# Investigation of Different aspects of the Side-Coupled Cavities type Interaction Structures for the Slow Wave High Power Electron Beam Devices

**Thesis Submitted in Partial Fulfillment for the Award of Degree**

## Doctor of Philosophy

**by**


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CHAPTER 6

# SUMMARY, CONCLUSIONS, AND FUTURE SCOPE

**6.1. Summary and Conclusions**

**6.2. Suggestions for Future Research**

# SUMMARY, CONCLUSIONS AND FUTURE SCOPE

## 6.1. Summary and Conclusions

High-average power HPM sources are in need for the development of HPM systems for several strategic and important potential applications in various fields, such as, electronic warfare, directed-energy weapon, jammer, imaging, high power radar, study the effect of HPM on the survivability/ vulnerability of electronic component or devices, food irradiation, material processing, cargo inspection, scientific, medical, and others. A huge research gap has been identified between the high-average-power or high-energy, high-repetition-based devices and the high-peak-power or single-shot or low-repetition microwave sources, which gives motivation to the author to carry out research on such type of devices.

Due to the high efficiency, compact size, multiple frequency operation, frequency stability, frequency tunability, and long pulse operation with high PRR, the grid-less reltron attracts the researchers to perform the research. To know the behavior of the RF interaction structure (i.e. the core of any device) in the presence and absence of the electron beam is very important for a better understanding of the device's mechanism. Therefore in this thesis, earlier in Chapter 2, we investigated the behavior of SCC in the absence of an electron beam. In this chapter, we proposed an alternative method to calculate the magnetic coupling coefficient (or inter-cavity coupling coefficient) in terms of SCC's structural parameters. In addition, an empirical expression was also proposed to estimate the resonant frequency associated with the fundamental resonance mode, including the effect of the magnetic coupling factor ($k$). The proposed empirical expression removes the flaws that exist in the literature described earlier. After completing the SCC behavior in the absence of an electron beam, in Chapter-3 we examined the behavior of SCC in the presence of an electron beam. In this chapter, we first proposed an equivalent model of the SCC and then derive EM expressions associated with different regions of the structure. These EM expressions were equated in the derived boundary conditions to get the dispersion relation. The temporal growth rate behavior was also investigated for the SCC and found that the temporal growth rate associated with the fundamental resonance mode was highest, which specifies that imaginary frequency associated with fundamental resonance mode increases rapidly as compared to the other resonance mode frequency. After examining the SCC behavior, simulations of grid-less reltron were performed, and then a new variant of the reltron was proposed to improve the performance of grid-less reltron. Finally, the work of the thesis is aligned as follows:

In Chapter 1, the basic idea behind the origin of the HPM source, the definition of the HPM source, and then the various possible way to classifying the HPM source was described. Furthermore, a detailed literature review of reltron, the various approaches to classify it, the key features, and the various potential applications were discussed. Finally, the motivation and research objectives behind this research study were given.

In chapter 2, the fundamental resonance mode frequency (i.e. frequency associated with the $\pi/2$-mode) of the pillbox cavity-based SCC was investigated theoretically using an equivalent circuit approach. Then an expression was developed to calculate the magnetic coupling factor ($k$) in terms of their structural parameters. This developed theoretical analysis provides an alternative approach to calculate the value of the magnetic coupling factor ($k$), which gave a reference value of design and experimental verification. Furthermore, an empirical expression was also proposed to estimate the resonating frequency associated with the fundamental resonance mode, in which the effect of the magnetic coupling factor ($k$) was included. The proposed empirical expression to calculate the resonating frequency associated with fundamental mode removes the flaws, which exist in the previously reported expression. The results from the proposed empirical expression and simulation were compared to validate the theoretical analysis. The relative error between the simulated results and the proposed empirical expression was below 1%, which shows good agreement and validates the performed theoretical analysis.

In chapter 3, the SCC structure was analyzed in the presence of an electron beam for its dispersion characteristics using the field matching approach. Since the SCC structure had the potential to be used as a beam wave interaction structure in a slow-wave microwave oscillator such as transit time oscillator, backward wave oscillator, traveling wave tube, etc. The SCC also found its application as the beam-wave interaction structure in a highly efficient reltron oscillator. Therefore, the dispersion behavior and the temporal growth rate behavior were investigated. Simultaneously the effects of different beam radii on the temporal growth rate were investigated and the results indicate that the instability grew rapidly with larger beam radii. To validate the preciseness of the derived analysis, the analytically obtained dispersion curve was compared with the simulated dispersion curve for the special case (i.e. $r_e = 0$). The analysis helped the system engineer to get a better understanding of the structure and reduce the complexity of the SCC's design.

In Chapter 4, we discussed the pulse shortening phenomenon in the conventional reltron, which was based on explosive emission cathode. The high-density electron beam generated through the explosive emission cathodes gave a high-density plasma inside the device which was responsible for the pulse shortening in explosive emission-based HPM source and it also limits the PRR of the device. This problem can be avoided by using the thermionic emission cathode in the reltron (i.e. grid-less reltron). In this case, the plasma density was lower due to lower current and remains in its super-conducting zone. Hence, longer pulse operations with a higher PRR became feasible. The design methodology of the grid-less reltron, the effect of the different structural parameters of the RF interaction cavity on the EM behavior. The effect of the different electrical parameters on the device performance was also presented. To validate the developed design methodology, the designed grid-less reltron was compared with the experimental reported device. The simulation results found that the designed device generates an RF output power of ~22 MW at the operating frequency of 2.856 GHz with a device efficiency of ~44%. The simulated results were found to be within 5% of the experimental values. The design methodology and simulation studies of the grid-less reltron might be useful for the HPM system designers looking for higher RF energy, longer RF pulse with a high PRR HPM source.

In chapter 5, a novel variant of the reltron i.e. grid-less reltron with explosive emission cathode was proposed to overcome the problem associated with the gridded reltron (i.e, low RF pulse width, and low PRR) and grid-less reltron (i.e. low RF output power). A comprehensive simulation study was carried out to analyze the effect of various electrical parameters on the RF performance of the proposed device. The simulation study showed that the proposed variant was capable of producing peak RF power comparable to the gridded reltron while the pulse width was comparable with the grid-less reltron. The proposed device operates with a lower operating voltage, so the probability of plasma formation (which was the main cause of pulse shortening) was greatly reduced, and this lower operating voltage also helped to achieve a higher PRR of the device. From this simulation study, the author hoped, that the proposed variant meets the demand for a compact HPM device capable of generating high peak RF power, long RF pulse width, and high repetitive pulse operation.

In the last chapter i.e. Chapter 6, the work embodied in the present thesis was summarised, and significant conclusions were drawn from the major findings.

## 6.2. Suggestions for Future Research

In the present thesis, the RF interaction cavity of grid-less reltron oscillator i.e. SCC were studied through various analytical approaches as well as EM simulation software. Also, a comprehensive simulation study of grid-less reltron was performed to investigate the structural and electrical parameter dependency. Finally, a new variant of grid-less reltron was proposed to improve the RF output power of the device and investigate its RF performance for the different possible electrical specifications through simulation. During the research study, some research gaps were found and these gaps listed below for future research studies:

(1) The structures proposed here in the current thesis should be worked on (i.e. low-impedance coaxial reltron or radial reltron) to further improve RF performance.

(2) To improve the performance of the device, the unsymmetrical double-gap output section can be used.

(3) Research should be done on a proposed parallel reltron configuration to improve the performance of the device. In this configuration, the same input is applied parallelly to two or more reltron structures, and then separately generated RF output power is added with the help of a power combiner.

(4) Research studies are needed in the beam dump or collector section to further improve the performance of the device which is not explicitly described in the literature.

(5) The present work is focused only on the oscillator, but the work can be extended to the amplifiers as well.