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COPLANAR WAVEGUIDE SHORT GAP RESONATOR FOR MEDICAL APPLICATIONS

Y.X.Wang

Beijing Institute of Radio Measurement

Beijing, China

Abstract

A coplanar waveguide short gap resonator as an electromagnetic energy coupler for medical applications is described. The principles and design formulas are given and the experimental results are provided. From the data obtained on a phantom, it can be shown that this coupler can couple the EM energy more efficiently.

Introduction

In recent years an increased interest in applications of electromagnetic techniques for medical diagnostics and therapy has been observed. Among several factors for various such applications one of the most important is to design EM energy couplers to couple the EM energy into tissue efficiently. Various kinds of EM couplers have been reported (1)-(4) and briefly reviewed in (1). Based on the theory of coplanar waveguide (CPW) reported in (5), (6), a new CPW short gap resonator as a coupler is proposed and basic design formulas are given. Experimental results of the couplers at 915 MHZ, including impedance matching, relative coupling efficiency and leakage obtained on a phantom are provided.

Design Principles

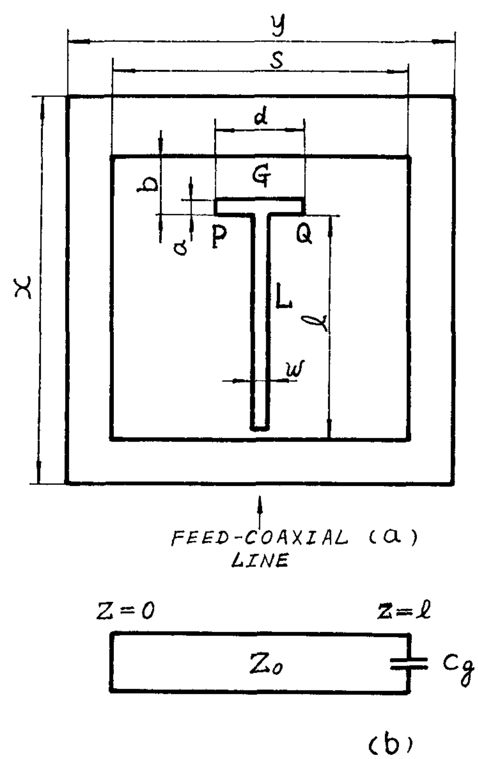

Fig.1 Coplanar waveguide short gap cavity (a) and its equivalent circuit (b)

A CPW short gap cavity shown in Fig.1 (a) can be considered to be a section of CPW transmission line L terminated in a gap G (leading to the equivalent circuit of Fig.1 (b)) provided that the gap region G is small compared with wavelength. The gap capacitance is much larger than the capacitance elsewhere in the cavity. From the equivalent circuit, the transcendental equation can be written: (7)

$$jZ_o \tan \beta l + \frac{1}{j\omega C_g} = 0 \qquad (1)$$

where $\beta = 2\pi/\lambda_g$

Z_o: CPW characteristic impedance,

C_g : gap capacitance,

l: length of the cavity.

For this equation, there are various solutions, as shown in Fig.2. When ω, Z_o and C_g are given, the length of cavity, l, can be calculated by

$$\beta l = \tan^{-1} \frac{1}{\omega Z_o C_g} + n\pi \qquad (2)$$

where n=0, 1, 2, ······ .

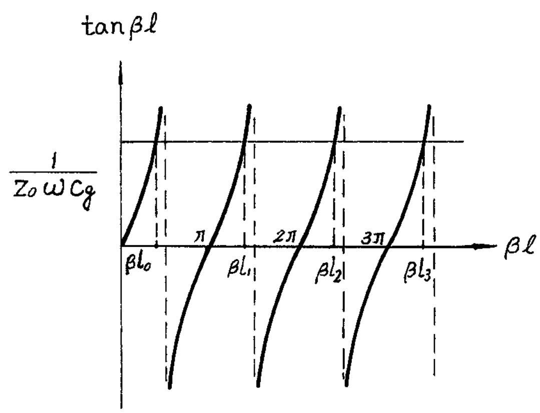

Fig.2 Solution of equation (2)

The characteristic impedance of CPW is

$$Z_o = \sqrt{\frac{\mu_o}{\varepsilon_o}} \frac{K'(k)}{2K(k)} \Big/ \sqrt{(\varepsilon_{r_1}+1)(\varepsilon_{r_2}+1)} \qquad (3)$$

where K(k): complete elliptical integral of the first kind,

$K'(k) = K(k')$, $k = w/s$, $k' = (1-k^2)^{\frac{1}{2}}$.

So the dimensions of CPW, w and s, can be calculated.

To calculate the gap capacitance, C_g, the strip PQ and ground plane of the gap region can be simplified to nonsymmetrical coplanar line (NCL) as shown in Fig.3 (a). If we assume the propagation of TEM wave, NCL may be analysed by conformal mapping as shown in Fig.3 (b). (8) In this case the capacitance per unit length of NCL is given by

$$C = (\varepsilon_{r_1} + \varepsilon_{r_2})\,\varepsilon_o \frac{a_1}{b_1} \qquad (4)$$

where $a_1/b_1 = K(k)/K'(k)$, $k = a/b$.

The gap capacitance is

$$C_g = C \cdot d \qquad (5)$$

where d is the length of strip PQ.

In practice this length d can be adjusted to change the gap capacitance.

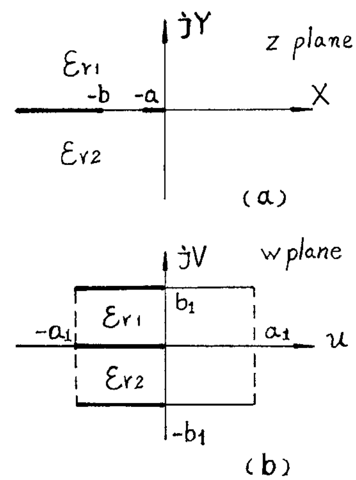

Fig.3 Conformal mapping of NCL

Experimental Results

Experimental CPW short gap resonators as couplers are designed to couple EM energy (f=915 MHZ) into tissue ($\varepsilon_{r_1}=1$ and $\varepsilon_{r_2}=56$).For equation (2), n=1 is chosen, and the length of cavity is about $\frac{3}{4}\lambda_g$. The gap capacitance is 2.5 pf. The other dimensions of the coupler are: s=3.32 cm, w=0.1 cm, l=2.8 cm, d=1.2 cm, a=0.1 cm and b=0.3 cm. Its thickness and dimensions of ground plane are not critical. The 3.5 mm coaxial line is used as the feeder.

The coupler is tested by measuring electrical field components radiated into artificial muscle. The data show that although electric fields along the center conductor decrease rapidly, because of the gap , the axial component of electric field at gap region is still about the same as that of the center of coupler. So the distribution of electric field along the coupler is relatively homogeneous.

The VSWRs for coupler facing both artificial muscle and real tissue are shown in Fig.4. The coupler was found to be well matched in a relatively broad range of frequencies. As for the coupling efficiency an experiment to measure transmission through a human torso phantom is conducted with a pair of the couplers. The coupling efficiency of this coupler is at least 3 DB better than that of other CPW couplers.

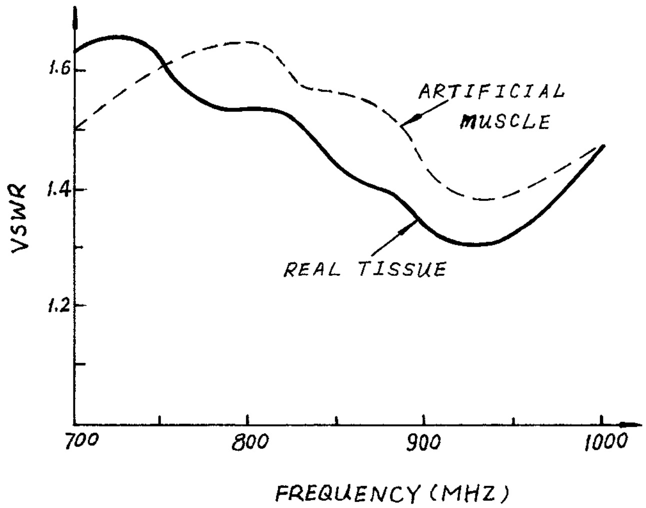

Fig.4 VSWRs of the coupler versus frequency

Conclusions

The design formulas and experimental results of a CPW short gap resonator for medical applications are presented. The experimental results obtained on phantom are encouraging. The results clearly demonstrated that the coupler has high coupling efficiency . At the same time the coupler has the advantage of being small, lightweight and capable of conforming to the shape of body. Although the coupler was designed and tested at 915 MHZ, using the formulas in this paper, resonators operating at other frequencies can be designed.

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