PIC Simulation Study of L-band Bifrequency Magnetically Insulated Line Oscillator

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Abstract

A bifrequency magnetically insulated line oscillator (BFMILO) generating RF at two frequencies in L-band with azimuthal partition has been presented. The standard device design methodology has been followed with tuning the cavity depth in azimuthal direction for the design of two different and stable frequencies and validated through simulation. The dispersion diagram for *L*-band bifrequency calculated through eigenmode simulation. For the PIC simulation of the device, typically selected beam parameters: diode voltage of 420 kV and diode current of 38 kA, generates the RF of ~1.28 GW at frequencies 1.31 GHz and 1.53 GHz. The overall power efficiency of ~8% has been achieved through the device. In addition, modification in the collector with the introduction of beam dump disc, improves the overall efficiency to ~9.8%.

1. Introduction

The magnetically insulated line oscillator is a gigawatt level High Power Microwave (HPM) device operating in GHz frequency range [1-5]. Due to the ability of its self-magnetic insulation, it can operate at high input voltage without vacuum breakdown [4]. For academic and potential practical purpose MILO can be designed with the ability to generate two stable and separate frequencies named as BFMILO [1-2].
The generation of two frequencies from a single HPM device has been investigated in recent years because of its uses in plasma heating, energy transmission in long distances and electronic warfare systems. The HPM sources which generate dual-frequencies are a Cerenkov oscillator, a relativistic backward oscillator (RBWO) and MILO. There are three different ways to divide the structure to obtained bifrequency: one is to tune the cavity depths in the azimuthal direction, another is to change plate heights in different azimuthal partitions and the last is to do both the plate heights and cavity depth [1-2]. To obtain a stable bifrequency oscillation, SWS design uses 2nd way with two different cavity depths by changing SWS discs with two different inner radiuses in the azimuthal direction. The dual cavity SWS supports an operating mode corresponding each of the two azimuthal cavity depth. Each mode has an operating frequency to support two stable and separate oscillation frequencies.

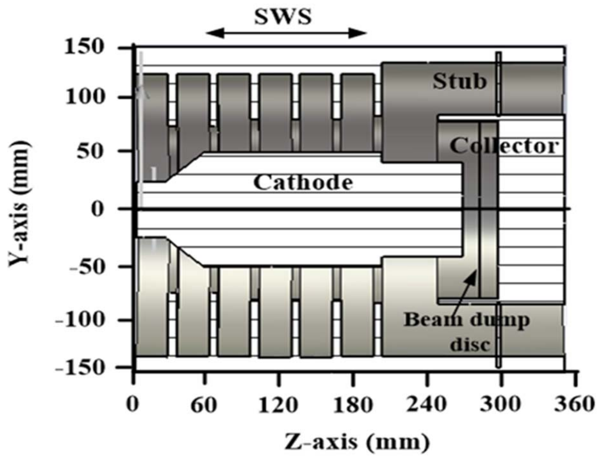

Figure 1. Schematic diagram of azimuthal partition bifrequency MILO.

Figure 1 shows the schematic diagram of azimuthal partition bifrequency MILO. The design methodology follows the similar procedure as the conventional MILO with two choke discs at the input side, three SWS disc of radius rd, extractor disc, the cathode of radius rc, collector and stub. Azimuthal partition at 1800 forms two different cavity depth rw1 and rw2. Step ladder cathode designed in this device for better magnetic insulation and beam wave interaction.
In this Paper, a detailed PIC simulation of BFMILO followed by cold simulation has been performed for L-band generating frequencies of 1.31 GHz and 1.53 GHz. In section II, beam absent simulation is performed for obtaining the operating frequency and modes for the device through dispersion characteristics and field patterns, respectively. In section III, beam present simulation has been performed for explaining the beam-wave interaction and RF output power developed in the device followed by modification in the collector design for performance improvement. Section IV concluded the study of the BFMILO.

2. Eigenmode Simulations

The beam absent simulation of the azimuthal partition unit cavity structure is performed using the device design parameters given in table I. eigenmode solver of 'CST Microwave Studio' is used for cold test of SWS structure. To define the operating frequency of the device, the dispersion characteristic of the SWS structure is evaluated for different modes. Figure 2 shows the dispersion curve for five different modes. Due to the azimuthal partition of the SWS cavity, asymmetric modes are generated inside the structure. Mode 1 is the fundamental symmetric mode, mode 2 and mode 3 are the degenerate HEM_{11} mode and mode 4 and mode 5 are the degenerate HEM_{21} mode [3]. The magnetic field vector distribution of mode 1 and mode 3 shown in Fig. 3 explain the maximum field distribution in two different azimuthal partitions [3]. In mode 1, the magnetic field distribution mainly located in the azimuthal cavity of 180^0-360^0. Similarly, the magnetic field distribution of mode 3 located in the azimuthal cavity of 0^0-180^0. Thus, mode 1 and mode 3 are the operating modes of the BFMILO with π-mode frequency of 1.31 GHz and 1.53 GHz, respectively.

Table 1. Design Specification of BFMILO [1].

Particulars	Specifications
Voltage	420kV
Current	38kA
Cathode Radius (r_c)	55 mm
Anode Radius (r_w)	129 mm, 140 mm
SWS Disc Radius (r_d)	86 mm
Extractor Disc Radius	90 mm
Choke Disc Radius	80 mm
Disc Thickness (T)	7 mm
Periodicity (L)	34 mm

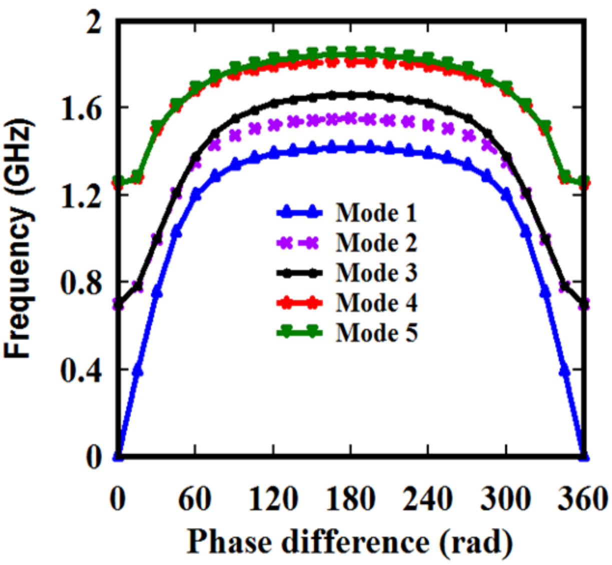

Figure 2. Dispersion curve for azimuthally non-uniform structure with rw1=129mm and rw2=140mm.

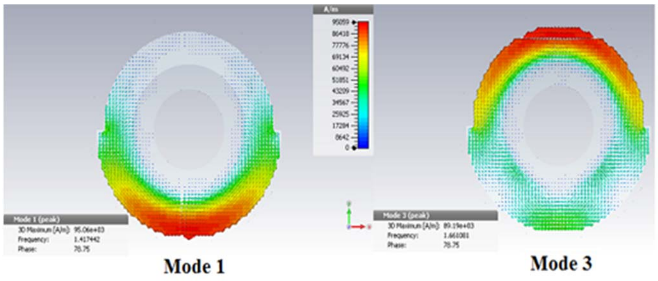

Figure 3. Magnetic field vector distribution for operating modes: mode 1 and mode 3.

3. PIC Simulations

After the cold simulation, which describes the operating modes and frequency of the structure, beam present simulation is carried out using PIC solver of 'CST Particle Studio'. A high voltage of 420 kV DC pulse is applied between cathode and anode which causes electrons emission from the cylindrical cathode curved surface generating 38 kA current. Emitted electrons initially move radially toward slow wave structure generating current and after magnetic insulation flow in axial direction [4]-[5]. Magnetic insulation achieved by the device by current called 'critical current'. The critical current required to maintain magnetic insulation can be achieved by load length (cathode projecting inside the collector). The magnetically insulated electron sheath induces noise and generates oscillation at two frequencies when drift velocity of electrons become equal to phase velocity supported by SWS cavities in different azimuthal partition [1-3]. Figure 4 shows the beam wave interaction of the magnetically insulated electron sheath in two different azimuthal cavities at different time instance. It can be seen from the figure 4 that the beam wave interaction is not azimuthally symmetric which conforms the hybrid modes generation inside the device. Figure 5 shows the input power of the device after the application of 420 kV of DC voltage at the input side which is ~16.15 GW. A waveguide port is added at the output side of the device to observe the output RF signal at different modes. Figure 6 shows the RF signal generated after beam wave interaction at mode 1 (TE_{11}) and mode 3 (TM_{01}) with time.

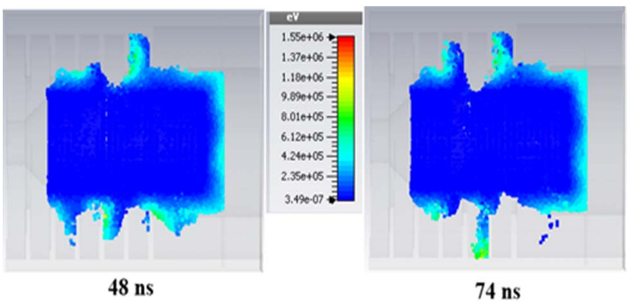

Figure 4. Phase space of the electron particles at different time.

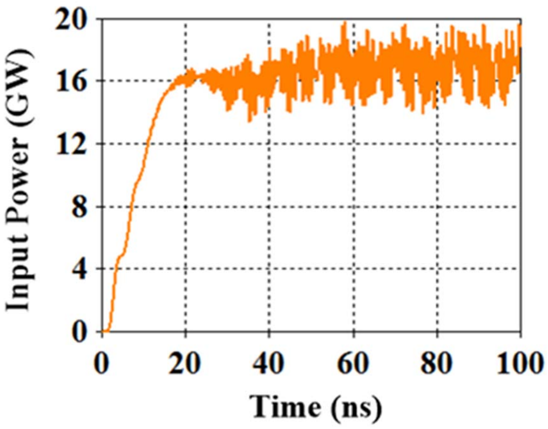

Figure 5. Temporal wave particle power transfer.

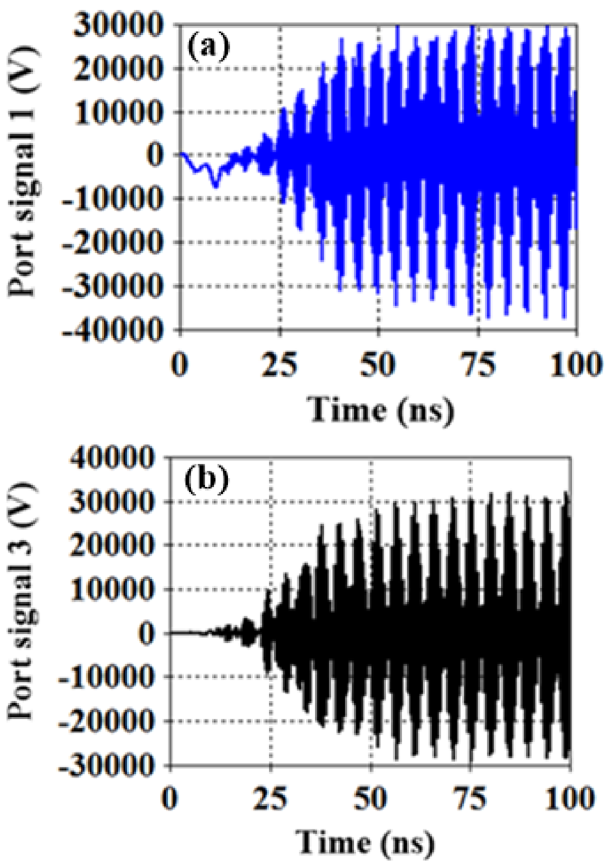

Figure 6. Temporal RF port signal of (a) mode 1 (b) mode 3.

The FFT of the voltage signal generated at the output port is shown in figure 7. It can be observed from the figure that the device operated at two frequencies *i.e.* 1.31 GHz and 1.53 GHz. The drop in the frequency from the cold test to the PIC simulation is due to beam loading effect. After combining the RF signal generated at mode 1 and mode 3, the peak RF output power of 1.29 GW and modified RF output power of 1.59 GW is obtained. Figure 8 shows the combined temporal RF output power of the two modes.

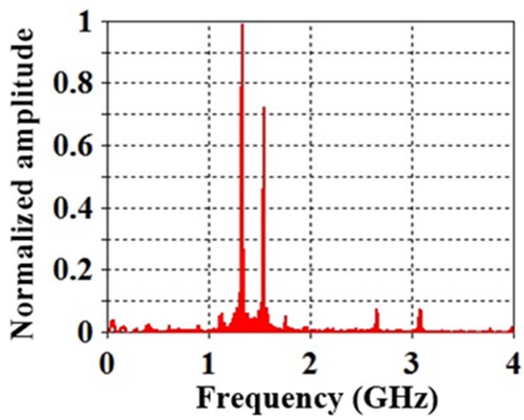

Figure 7. Frequency spectrum of RF signal.

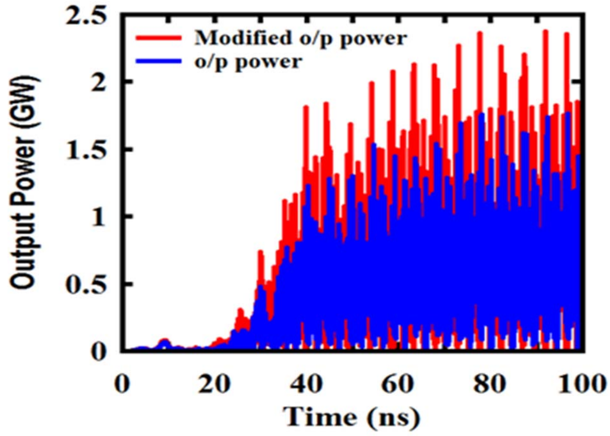

Figure 8. Combined temporal RF output power of the two modes with and without collector design modification.

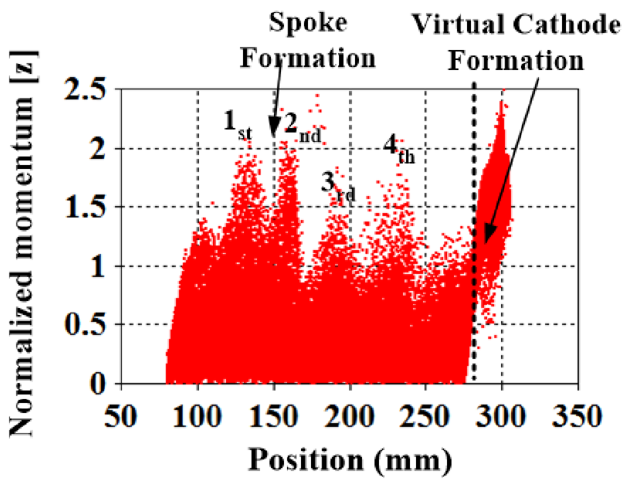

Figure 9. Virtual cathode formation at the collector through beam dump disc.

Further, to improve the performance of the device, a beam dump disc is used inside the collector. This beam dump disc accumulates the electrons present inside the collector and helps in the formation of virtual cathode. The virtual cathode formed inside the collector help to reflect back the bunch of charges towards the SWS cavities for further beam wave interaction [5]. Figure 9 shows the normalized momentum at different axial position of the device. It can be seen from the figure that virtual cathode is formed at the beam dump position with is at 280 mm.

4. Conclusion

A detail study of *L*-band Bifrequncy MILO is performed through simulation. The device design is validated through cold test using dispersion curve and field vector plot. After then, the device performance evaluated with the typically selected beam parameters: diode voltage of 420 KV and diode current of 38 kA. RF signal generated at two modes is obtained at the output with combined RF peak power of ~1.29 GW. The overall efficiency of ~8% is obtained through the device. After the validation, a beam dump disc is used for reuse of electron beam present in collector results performance improvement by enhancing efficiency to ~9.8%.

5. References

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