COUPLING AND POLARIZATION CONTROL IN A MM-WAVE UNDULATOR*

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Abstract

To reduce the linac energy required for an FEL radiating at a given wavelength, and hence its size, a smaller undulator period with sufficient field strength is needed. Previous work from our group successfully demonstrated a microwave undulator at 11.424 GHz using a corrugated cylindrical waveguide operating in the HE_{11} mode. Scaling down the undulator period using this technology poses the challenge of confining and coupling the electromagnetic fields while maintaining overmoded features for power handling capability and electron beam wakefield mitigation. We have designed a mm-wave undulator cavity at 91.392 GHz. This undulator requires approximately 1.4 MW for sub-microsecond pulses to generate an equivalent K value of 0.1. Transferring such amounts of power in mm-wave frequencies requires overmoded corrugated waveguides, and coupling through irises creates excessive pulsed heating. We have designed a novel mode launcher that allows coupling power from a highly overmoded corrugated waveguide to the undulator through the beam pipe. Additionally, this mode launcher can be used along with grating polarizers to control the polarization of the produced light.

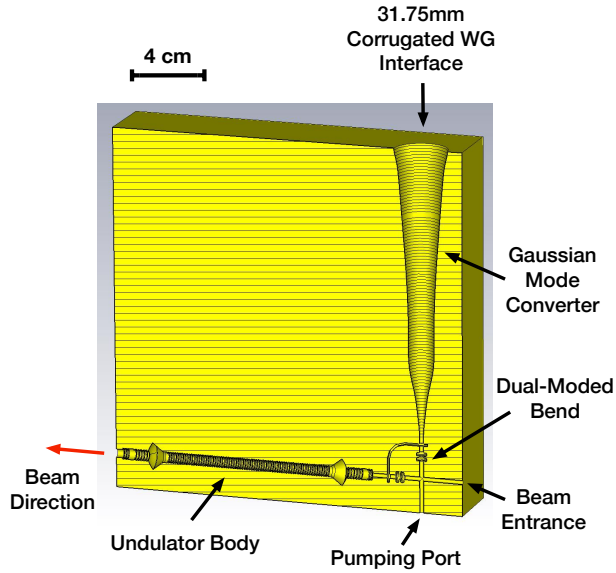

Figure 1: Millimeter-wave undulator with coupling system cross-section.

INTRODUCTION

Synchrotron light sources and Free-Electron Lasers (FELs) are very large and expensive facilities. These facilities typically employ permanent magnet undulators, which present several limitations on how short their period can be while maintaining reasonable field strength and beam aperture. In order to reduce the undulator period, and hence the size and cost of light source facilities, several alternatives to traditional permanent magnet undulators have been investigated, one of which is microwave undulators [1]. Microwave undulators present the advantage of fast control of the polarization of the produced light. A microwave undulator has been successfully demonstrated at 11.424 GHz [1].

Polarization control in synchrotron light sources and FELs has several applications in the study of magnetic materials [2–4] and biological molecules [5,6], including drugs [7]. Circularly polarized light has been generated in synchrotron light sources using off-plane bending magnet radiation [8] and a variety of insertion devices [9]. Circularly polarized ultraviolet and soft X-ray light has also been generated in FELs [10, 11]. Recently a delta undulator [12] was installed in the Linac Coherent Light Source (LCLS) at SLAC to produce even higher energy polarized X-rays [13]. The time required for the LCLS delta undulator to switch polarization between left and right was 35 s [13]. Other methods of producing polarized soft X-rays include high harmonic generation sources [14], which are not efficient in the X-ray regime, and using magnetized films [15, 16], which are limited to specific wavelengths, low intensity, and only up to 60 % circular polarization.

We have designed a novel mm-wave undulator cavity at 91.392 GHz [17]. In this work we report the design of the coupling system for the undulator, which preserves the polarization of the input and has large apertures for pumping and for the electron beam to enter the undulator. Figure 1 shows the undulator with the coupling system. Power is transferred to the undulator from a mm-wave source through an overmoded corrugated waveguide in order to minimize the losses. The standard rectangular waveguide WR10 has more than 3 dB m^{-1} attenuation [18], while a 31.75 mm corrugated waveguide has approximately 0.004 dB m^{-1} attenuation [19]. Additionally, for the device to operate under vacuum, a vacuum break with a flange is required. Due to the small dimensions of WR10, it is very difficult to implement a reliable vacuum flange for this waveguide. We therefore decided to place the vacuum break at the interface with the corrugated waveguide, where a standard flange exists. The coupling system consists of a Gaussian to cylindrical TE_{11} mode converter and a dual-moded bend. These components

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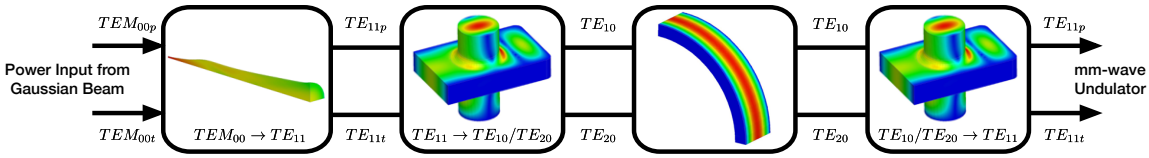


Figure 2: Coupling system schematic.

and the respective mode conversions are shown schematically in Fig. 2.

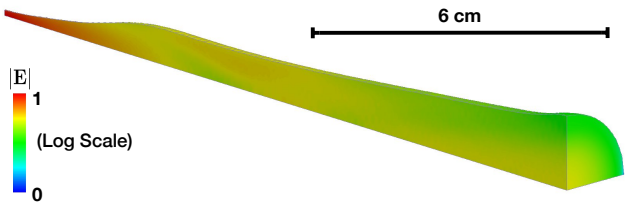
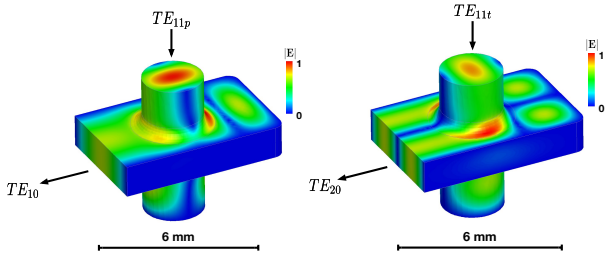


Figure 3: Surface electric field profile of the Gaussian to TE_{11} mode converter (log scale).



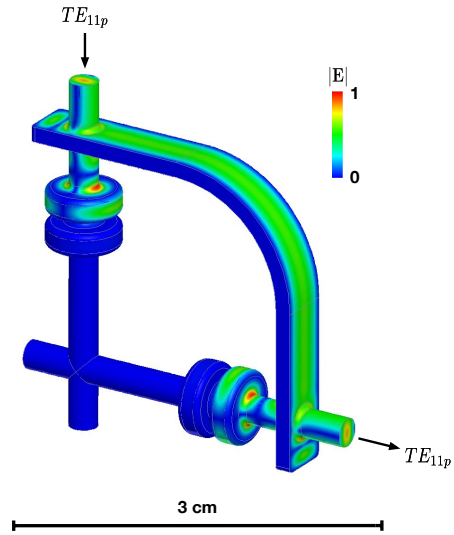
(a) Parallel polarization. (b) Transverse polarization.

Figure 4: Surface electric field for the cylindrical TE_{11} to rectangular TE_{10}/TE_{20}.

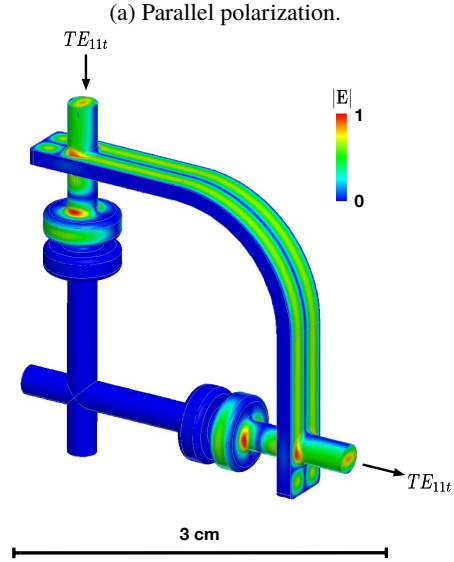
COUPLING SCHEME DESIGN

Gaussian to TE_{11} Mode Converter Design

The Gaussian to TE_{11} mode converter is used to convert a Gaussian TEM_{00} mode to a smooth-walled cylindrical waveguide TE_{11}. The smooth cylindrical waveguide is sized to only support TE_{11}. This mode converter is axisymmetric, and therefore the two polarizations TEM_{00p} and TEM_{00t} of the Gaussian mode convert to the equivalent polarizations in the cylindrical waveguide TE_{11p} and TE_{11t}. Figure 3 shows the Gaussian to TE_{11} mode converter. The complex Gaussian coupling factor is 0.99, the cross-polarization level is −23 dB, the Gaussian beam waist is 0.94 cm, and the reflection coefficient from the cylindrical waveguide is 0.0028. This mode converter was synthesized using a Mode Matching Code [20] and the method described in [21]. At the Gaussian side of this mode converter there will potentially be a vacuum window, to isolate the vacuum system of the undulator from that of the RF transport lines.



(a) Parallel polarization.



(b) Transverse polarization.

Figure 5: Surface electric field of the dual-moded bend.

Dual-Moded Bend Design

The TE_{11} coming from the Gaussian to TE_{11} mode converter is subsequently converted to a rectangular waveguide mode. The rectangular waveguide is sized to only support TE_{10} and TE_{20}. As shown in Fig. 4, the cylindrical TE_{11p} is converted to the rectangular TE_{10} and the cylindrical TE_{11t} is converted to the rectangular TE_{20}. The bottom of this mode converter is opened by adding chokes. We designed a two-piece choke, shown in Fig. 5 to account for manufactur-

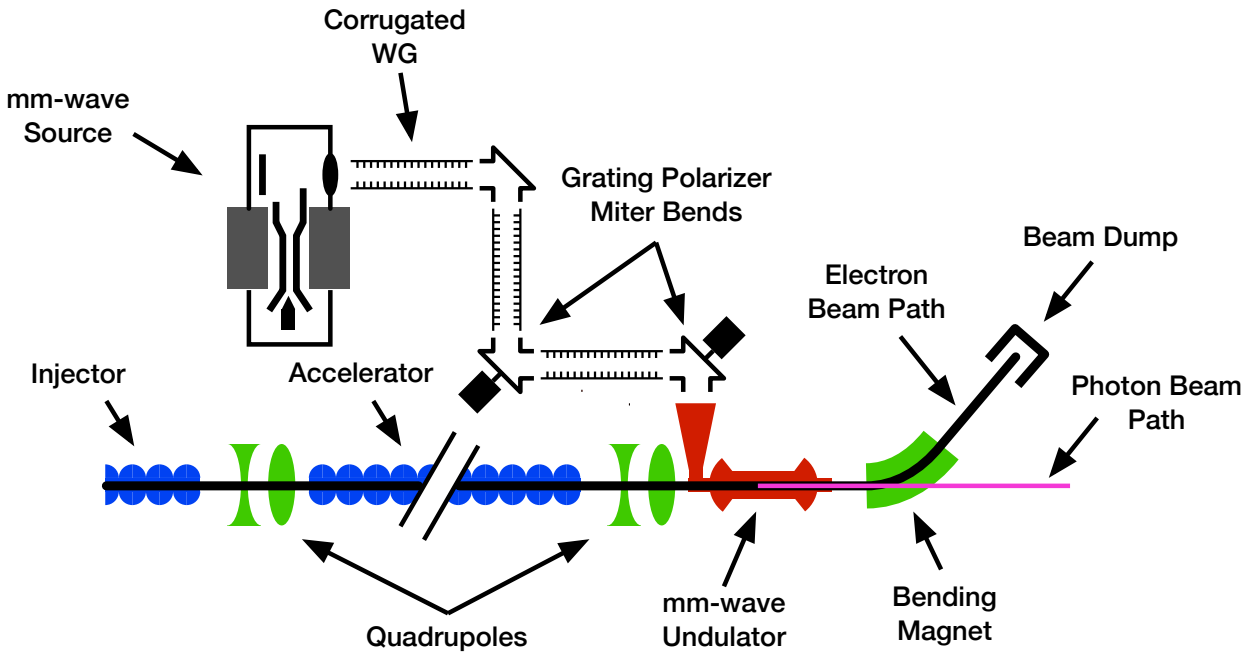


Figure 6: Light source schematic utilizing the mm-wave undulator with polarization control.

ing tolerances. The two rectangular waveguide modes are then transmitted through an E-plane bend, connected to a second rectangular-to-cylindrical mode converter.

Figure 5 shows the system of the two rectangular to cylindrical mode converters, the rectangular bend, and the chokes. The system is optimized so that there is no phase slippage between the two polarizations of TE_{11} at the end of the mode converter. As can be seen in Fig. 5, each polarization of TE_{11} at the input cylindrical waveguide is transmitted unaltered to the output cylindrical waveguide. The use of chokes allows for two orthogonally placed through holes, one for the electron beam to enter the undulator, and one to pump the vacuum space of the mode converter. For a 10 MW power flow through this mode converter, the peak magnetic field on the metal surface is 282 kA m^{-1}. From [22] the peak pulsed surface heating for 250 ns RF pulses is 48 °C, which is considered safe for copper [23]. Figure 1 shows the entire system assembly with the undulator.

POLARIZATION CONTROL

Polarization of the produced light is directly controlled by the polarization of the Gaussian mode incident to the undulator system of Fig. 1. TE_{11} gyro traveling wave tubes such as the one reported in [24–26] could be modified to produce variable polarization by having two input signals separately coupled to the two polarization of the TE_{11}. A change of polarization between left and right could be achieved between RF pulses, the spacing of which is typically on the order of milliseconds. Another method to control and change the polarization is the use of a pair of grating polarizer miter bends with motors [27]. In this case, the speed of polarization change is limited by the motors and is on the order of a second. Figure 6 shows the schematic of a light source utilizing the mm-wave undulator with polarization control.

CONCLUSION

We reported the design of a novel coupling scheme for a mm-wave undulator at 91.392 GHz. Power is transferred from the mm-wave source through a 31.75 mm corrugated waveguide. The HE_{11} in the corrugated waveguide is converted into cylindrical TE_{11}, and then bent 90° while preserving polarization. Power is coupled into the undulator through the beam pipe. This coupling scheme allows for fast change of polarization between left and right on the order of a second using grating polarizers, and on the order of milliseconds through the mm-wave source. In comparison, the time to switch polarization between left and right for the LCLS delta undulator is 35 s.

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