Re-circulation

Re-visited

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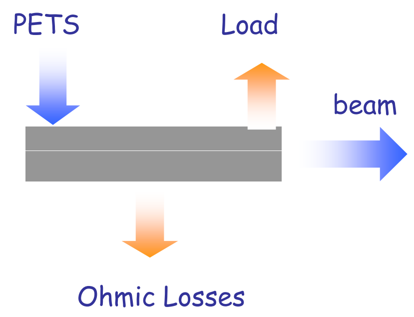
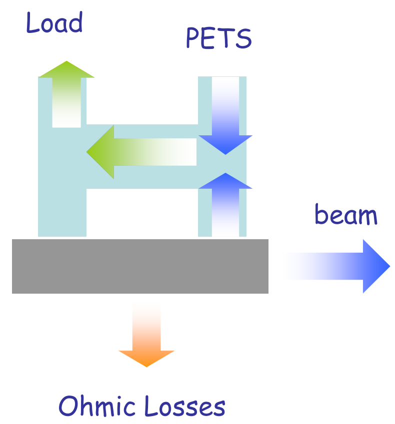
Motivations

➢ The re-cycling of RF power in a Traveling Wave structure can potentially allow for increase of the RF-to-beam efficiency.
➢ Compared to the conventional TW, in this regime, there is no power dissipated in RF load during steady state operation.
➢The beam loading compensation comes naturally for this scheme.
➢ With application of the tunable element in a feedback loop it is possible to terminate the power delivery into the accelerating structure (alternative to the Petsonov)

Traveling wave

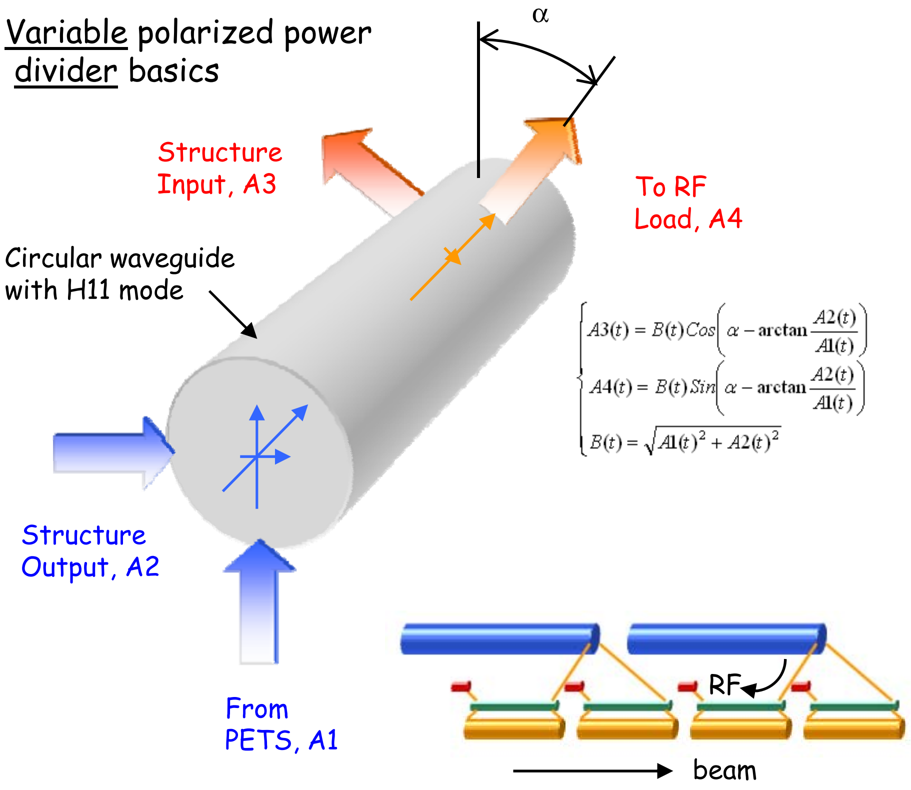


Traveling wave
with re-circulation



The RF power divider/combiner is a key element of the scheme. It can be build in a different ways (classical planar hybrid for example). However it is very useful to have the design which provide certain tuning capability of the system:

Variable polarized power divider basics



$$\begin{cases} A3(t) = B(t)Cos\left(\alpha - \arctan\frac{A2(t)}{A1(t)}\right) \\ A4(t) = B(t)Sin\left(\alpha - \arctan\frac{A2(t)}{A1(t)}\right) \\ B(t) = \sqrt{A1(t)^2 + A2(t)^2} \end{cases}$$

⚠ For any azimuthal position, the structure RF input phase remains constant.

2. RF power re-circulation in the CLIC accelerating structure.

I. Syratchev, LC99, April 1999

2.1 Initial assumptions:

1. Let us consider that the best ramp is a linear grows of the RF amplitude starting from the optimal amplitude A_0.
2. In the case with-re-circulation this situation comes out to be satisfied automatically, if the from-PETS rf pulse has the same ramp duration (from 0 to 1) as the filling time of CAS.
3. Lets the beam is injected after n filing times, when probably we managed to construct the pulse shape that we need for EC condition.
4. To simplify the analysis let us consider that the feedback delay time is equal zero, but feedback losses are accounted.

Basic equations

The RF amplitude at the input of the TDS can be written as (see APPENDIX I):

$$E_{in}(t) = (E_{PETS}(t)^2 + E_{rec}(t)^2\eta)^{1/2}Cos(\alpha - \Psi(t)) \quad (5)$$
$$E_{load}(t) = (E_{PETS}(t)^2 + E_{rec}(t)^2\eta)^{1/2}Sin(\alpha - \Psi(t)) \quad (6),$$

where α - combining angle that must be optimized to cancel power in a load of the combiner; $E_{PETS}(t)$ – the output pulse from PETS,

$\Psi(t) = a\tan\left(\frac{E_{rec}(t)}{E_{PETS}(t)\eta^{1/2}}\right)$ (3) – describes the rotation of the general vector and

$E_{rec}(t) = E_{in}(t - t_{fill})\exp\left(-\frac{\pi f t_{fill}}{2Q}\right) - E_{beam}(t - t_{inj})$ (7) - Backward wave amplitude, η - feedback efficiency, t_{fill} and t_{inj} – filling and beam injection times, E_{beam} – beam-induced voltage at the end of the structure which can be defined in a simple manner as a linear ramp:

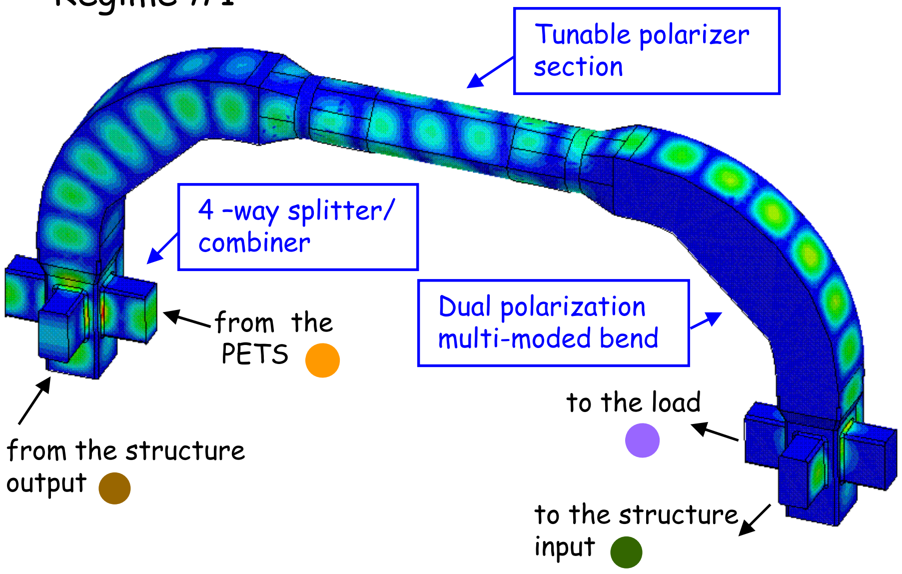
$$E_{beam}(t - t_{inj}) = \begin{cases} E_{bss}\frac{t - t_{inj}}{t_{fill}} & t < t_{inj} + t_{fill} \\ E_{bss} & t > t_{inj} + t_{fill} \end{cases} \quad (8),$$

where E_{bss} – beam induced voltage at the end of the structure in a steady state. For the given structure parameters after normalization by $E_{PETS}(t)$ we will have only two free parameters - α and E_{bss} (i.e. beam current) that help us to optimize the Exact Compensation (EC) conditions.

2.2 EC conditions.

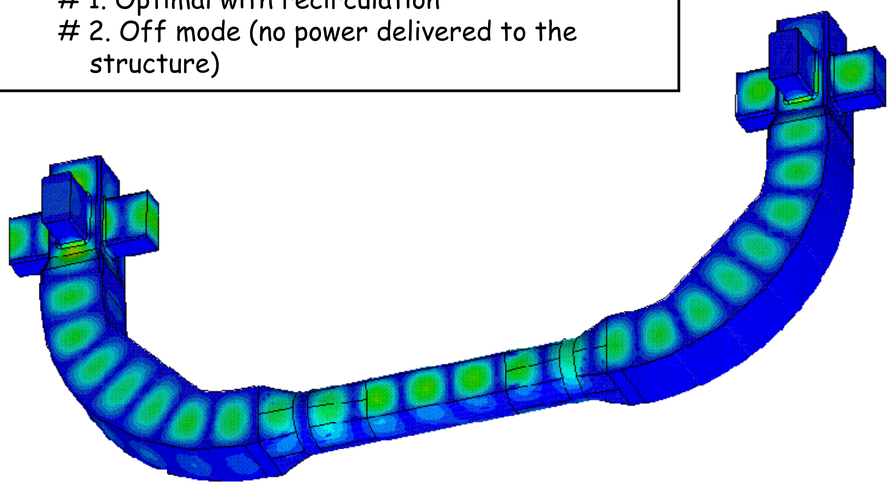
EC1. This condition was defined above.
EC2. Under EC2 conditions we suppose that the signal in a combiner load while beam passing through the structure must be zero, that is together with EC1 corresponds to the most efficient utilization of the input power. It will be satisfied with a proper choice of the beam loading (i.e. amplitude of E_{bss})

Regime #1



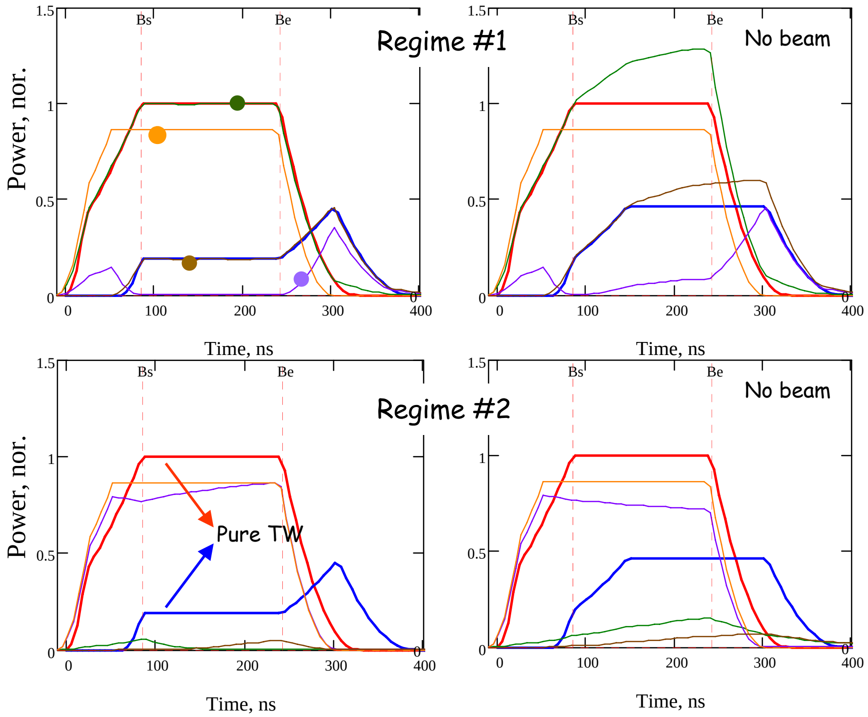
Depending on the polarizer azimuthal orientation, the different regimes of operation can be realized:

- # 0. No recirculation (α=0)
- # 1. Optimal with recirculation
- # 2. Off mode (no power delivered to the structure)

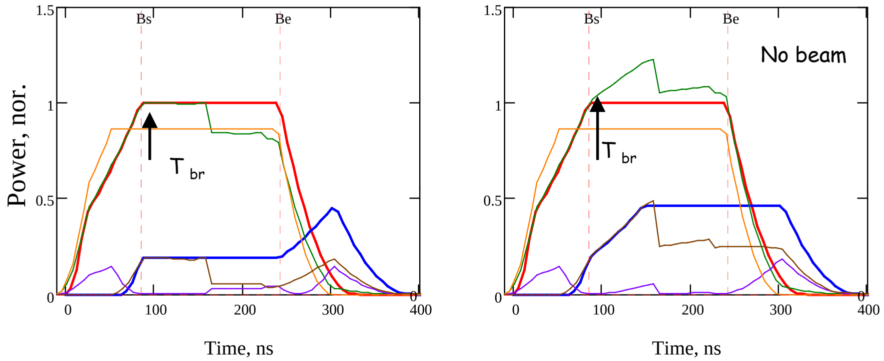


Regime #2

Re-circulation optimised for the CLIC-G accelerating structure;
RF/beam gain in efficiency: 12.1%
PETS peak power reduction: 15.8%



In the case of breakdown in a first cell (missing energy 50%)



Discussion

- The first exercise with re-circulation optimised for the present CLIC accelerating structure (CLIC-G) showed quite a potential: the RF-to-beam efficiency can be increased by ~ 12% (from 27.7% to 31 %)
- The same time, PETS peak power reduction by ~ 16% will also bring a number of advantages.
- It is certainly advisable to make a new optimization of the CLIC structure in a presence of the re-circulation targeting further possible increase of efficiency.
- The development of the "simple", electrically controlled high RF power phase shifter can significantly increase the flexibility and value of the system.