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ELECTRON SOURCE USING A HIGH–FREQUENCY CAVITY RESONATOR

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A special cylindrical resonator with a coaxial screw and a small apperture above it, is supplied with RF energy. The strong electrical field appearing around the sharp tip on the screw causes pulsating electron emission. By extracting electrons from the emissive region with a system of suitable electrodes, a bunched electron beam can be obtained. This paper presents the design of such a resonator, gives some experimental results and discusses other possibilities regarding its construction.

1. *Introduction*

Resonant circuits can be either of lumped type, made by combining a capacitor and an inductor, which are small compared with the wavelength, or of distributed type. In a lumped–element circuit, the capacitor is used for storage of electric energy and the inductor stores magnetic energy; at resonant frequency, there is exchange of energy between the inductor and the capacitor every quarter–cycle. The same occurs in the distributed resonant circuit, however, the same region is used for both energies. Distributed resonant circuits utilize the resonant properties of standing waves set up by interference between forward and reverse travelling waves and, hence, are generally of a size comparable with the wavelength.

For the simple–shape resonators, we can use Maxwell's equations and solve them analytically. If resonators are not simple, the only solution is to use exact equations and approximate numerical methods for solving them [1], or to calculate resonators with analytical equations for simple–shape resonators. However, practical devices give different results than expected. Main reason is imperfect manufacture of the resonator (rough walls, tolerances, etc.). So, we calculate the resonator by one of the above mentioned methods, manufacture it, and measure its characteristics (resonant frequency). Then, we correct its shape and dimensions accordingly. During measurements the resonator is held in high vacuum.

We used special cylindrical resonator with coaxial needle and a small apperture above it. The resonator is supplied with RF energy. The strong electrical field appearing around the sharp tip on the screw causes pulsating electron emission. By excracting electrons from the emissive region with a system of suitable electrodes, a bounched electron beam can be obtained. This resonator is ment to be used in device for measuring quality of super–conducting resonator.

2. *Field emission*

Field emission from the metal surface appears in an electric field E of an intensity 10^9 V/m or stronger. This type of emission does not depend on the temperature of the metal like thermionic emission. It is a quantum mechanical phenomenon and differs from thermionic emission modified by Schottky effect [3]. The principle is shematicaly shown in Fig. 1. In a strong electric field the potential hill is lowered and tunneling of electrons becomes possible.

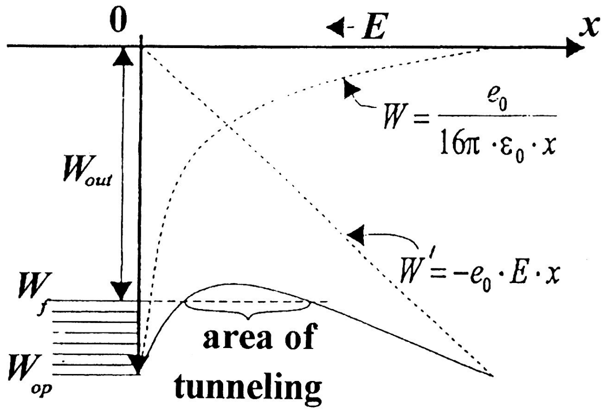

Fig. 1. Potential barrier is lowered by the external electric field and tunneling of electrons becomes possible. The symbols are: W_f – Fermi–level energy, W_{out} – work function, W_{op} – starting level of potential energy, e_0 – elementary charge.

At sharp points, the intensity of electric field is very strong. At every point on the surface of a tip, the electric field tends to be perpendicular to the surface. The two effects occur at the sharp tip of the screw shown in Fig. 2. For a strong field, the consequence is field emission [3]. Because the field is oscillating, the field emission is pulsating. Extracting electrons from the emission region with a system of suitable electrodes yields a bunched electron beam.

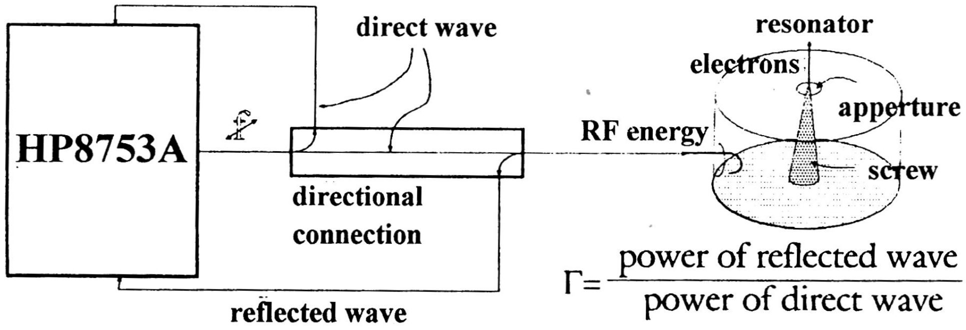

Fig. 2. The resonator (at right) and the arrangement for measurements with a HP8753A generator.

3. The resonator

We consider a special cylindrical resonator with a coaxial screw and a small apperture above the sharp point of the screw. The resonator is supplied with RF energy by a small antenna within it (Fig. 2).

All shapes of the fields and boundary conditions remain the same as in standard resonators. Complete solutions of the equations can be found in Refs. 2 and 9.

It has been shown [2,5–7] that many modes may exist in resonators. Any linear combination of modes is also a solution of Maxwell's equations. The only requirement is that solutions of Maxwell's equations must satisfy all boundary conditions in the cavity, no distinction being made between walls and terminations.

In the simplest mode, also called the principal mode, the only field components which will be different from zero are E_r, E_z, H_φ, and furthermore, all field components will be independent of the angular coordinate φ. Since charge and current density are equal to zero, Maxwell's equations simplify to

$$\frac{\partial E_r}{\partial z} - \frac{\partial E_z}{\partial r} = \mu \frac{\partial H_\varphi}{\partial t} - \frac{\partial H_\varphi}{\partial z} = \varepsilon \frac{\partial E_r}{\partial t}$$

$$\frac{1}{r}\frac{\partial}{\partial r}(rH_\varphi) = \varepsilon \frac{\partial E_r}{\partial t} \tag{1}$$

$$\frac{1}{r}\frac{\partial}{\partial r}(rE_r) + \frac{\partial E_z}{\partial z} = 0.$$

The simplest solution of these equations is $E_r = 0$ and E_z independent of z and r and only time–dependent:

$$E_z = -\frac{V}{d}, \quad E_r = 0, \quad H_\varphi = -\frac{\varepsilon r}{2d} j\omega V. \tag{2}$$

Also, condition $2\pi a/2l \ll 1$ must be satisfied. In coaxial portion of the cavity, E_z may be assumed to be equal to zero and we get

$$E_r = A\frac{\sin(kz)}{r}, \quad H_\varphi = j\frac{A}{\omega}\frac{1}{\mu}k\frac{\cos(kz)}{r}. \tag{3}$$

So, if we calculate d from Eq. (4) as function of b, a, h, f and choose $b = 52$ mm, $a = 2$ mm, $h = 50$ mm and $f = 2.2$ GHz, we get $d = 0.69$ mm.

$$Ak\frac{\cos(kl)}{a} = -a\varepsilon\mu\omega^2 \frac{1}{2d}V, \quad V = a\sin(kl)\ln\frac{a}{b}$$

$$\Rightarrow k_0\frac{a^2}{2d}\tan(k_0 l)\ln\frac{b}{a} = 1 \quad \lambda = 2\pi\sqrt{\frac{a^2 l}{2d}\ln\frac{b}{a}}. \tag{4}$$

4. *Realization and measurement*

The cylindrical resonator was made of copper (see Fig. 3). Within the resonator, there is an axial screw with a sharp point. The resonator has been excited by a small antenna, connected to the high–frequency generator via a BNC connector.

The measurements of the resonator have been made with the Network Analyzer HP8753A. This instrument also allows measurement of the reflection coefficient, Smith chart and some other characteristics. Schematic of the measuring system is shown in Fig. 2. At accommodation of resonator to the generator in resonance, the reflection coefficient G had a very small value. This is shown in Figs. 4 and 5.

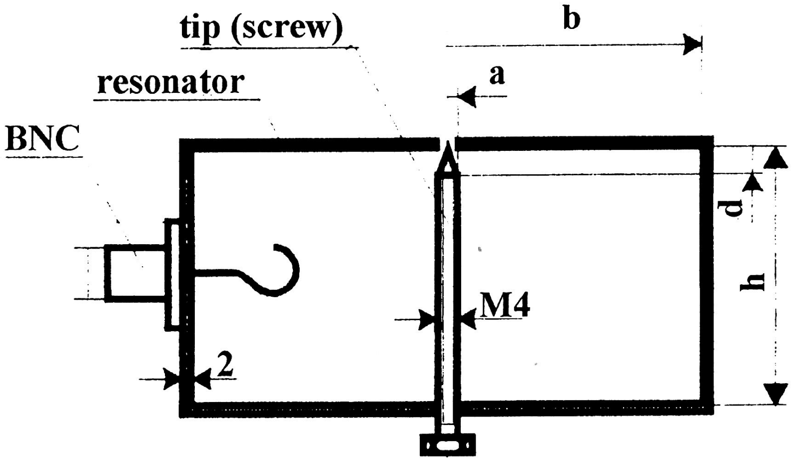

Fig. 3. Drawing for manufacturing.

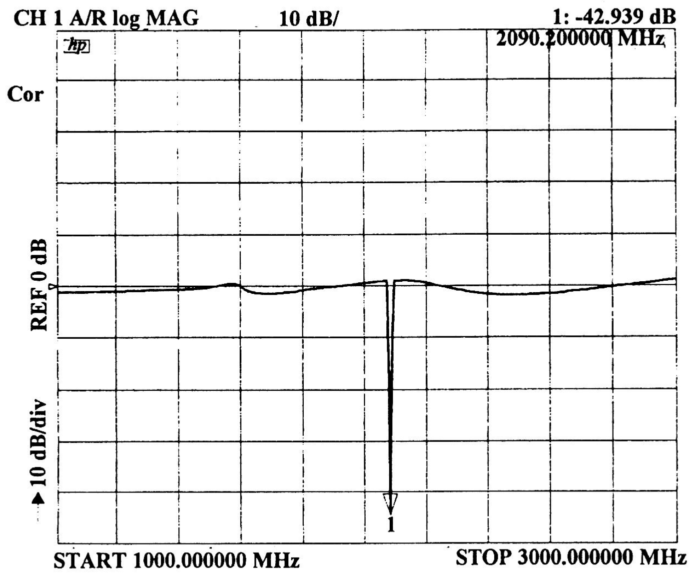

Fig. 4. Accomodate resonator response without screw in it; y-axis 10dB/div.

Figure 4 shows the resonant frequency at $f = 2.090$ GHz (marker 1), that we expected. When the screw with the sharp tip was positioned in the resonator, the resonant frequency shifted to $f = 2.899$ GHz (marker 3, Fig. 5) and a new parasitic resonant frequency arose at $f = 1.181$ GHz (marker 2, Fig. 5).

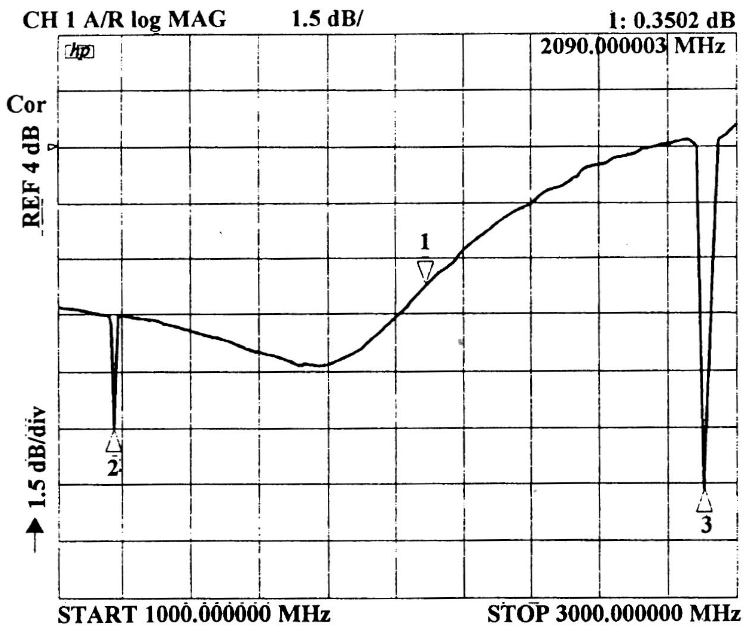

Fig. 5. Accomodate resonator response with the screw within it, y-axis 1.5dB/div.

5. Conclusion

From the measured results, we see that in order to obtain resonant frequency of 2.2 GHz, we have to correct the dimensions to $b = 68.48$ m , $a \approx 2$ mm, $h = 65.85$ mm.

With all simplifying, which we have to take in account, we got usefull and relatively good result. A lot of things during our discussion was oversimplified, because we could not consider all influences in manufacturing of the resonator. On the other hand, there is limitation in software and hardware that has been on disposal.

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ELEKTRONSKI IZVOR S VISOKOFREKVENTNIM REZONATOROM

Sagrađen je poseban cilindričan rezonator s koaksijalnim vijkom. Snažno radiofrekventno električno polje oko šiljatog vrha vijka, koji je uz malen otvor na rezonatoru, uzrokuje poulzirajuću emisiju elektrona. Izvlačenjem elektrona iz područja emisije pogodnim električnim poljem mogao bi se postići pulzirajući elektronski snop. Opisuje se gradnja i ispitivanje takvog rezonatora.