Propagation of the Electromagnetic Waves
Practical 1. STUDY OF THE ELECTROMAGNETIC WAVES IN A TWO-WIRE TRANSMISSION LINE

Introduction

Electromagnetic wave can propagate in all possible directions in isotropic and homogeneous medium - free space, which contains no electrical conductors. To transmit the electromagnetic energy or information in a certain direction by mean of electromagnetic wave, one need to use leading systems such as wires, metallic pipes – waveguides, dielectric rods and so on.

One of the simplest system of such kind is a two-wire transmission line, which consists of two long cylindrical wires with wire diameter equal to r, and separated from each another by certain distance $h >> r$.

The external field of such system is very small in comparison with the field between the wires, so we could say without loss of generality, that the electromagnetic wave will mainly propagate between the wires.

It can be shown, that the voltage U between the wires of an infinitely long line is defined by the wave equation:

$$L_0 C_0 \frac{\partial^2 U}{\partial t^2} = \frac{\partial^2 U}{\partial z^2} , \tag{1}$$

where z - is the cross section of the line under consideration, L_0 and C_0 - are an inductance and capacitance per unit length of the line.

The solution for the wave equation (1) defines the running wave of voltage:

$$u = U_m \cos\left[\omega\left(t - \frac{z}{v}\right)\right] , \tag{2}$$

where

$$v = \frac{1}{\sqrt{L_0 C_0}}, \tag{3}$$

Or one can think about the running wave of current in the line:

$$i = I_m \cos\left[\omega\left(t - \frac{z}{v}\right)\right] , \tag{4}$$

and in the same way, about running waves of electric and magnetic E and B fileds in the line.

The running wave mode could be realized in the infinitely long line or in the actual one (line with a certain length), which is connected to a matched load. The resistance of such matched load is called the wave resistance of the line or the impedance of the line and is equal to:

$$Z_0 = \frac{U_m}{I_m} = \sqrt{\frac{L_0}{C_0}}, \tag{5}$$

To calculate the propagation speed of waves in the line, one need to use the relation between the L_0 and C_0 and the geometrical parameters of the line. Assuming that the conductors are in the vacuum:

$$L_0 = \frac{\mu_0}{\pi}\ln\frac{r+h}{r} \cong \frac{\mu_0}{\pi}\ln\frac{h}{r} \qquad \left(\frac{H}{m}\right), \tag{6}$$

$$C_0 = \pi\varepsilon_0\frac{1}{\ln\frac{h+r}{r}} \cong \pi\varepsilon_0\frac{1}{\ln\frac{h}{r}} \qquad \left(\frac{F}{m}\right) \tag{7}$$

Taking into account relations (3) and (6), (7) one can come to a very important result:

$$v = \frac{1}{\sqrt{L_0 C_0}} = \frac{1}{\sqrt{\varepsilon_0\mu_0}} = c, \tag{8}$$

This result states, that the propagation speed of electromagnetic waves in a line is equal to the one in a free space.

If the line is surrounded with a dielectric material, then the wave speed in such line will be reduced:

$$v_{aver} = \frac{c}{\sqrt{\varepsilon\mu}}, \tag{9}$$

Here ε and μ stands for the relative permittivity and permeability of a given dielectric material. For the majority of dielectric materials μ = 1, which means that the relation (9) can be rewrite in the following way:

$$v_{aver} = \frac{c}{\sqrt{\varepsilon}}, \tag{10}$$

If an incoming wave, which propagates along the line, hits the conductive bridge (Z = 0), which shorts the wires of the line, a reflected wave will appear. Due to interference of the incoming and reflected waves, one can observe a peculiar interference pattern in the line, which is called a ***standing wave***. One need to meet an obvious condition to observe a standing wave mode in the line. This condition sounds as following: an integer number of half wavelengths should be packed on the length of the line (or in relation to the experimental setup for this practical work - an integer number of half wavelengths should be packed on both sides from the conductive bridge).

Using the theory of oscillations for the oscillatory circuits with distributed parameters, one could say, that the resonant qualities of the circuit appears when the natural oscillation frequency f_0 of the line or its' harmonic overtones nf_0 (n = 2,3,. . .) match with the frequency of the driving force (frequency generator). As the result, the amplitude of the standing wave increases.

The latest case is used in this practical work. Two-wire transmission line is driven with a high frequency generator. Changing the length of the line and, as the result the set of its' natural frequencies, one can meet the conditions of the standing wave mode for the given line. Knowing the distance between two series resonances along the line, one can calculate the oscillation frequency ϑ of the generator:

$$\vartheta = \frac{c}{\lambda}. \tag{11}$$

where ϑ - is the oscillation frequency, c – is the speed of light in a free space or the speed of electromagnetic wave in the media, λ - is the wavelength of electromagnetic wave.

Experimental setup

The experimental setup is shown in Fig. 1. This setup employs the generator of decimeter waves. Its' oscillatory circuit doesn't include inductors and capacitors, which are typical for low frequency generators. The inductive and capacitive components in this generator are replaced with two metal pipes, which form the segment of the two-wire transmission line. Oscillation frequency from the generator is defined by the length and the distance between these metal pipes.

The two lines (long and short one), which are used in this work, have additional external segment with an incandescent lamp indicator. The short line is placed into the bath with water. Placing the external segment of the line above the generator (metal pipes segment of the generator), one can drive the forced oscillation in this line. The brightness of the incandescent lamp indicator allows to rate the amplitude of oscillations. The length of each line can be adjusted by changing the position of the conductive bridge.

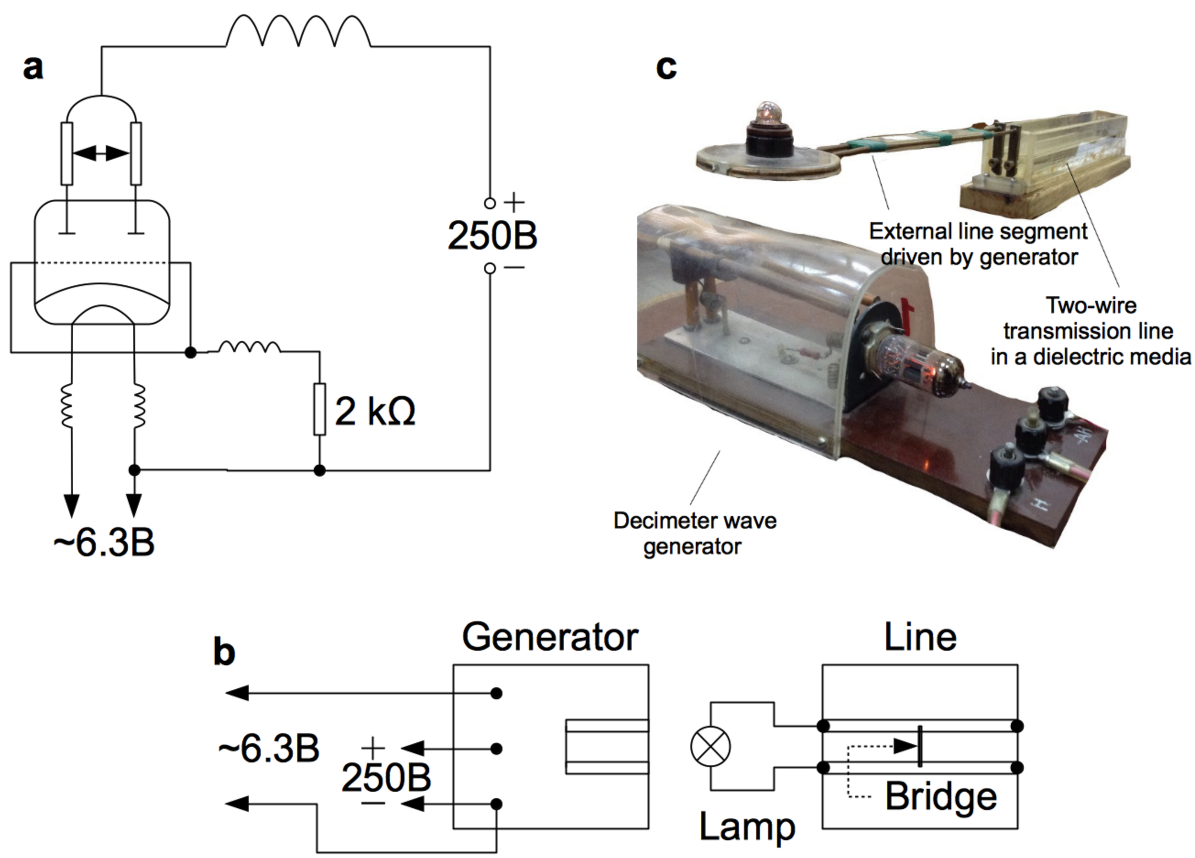

Figure 1: Experimental setup: a) biasing scheme of the lamp decimeter wave generator; b) position scheme of the elements of the setup; c) photos of actual elements of the setup.

Measurement and data processing

Task 1. Measurement of the wavelength of electromagnetic wave in the air

Turn on the generator and place it under the external segment of the long line. Moving the conductive bridge along the line, find two successive positions of the bridge, which associated either with the brightest glows of the incandescent lamp indicator or extinct states of the incandescent lamp indicator. Knowing the distance between two successive positions of the bridge, calculate the wavelength of the electromagnetic wave in the air. Calculate the oscillation frequency of the generator, which is used in this practical work.

Task 2. Measurement of the wavelength of electromagnetic wave in the dielectric media

Repeat the measurements from the first task, but with the short line dipped into water. Measure the wavelength in water. Calculate the permittivity of water from the data (wavelength in air/water), which were measured in both tasks. Consider the permeability of water equals to 1 in all your calculations.

Questions

1. What is the principal difference of electromagnetic waves propagation in a transmission line in comparison with a free space.
2. Draw field patterns for E and B fields in the line in case of running and standing waves in the given moment of time. How will these patterns change over time Δt, which is shorter than the period of oscillations.
3. Draw the direction of the Poynting's vector in different points along the line for two cases. The first case is the running wave mode in the transmission line. The second case is the standing wave mode in the transmission line.
4. What is the principal difference between the resonant phenomenon in systems with distributed parameters (a two-wire transmission line) from the one in the systems with lumped parameters (an oscillatory circuit)?
5. One could use either a glow neon lamp or a incandescent lamp to probe the amplitude of the electromagnetic wave in the line. To which parameter in the line is sensitive each of those indicators?