RF Design of the UCLA/INFN Hybrid SW/TW Photoinjector

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Abstract. With increasing demand for high brightness, low emittance beams for use with free-electron lasers, Compton scattering systems and wake-field accelerator experiments, stringent requirements have been placed on the design and operation of the 1.6 cell photoinjector. The proposed hybrid photoinjector combines the BNL/UCLA/SLAC style 1.5/1.6 cell standing wave gun with a traveling wave accelerator. Our goal is an injector that meets today's requirements and is scalable in design to meet tomorrow's demands: emittances in the region of 1 mm-mrad for higher brightness as well as higher currents. The hybrid photoinjector also offers higher energy operation, enhanced cost effectiveness and better scalability than current designs such as integrated PWT photoinjectors and split gun/accelerating sections. The use of both SW and TW systems allows for higher gradients (E_o = 70 MV/m) in the SW gun for effective capture at lower emittances, while the lower energy acceleration in the TW sections (E_o = 13.5 MV/m) allows generation of higher energy beams which are less sensitive to space charge effects. We note the current results of simulation of beam dynamics, $\varepsilon_{n,x}$ = 3 mm-mrad, an energy spread of 1.5% with beam energies of 21 MeV at currents as high as 1.2 kA. Further we explore the possibilities of scalability to higher frequencies, analysis of coupling design, present cold test preparations and simulated RF analysis of the structure.

Keywords: photoinjector, hybrid, RF, electron sources, standing wave, traveling wave
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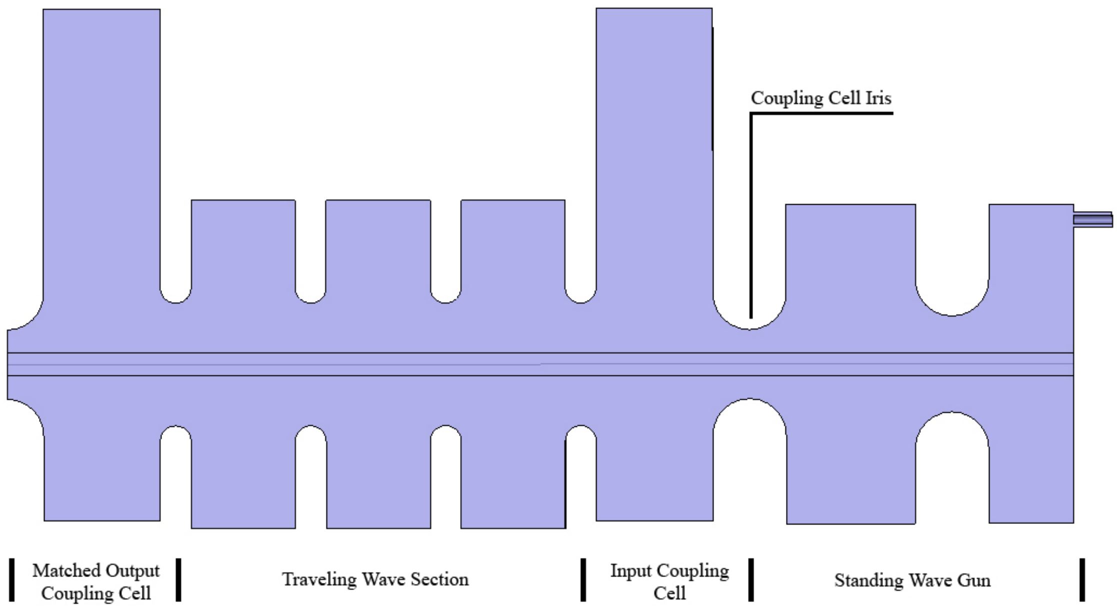
INTRODUCTION

We present the method used for integration and design of a standing wave gun and traveling wave accelerator to produce a high current, low emittance electron source for future implementation at the UCLA Pegasus Lab and the INFN Laboratori Nazionali di Frascati.

The creation of the 1.6 cell photoinjector opened the door for new experiments due to, in particular, it's ability to produce excellent beam parameters [**?**]. Even so, the current generation of photoinjectors is presently at the stage of input symmetrization to suppress multipole effects and iris manipulation to enhance field seperation, all with the goal of better resulting beam parameters [**?**]. While the photoinjector performs it's duties admirably, it still suffers from a few drawbacks which can be addressed through the use of integrated photoinjectors [**?**]. The UCLA/INFN hybrid photoinjector offers improvements over the 1.6 cell photoinjector such as higher current, lower emittances and less RF infrastructure.

The ultimate goal of the hybrid injector is ease of implementation and the ablity to



Source: HFSS

FIGURE 1. A dissected Drawing of the Hybrid Gun.

scale to higher frequencies. Such scaling, while possible using the BNL/UCLA/SLAC style 1.6 cell gun, becomes prohibitively expensive and in some cases is not possible due to lack of available equipment, such as circulators, at higher frequencies. The main advantage of the hybrid gun over a standard 1.6 cell BNL/UCLA/SLAC style gun is simple: instead of power being divided at the port coupling the waveguide to the standing wave gun, the power is divided in a coupling cell. The coupling cell is capacitively coupled to a loaded traveling wave line on one side and a standing wave gun on the other.

Advantages of the Hybrid Photoinjector

Simulations of the hybrid gun have shown promise for excellent beam dynamics. UCLA PARMELA simulations show beam parameters in the realm of 21 MeV, 100 micron rms pulse length beams with eimittances of 3 mm-mrad for 1 nC bunches. These beam parameters are due, in part, to the lack of drift between the gun and the first accelerating cavity, avoiding unnecessary longitudinal beam growth, and the ponderomotive focusing due to alternating field gradient at the irises of the cavities. Further analysis of beam dynamics can be found in other papers of this proceedings [**?**].

This hybrid system also offers better power efficiency than some of the present split and integrated electron creation and capture systems. Which is to say, the resulting electron bunches are accelerated to higher energies per megawatt in contrast to similar systems. For example: the UCLA Pegasus PWT Injector produces beams on the order

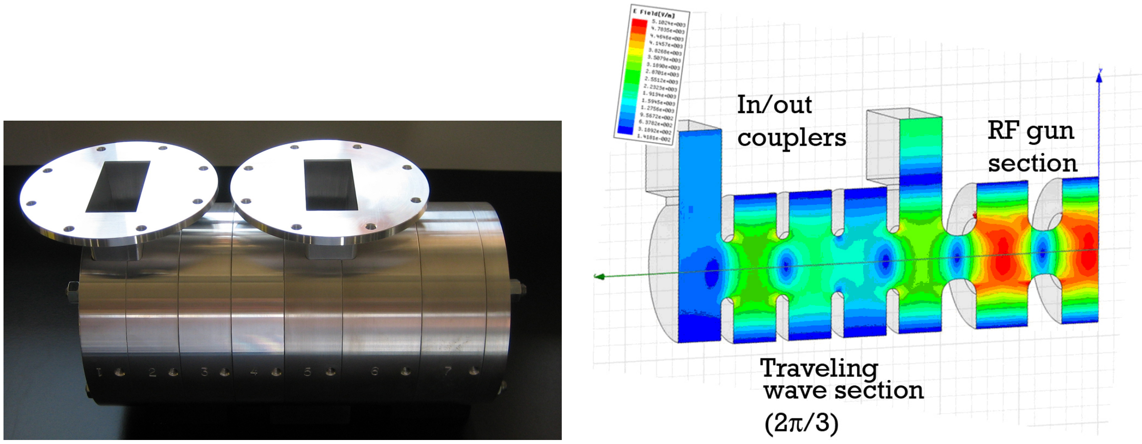


FIGURE 2. (a) Photo of the hybrid photoinjector cold test structure. (b) HFSS plot of the E-Field amplitude along the hybrid structure.

of 18 MeV from a 25 MW source [**?**], while simulations of the hybrid gun show beam energies of 21 MeV for that same 25 megawatts of input power. As well, the hybrid system splits power in a coupling cell which significantly reduces the amount of reflected power during the fill time of the gun. The division of power inside a coupling cell, instead of at the waveguide iris, decreases the amount of power reflected back into the RF system. Simulation results show a difference of 2.5 dB reflected power between fill times and normal operation. This reduction of reflected power is what gives the hybrid system it's ability to scale to higher frequency and thus higher brightness beams [**?**] as the requirement of circulators and isolators, to deal with reflected power, for standing wave structures at higher frequencies can prove costly and challenging.

DESIGN

The design of the hybrid photoinjector began with HFSS and SuperFish simulations and has progressed to cold test model analysis. First the traveling wave section was designed, in this case it was based on a design by Agostino Marinelli [**?**]: a $\frac{2\pi}{3}$ constant gradient, matched impedance TW linac designed for X-band. The di Laurea design was appropriately scaled to S-band, modified for integration with a standing wave gun and the phase advance was checked to ensure proper operating parameters. Next the 1.6 cell style gun was stripped of its waveguide and inputs, gained an exit iris identical to the connecting iris on the TW system and was tuned appropriately. Finally, the two pieces were joined together and the SW gun was given a final tuning to ensure proper resonance conditions, such as field balance, and once more the phase advance throughout the system was checked.

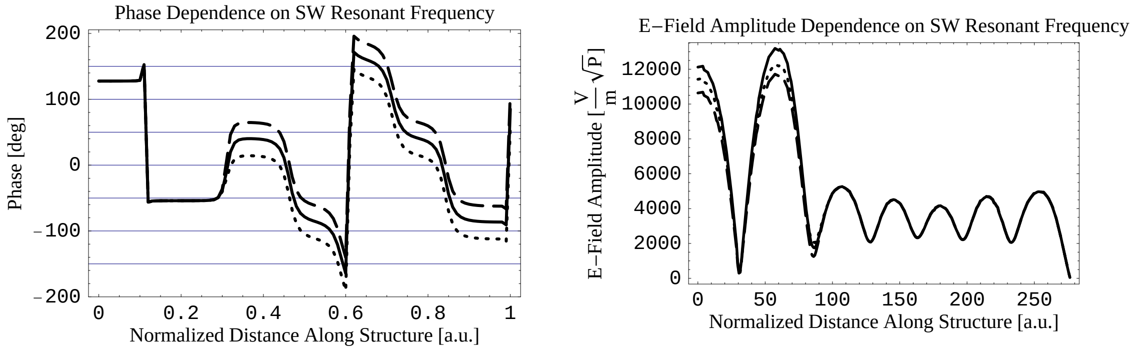


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FIGURE 3. (a) Phase advance due to change in resonance frequency in the gun. (b) The change of the E-Field amplitude along the hybrid with a change in driving frequency. In both plots the solid line represents the structure driven on resonance, the dashed line represents the system driven +50kHz and the dotted line -50kHz.

DESIGN POINTS OF INTEREST

There were a few developmental points of interest when designing the hybrid photoinjector. First, the ratio of the field intensities in the traveling and standing wave sections, set carefully by selection of coupling iris diameter. Second, a $\frac{\pi}{2}$ phase advance between the SW gun and the coupling cell. Finally, temperature control required of the final system for proper operation. These design points do not pose a serious threat to the hybrid gun's operation if care is taken to properly account for them.

Coupling Iris Tuning

The effect of the coupling cell iris is not unexpected as any change to the coupling cavity's geometry requires a corresponding change in the $Q_{e,w}$ (the external Q with respect to the waveguide) to ensure proper phase advance [**?**]. The iris between the traveling wave section and the standing wave gun behaves exactly as the iris between a waveguide and 1.6 cell gun would. Adjusting the iris parameters changes the external Q of the standing wave system and thus the magnitude of fields seen in the standing wave system. As one increases the diameter of the coupling iris the ratio of the fields between the two systems approaches unity. In Eq. 1, ϕ is defined as the phase advance per cell and κ in Eq. 2 as the inter-cell coupling parameter, where a is the iris radius. This change in phase advance in the TW system with changes to the coupling iris forces one to retune the $Q_{e,w}$ every time one wishes to adjust the amount of field in the gun. While it is possible to tune the coupling cell with the SW section attached this adds complexity and computation time to an already time consuming model and is simply easier to do before the two systems are joined.

$$\cos\phi = \frac{\omega_0^2 - \omega^2}{\omega_0^2 \kappa} \qquad (1)$$

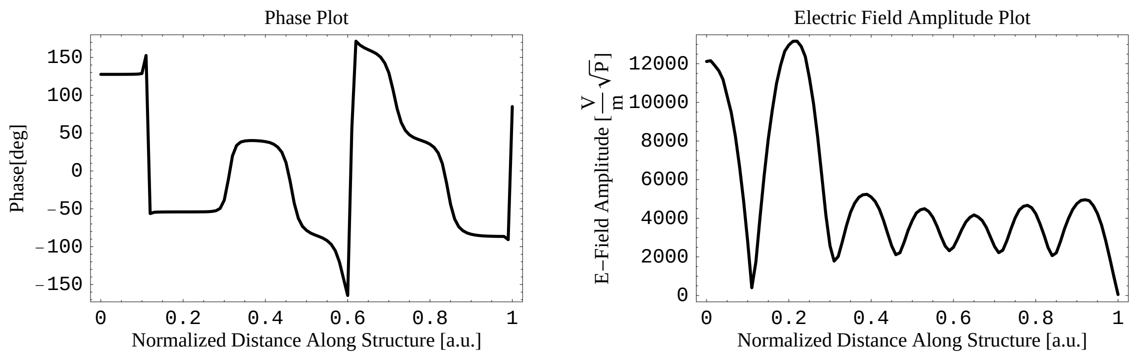

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FIGURE 4. (a) Simulated phase advance along a three TW cell hybrid model, as shown in Fig. 1. Here we see the $\frac{\pi}{2}$ phase advance following the gun and the $\frac{2\pi}{3}$ phase advance per cell in the TW section of the hybrid. (b) The electric field amplitude on axis in the hybrid gun model.

$$\kappa = 1.57\frac{a^3}{LR^2} \tag{2}$$

$\frac{\pi}{2}$ Phase Advance

Figure 4a shows a phase advance of $\frac{\pi}{2}$ between the standing wave gun and the traveling wave linac. Interestingly, this phase advance does not depend on the geometry of the coupling cell. Preliminary analysis has shown that transmissions lines coupled capacitively to simple loads do experience a phase advance of $\frac{\pi}{2}$ and further analysis is underway to more completely elucidate the underlying reasons for this phase advance.

The hybrid's natural $\frac{\pi}{2}$ phase advance allows for the development of two different hybrid structures. The first system, as developed here, is an Integrated Velocity Bunching system which takes advantage of the $\frac{\pi}{2}$ phase advance to place the bunch at the zero crossing in the first cell of the traveling wave structure. The second system, the Integrated Accelerating Structure, simply places the bunch back on crest in the first cell in the traveling wave section for pure acceleration. The difference between the two systems is the length of the coupling cell, which is used to temporally align the bunch with the desired phase.

Sensitivity to Temperature

Simulation has shown the hybrid gun to be temperature sensitive on the order of 0.1°C. Figure 3a shows the phase advance in the hybrid on resonance and ± 50kHz off resonance. Analysis shows 0.5°RF change per kHz which leads us, using the the standard thermal expansion adjustment 48 kHz per °C for copper, to 22°RF per °C and a required temperature control of 0.1°C for proper bunch-phase alignment downstream.

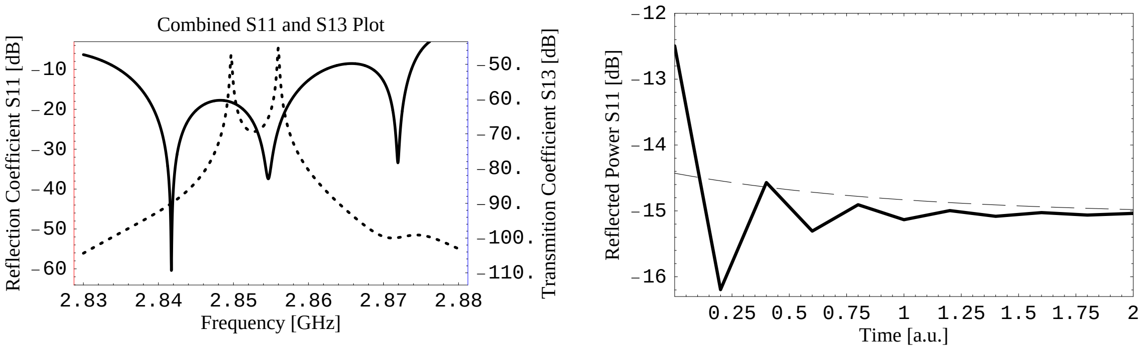

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FIGURE 5. (a) Complementary S11 and S13 plots. The S3 port being a coaxial cable placed on the half cell of the gun. Seen here the S13 port is receiving power and thus so is the SW section, however it does not have an impact on the S11. (b) The time domain response of the hybrid gun at the S11 port. The dashed line represents a fit.

Reflected Power

The design crux of the hybrid is it's ability to scale to higher frequencies without the difficulties associated with scaling in standing wave structures. To remove these difficulties the system has been designed to minimize the impact of the standing wave section on the S11. Simulation results shown in Fig. 5b show the power reflected as a function of time and in Fig. 5a the S11 of the structure. We see in the latter that the gun has no real impact on the S11 and through repeated simulation it has been seen that the gun, when especially well tuned and coupled ideally, adds at most two small "notches" to the S11. This reduction in reflected power is due to the design of the coupling cell to split the power between the standing wave and traveling wave systems. The present coupler has been designed to split approximately 10% of the input power into the standing wave section. While power is still being reflected at the iris into the standing wave section during the gun's fill time, this reflected power is split between returning to the source and traveling down the traveling wave section to the exit port. This power splitting is what allows for the small 2.5 dB difference in S11 during fill times.

CONCLUSION

We have demonstrated the feasibility of integrating standing wave and traveling wave structures to produce an injector capable of delivering beams useful to the accelerator community. The use of a coupling cell for power division has been shown to give promising results in terms of reflected power and thus the ability of the hybrid photoinjector to scale to higher frequencies. As of this writing the prototype model has been produced and is being prepared for cold test analysis. Current studies include a similar structure developed in the X-Band regime by Universita degli Studi di Roma "La Sapienza" (URLS) as well as investigation into methods for physical measurement of important parameters.

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