelength (pi seen from high energy beam) at the TM01 mode used in accelerators. When drifts are included the optimal length diminishes and the 3pi/4 mode becomes better than the pi mode!

Transit T value larger than 0.8 asks for gap lower than 2pi/3.The conflict on length is solved by adding drift (with noses). It is possible when coupling is made in the off-axis magnetic region of the cell (to side- or on-axis adjacent cell). But this conflicts with dynamics as reentrant cell favours mode trappings and space charge image increases with nearby conductor surfaces. Solutions changes with constraints relative importance. The efficiency varies by more than a 2-factor, from more than 120 MOhms/m to less than 60 MOhms/m at 3 GHz, coupling and roughness effects included.

*Figure 1* shows one-fourth of a cell for 3 cases left to right:

[left:] achieving in SW the highest efficiency at the price of reduced beam clearance, high gradient, dynamical side-effects. Such tubular drift geometry can accelerate 100 MeV protons at v/c=0.46 in the 3pi/4 *forward* alternative. Cell length is 5pi/4 to achieve beam synchronism with comfortable Q. The impedance ZTT given by SUPERFISH is 108 MOhms/m at 3 GHz for a 4mm beam clearance [7]. We designed before a similar geometry at the 3pi/4 *backward* alternative which could be used for CW electron acceleration at v/c=1 with 156 MOhms/m value! (unpub.)

[middle:] compromising with high peak field on nose either in SW or as here in Backward TW [5].

[right:] standard iris for TW in th 2pi/3 mode.

## COMBINATION OF CELLS IN SECTION

The *table 1* classify the use of cell, cell assembly in SW or TW, for different geometries at different modes. The case order follows the potential use from short to longer structures. Each case gives title plus some specifics as author name or linac example:

1. Single cell is used in the single gap or multigaps configuration as the Alvarez tank for protons. Note that it can be extended to high frequencies introducing few gaps inside a cell with tiny diametral bars in a simple and robust way. Then one could uses a chain of such "mini-Alvarez tanks" as cells coupled together in TW for protons acceleration at very low velocity to keep sufficient Q values and realistic wall thickness [8]. The *figure 2* shows two cells coupled backwardly in TW, each "6pi "cell with two bars which creates three gaps.

2. Multicells can be fed by a common coaxial manifold (12). The one time famous Disk And Washer or DAW structure do not separate feed and cells but a great number of resonances together with the supporting stems problem hinder its use.

TABLE 1: LINAC MODES & STRUCTURES

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SINGLE CELL:
1.1 single gap ("the accelerating cell")
1.2 multigaps (Alvarez)
in multicell TW (this paper)

MULTICELL combination:
2. fed by common manifold (Swenson) or common peripheral region as in Disk And Washer or DAW

3. SW, on axis iris or peripheral slot geometry:
3.1 pi (several cells only, rings RF units)
3.2 pi/2 (side-coupled, Los Alamos)
3.3 2pi/3 (on-axis ,Tran)
3.4 3pi/4 (this paper)

4. TW,
4.1 on-axis iris geometry for e-:
4.1.1 pi/2(bunchers)
4.1.2 2pi/3 (v/c=1)
4.1.3 3pi/4 (Boeing)
4.2 peripheral slot for e- or for p+:
4.2.1 3pi/4 backward for e-(Trieste)
4.2.2 3pi/4 forward for p+(Tronc)

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3. SW on-axis iris coupling has been used for high field compact structures where large beam clearance is required as for buncher or positron capture. But the majority of realisations uses peripheral slot coupling allowing drifts to benefit from a larger shunt impedance. Coupling gives fields in opposition in successive active cells:

3.1 a dephasing of pi is too critical unless one uses very few cells (at low frequency for rings or in supra with large iris coupling). The very poor coupling induces an high sensitivity of field flatness on imperfections. It is proportiomal to the squared number of cells.
3.2 pi/2, the simplest case, is achieved in a biperiodic geometry made of one flat on-axis coupling cell being put between each large accelerating or active one or better in a side-coupled fashion, removing the coupling cells outside the cylinder enveloppe of the active cells.

3.3 The number of coupling cells is halved when 2pi/3 is achieved in a triperiodic geometry made of one narrow on-axis coupling cell being introduced between pairs of large accelerating cells... Proper end cell conditions must be satisfied i.e. pi/2 end couplings to insure zero field in coupling cells together with equal field amplitudes in accelerating cells.

3.4 We suggest 3pi/4 could be achieved in a very interesting way for p+ acceleration as the shortest possible SW structure would include two active cells at each end, three active cells in the center, two coupling cells. There is no special end-conditions as previously and one benefits from an easy individual SW cell control. The *figure 3* shows such section with 7 active cells plus 2 coupling cells only, sufficiently short for p+ focusing between sections. Note that the field amplitudes is proportionnal to 2 in the central and end cells, 0 in the coupling ones, 1.41 in the remaining ones. The slight efficiency loss due to unequal energy stacking in active cells is evaluated at 3% in power. It is compensated by the lower coupling cell length loss. Active cell volumes can also be made slightly differents.

4. TW,

4.1. on-axis iris geometry for e- : beam and RF must circulate in the same "forward" direction to insure synchronism:
4.1.1 pi/2 was used for bunchers at the cost of efficiency to allows easy individual cell control, the quasi synchronous phase law being critical for high quality beam.
4.1.2 2pi/3 is the standard case as theoretically giving the best compromise between Q and T for the classical iris waveguide.
4.1.3 3pi/4 is only marginally lower in iris TW shunt impedance and presents interest in case of thick iris wall or v/c<1 in bunchers. Individual resonances are simpler to control.

4.2 peripheral slot for e- or for p+:the slot coupling increases efficiency:
4.2.1 3pi/4 backward for e-: beam and "backward" RF circulates in opposite directions to insure synchronism for every bucket. Trieste uses 3pi/4 mode coupling to facilitate individual cell test, but other modes as 4pi/5 etc. could be used.
4.2.2 3pi/4 forward for p+: beam and forward RF can circulate in the same directions if cells are made of length larger than (pi)(v/c). Then one bucket is accelerated and then "waits" inside the following drift before being accelerated in the next cell gap. One accelerates a 1.5 GHz beam micro structure with 3 GHz RF. The cell length or distance between two adjacent accelerating cells at the 3pi/4 RF coupling is (v/c)(2pi-3pi/4)= 5pi/4. This leads to too long cells at v/c=1 to have highest Q factor- but when v/c<1 as for proton acceleration the gain on Q becomes great (even more than a 5/3 ratio from the previous case allowing for a constant wall thickness). See ref.[7].

## SECTION COMBINATION

With respect to one RF source the sections can be: 1. fed in parallel, 2. fed in serie, 3.can be combined in a single unit with a unique coupler, 4.can be recirculated:

1. They are usually fed [one per dedicated RF sources or] in parallel using 3db couplers to reduce by a 2-, or with

two successive divisions by a 4- factor, the number of sources . Source protection occurs as reflected power is driven in the4th arm load of a 3db coupler.

2. The obvious serie alternative seldom used can be a one-to-one or a two-to-one cascade:

2.1 One-to-one: TW buncher can precede TW or SW accelerator [9]. The peculiar case of Backward TW asks for such solution so that the bunching depends not much on the beam loading. This leads to a very convenient set-up with interesting phase control property [10].

2.2 Two-to-one: identical TW structures of fixed group velocity and of 3 db attenuation each can be connected with 3db recombination of outputs as shown on *figure 4*. This can be an efficient cost saving approach.

3. The same coupler can feed a (main) TW plus (at lower coupling) a unique cell (or a short SW) which acts as buncher adjacent to a gun source as on *figure 5*.

4. A section can be recirculated. An astute solution is to associate a 3db coupler to 2 subsections [11].

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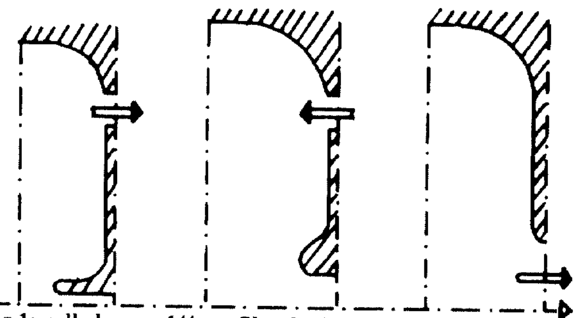

**Fig.1: cell shapes: 1/4 profile of cell, 3cases: highest Z (5pi/4 100 MeV p+acceleration), compromise with gradient (3pi/4 Backward TW), standard TW (2pi/3 mode)**

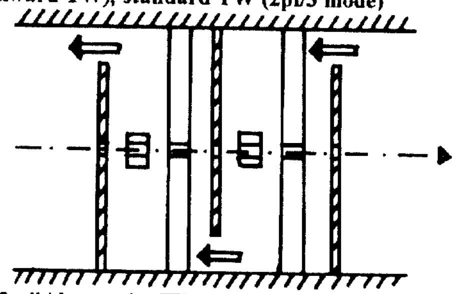

**Fig.2: "Alvarez in TW":2 TW cells with 3gaps (each cell includes two perpendicular bars in the TM01 Bacward slot coupled volume)**

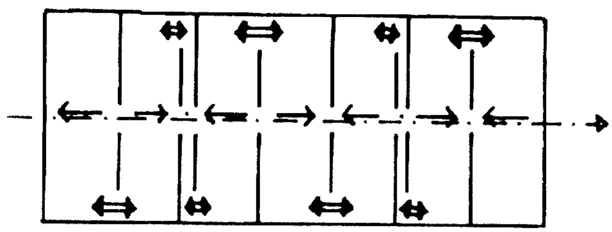

**Fig.3: 3pi/4 SW: 7 active cells + 2 coupling cells**

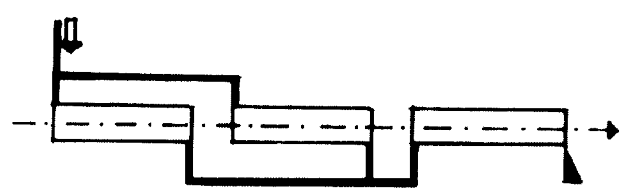

**Fig.4: 2:1 3db recombination of sections with 3db attenuation each.**

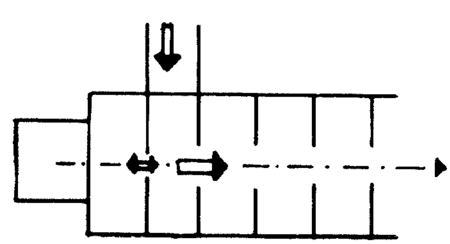

**Fig.5: The same coupler can feed TW section + SW cell.**