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Research Article

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Optimization of Klystron Cavity Using Dielectric Materials

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Abstract This paper describes the effect of replacing some metal part with dielectric in the design of klystron cavity in order to reduce losses and improve general efficiency of the cavity resonators, this will also save large amount of power since klystron are Megawatt device.

SUPERFISH modelling package was used in designing the dielectric klystron cavity, with a starting frequency of 1.2GHz.

The findings have shown that a piece of dielectric material with stable temperature and with high permittivity can act as microwave resonator with even better Q-factor, shunt impedance (R_{sh}), Geometric shunt impedance(R_{sh}/Q), frequency etc.

Keywords Resonator, Quality factor (Q), Klystron cavity, Dielectric, SUPERFISH

Introduction

The Klystron is one of the device classified as linear beam tube used in high power generation and amplification, it's prefer tube for high power, high stability amplifications of signals at frequencies from UHF – 30GHz.

Two Cavity Klystron Amplifier

The two-cavity klystron amplifier operates on the principle of velocity modulation [2]. It consists of cathode, focusing electrodes, two cavity resonators separated by a small distance forming a gab and collector at the tail end.

The first cavity which is close to the cathode is called the buncher cavity or input cavity, which velocity modulates the electron beam. The second cavity is called the catcher cavity or the output cavity, it picks amplified RF energy from the bunched electron beam [2].

The signal fed in through the buncher cavity set up the magnetic field which brings the resonator in operation. That is an electric field is originated within the cavity gab, and continue to change direction due to the changing magnetic field.

The electron being negatively charged particle would therefore be accelerated if they move against the direction of the electric field. On the other hand, the electron would be decelerated if they move in the same direction with the changing electric field within the cavity gab. With the alternating field present, the electron traversing along the drift tube would thus be alternately accelerated and decelerated, thus the average kinetic energy of the outgoing electrons is nearly equal to the energy of the incoming electrons and almost no energy is taken from the field of the first cavity, consequently they will enter the field free space between the two resonators at varying speed in the space known as drift space, the past electron would overtake the slow one and bunches will be form.

The second cavity or the catcher is located in the position where the bunches are fully formed or contain greatest number of electrons. The bunches arrived at the catcher cavity at an interval correspond to the frequency with which the first cavity oscillate, as both cavities are made identical, this interval also correspond to resonance frequency of the catcher cavity, therefore the later start to oscillate. The catcher cavity absorbed energy from the electron beam.
The alternating magnetic field inside the second or output cavity is partly link with the coaxial cable, and this initiate the output signal.
Klystrons are widely used in radar, satellite, wideband high communication, medicine, particle accelerators in physics, etc. Considering the vast and potential nature of the klystron application areas, provision of better cavity with low loss is paramount important and this research is a stepping stone in the right direction.

Materials and Method

This modelling was based on the designed and simulation of 1.3GHz Klystron cavity presented by [1], this research carried out further investigation using dielectric materials with permittivity(εr) = 37. The geometry and the design parameters of the klystron cavity and the drift tube are presented below

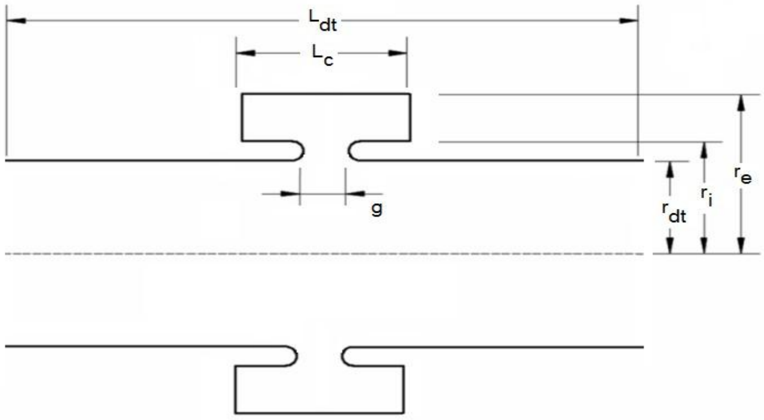

Figure 1: Geometry of a cylindrical klystron cavity and drift tube. [1]

Where;

L_c = cavity length,
r_{dt} = drift tube,
g = gab between two drift tube inside the cavity,
r_e = external radius,
r_i = internal radius, and
L_{dt} = length of the drift tube.

The starting frequency was set at 1.2GHz. All the dimensions are based on [1] except this paper presented in cm are shown in the table below,

Table 1: Cavity parameters for using the SUPERFISH

Quantity	Value(cm)
Cavity length(L_c)	4.50
External cavity Radius(r_e)	4.45
Internal cavity radius(r_i)	1.80
Gab(g)	0.50
Drift tube radius(r_{dt})	1.40
Length of drift tube(L_{dt})	12.0

Modelling of Klystron Cavity

Mellatic klystron cavity was first modelled using the values presented in table 1, base on paper [1]. Dielectric klystron cavity was also modelled using the same dimension as in table 1. Dielectric with a thickness of 0.40cm and with permittivity of 37 was used in the space between the cavity and the drift tube

Lastly, modelling of dielectric cavity with different dielectric thickness was also carriedout to determine the effect of thickness in dielectric cavity design.

Results and Discussion

SUPERFISH software was usedwith the cavity parameters on table 1. Starting frequency was set at 1.2GHz, and the simulation output shows that the unloaded Q is about 8600. Other important figures of merit from the output results are shown on table 2 below.

Table 2: Simulation results of Q, Rsh/Q, and frequency of metallic cavity

Quantity	Q	Cavity $R_{sh}/Q(\Omega)$	Frequency(GHZ)
Metal cavity	8600	71.98	1.293

The output also shows that the total wall losses for the modelled metallic cavity and the drift tube are about 11.63watts. The figure 2 shows the orientation of the electric field within the cavity and the drift tube.

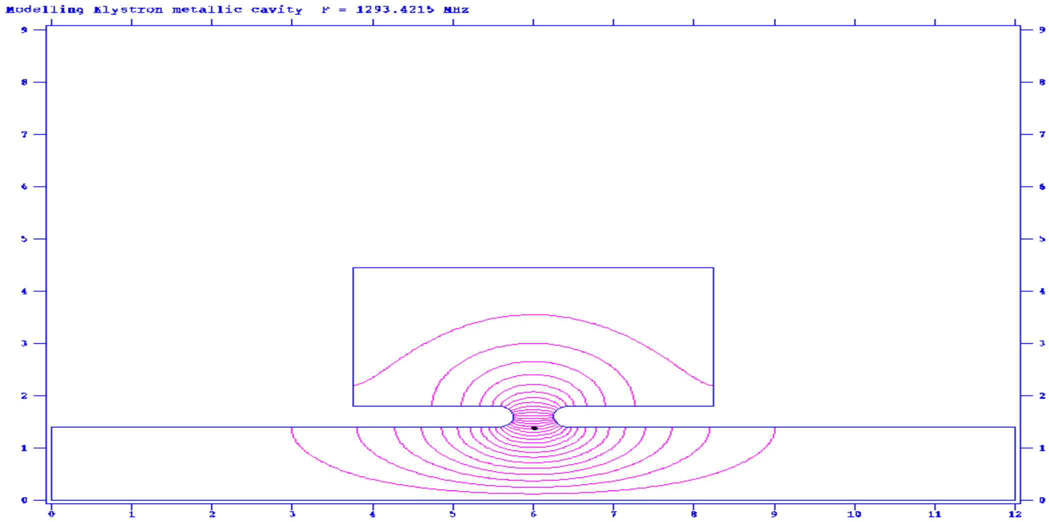

Figure 2: Cross section of electric field for cavity of fig 1 and dimension in table 1

The modelled klystron cavity figures of merit remain unchanged after SEG file test was also run to specify losses due to each segment of the cavity.

Modelling of Dielectric Klystron Cavity

Dielectric klystron cavity was designed using the same dimension as in table 1. The space between the cavity and the drift tube was used to incorporate the dielectric with a thickness of 0.40cm and with permittivity of 37. After the test, the SUPERFISH results for both metallic and dielectric incorporated cavity are shown in the table 2 below.

Table 3: Comparison between modelled Metallic and Dielectric Cavity Figures of Merit

Quantity	Q	Cavity $R_{sh}/Q(\Omega)$	Frequency(GHZ)
Metal cavity	8600	71.98	1.293
Dielectric Cavity	14309	97.93	1.487

The results in table 3 above clearly shows that using dielectric material with high permittivity in klystron cavity design rapidly raised the *Q*-factor and other important figures of merit. The unloaded *Q* sharply increased from 8600 to 14309 which is great improvement in the cavity design, when klystron applications are taken into consideration. The rapid rise in the *Q* factor indicates that the huge losses due to the metallic wall was subdued by the presence of high permittivity dielectric material. The figure below shows the SUPERFISH output file WSFplot of the dielectric klystron cavity.

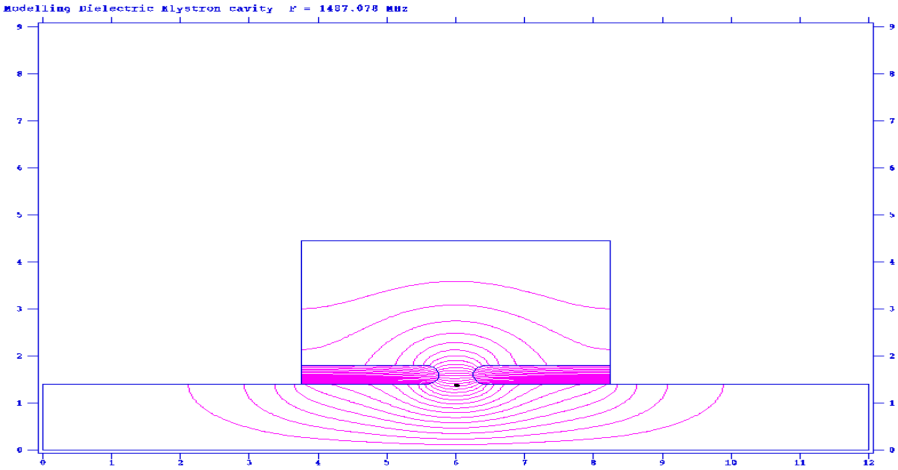

Figure 3: SUPERFISH output file WSFplot of dielectric cavity resonator

The fig 3 above shows the electric field orientation within both the metallic and the dielectric structure. The presence of the dielectric within the cavity produced more electric field within the dielectric, unlike the space has no electric field for metal cavity as in fig 2.

Modelling of Cavity with Different Dielectric Thickness

Several dielectric thicknesses was also tested with same dielectric permittivity constant of 37, and starting frequency of 1.2GHz. The SUPERFISH output results are presented in table 4 below.

Table 4: Different dielectric thickness with the corresponding output results

S/No	**Dielectric thickness (cm)**	**Q**	**R_{sh} (Mohms/m)**	**R_{sh}/Q (ohms)**
1	0.2	15625.7	31.893	122.5
2	0.3	14945.7	27.119	108.9
3	0.4	14309.0	23.356	97.9
4	0.5	13680.5	20.115	88.2
5	0.6	13037.7	17.171	79.02

It's clear from the table above that dielectric thickness used in the design plays greater role in getting higher or lower *Q*-factor and other figures of merit. The *Q*-factor, shunt impedance, frequency, etc. increased with the reduction in the dielectric thickness used and vice versa. Therefore, the smaller the dielectric used the better or higher *Q* the cavity would produce, this is good development since its will lead to miniaturization of cavity and subsequently reduction in cost of materials used.

The variations of the shunt impedance (R_{sh}), frequency (*f*), and the R_{sh}/Q values against the dielectric thickness are graphically shown below

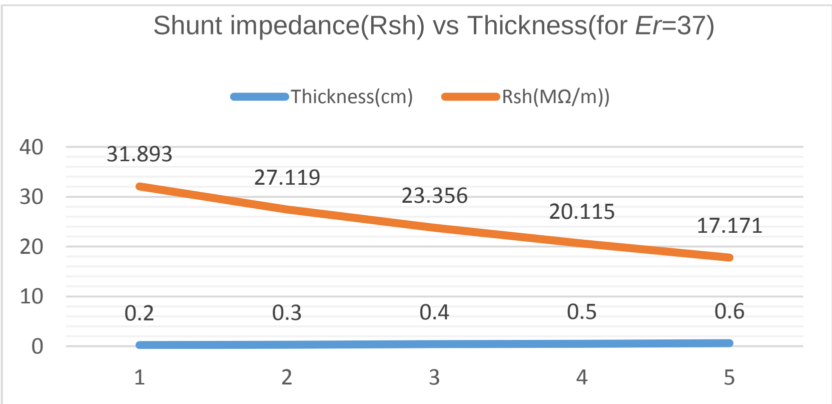

Figure 4: Graph of Shunt impedance against dielectric thickness

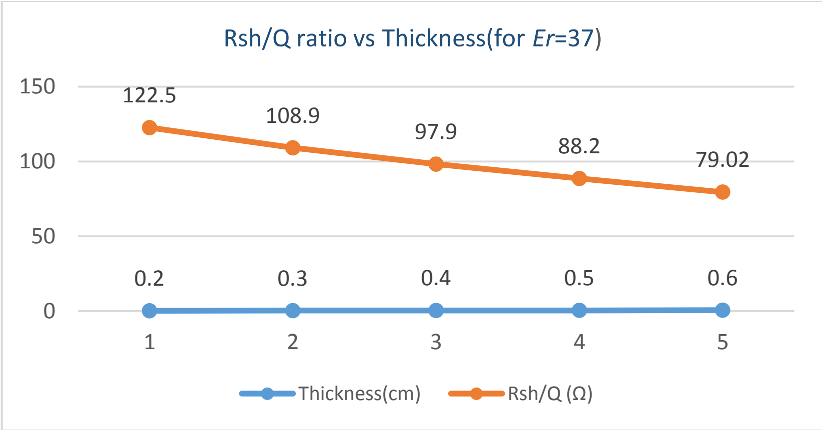

Figure 5: Graph of Rsh/Q ratio against the dielectric cavity for Er=37

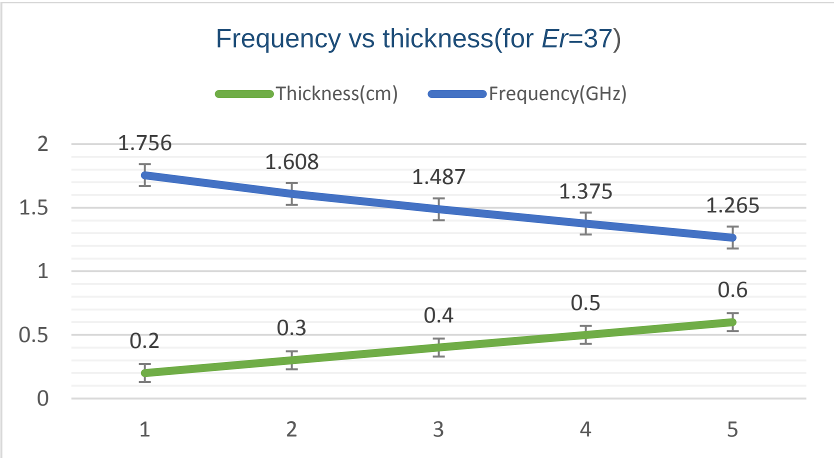

Figure 6: Graph of frequency against the dielectric thickness

Conclusion

This paper has examined the effect of using dielectric material in the design of klystron cavity for low loss and improved efficiency.

The findings has shown that dielectric material with stable temperature and with high permittivity constant can perperform similar function as microwave resonator with even better *Q*-factor and other important figures of merit The *Q*-factor with dielectric doubles compared to the convensional cavity. This was as a result of the dielectric/metal boundaty of the cavity recorded near zero losses, which subsequently reduced the overal losses and increased in the *Q*-factor.

Though, some dielectric material have disavantages of instability in temperature and mechanical fluaction, but many more are available which can stand the test and perform maximally.

In general, use of high permittivity dielectric material in microwave cavity design drastically reduces the high losses due to metallic conduction, and subsequently improve the overall efficiency of the cavity.

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