SOME APPLICATIONS OF THE ELECTRIC LINE SECTIONS

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Abstract

The paper deals with some issues of the electric resonance of quarter-wave electric homogenous line sections, and for some applications of these resonance systems with distributed parameters.

Key words: electric homogenous line, section, resonance, impedance transformer.

NIEKTORÉ APLIKÁCIE ÚSEKOV ELEKTRICKÝCH VEDENÍ

Resumé

Článok pojednáva o niektorých otázkach elektrickej rezonancie štvrť-vlnových úsekov elektrických homogénnych vedení, a o niektorých aplikáciách týchto rezonančných sústav s rozloženými parametrami.

Kľúčové slová: elektrické homogénne vedenie, úsek, rezonancia, impedančný transformátor.

1 Introduction

The homogenous electric line sections are distributed parameter systems, where impending to electric wave resonance and some other interesting properties. The total length of these sections is expressed as integral multiple of fourth part length of a standing electromagnetic wave along this line section. These electric lines take the form of an electric twin-lead or a coaxial cable whose end is either disconnected (open-circuit) or short-circuited. Ostensibly, they behave like conventional resonance circuits made of passive *LC*-type elements, however, their quality factor is usually much higher, chiefly at high frequencies (of the order of 10^2 to 10^3 MHz). Electric waveguide and microstrip line sections are used for very high frequencies (of the order of 10^4 MHz).

2 Transmission line section properties

It follows from the theory of homogenous lines [1], [2], [4] that wave impedance $\hat{Z}_0$ of a transmission line is defined by basic parameters *R, L, G, C.* However, it can also be determined by input impedance measurements if the end of the line of length l is short-circuited ($\hat{Z}_{1k}$) and disconnected ($\hat{Z}_{1p}$):

$$\hat{Z}_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}}, \qquad \hat{Z}_0 = \sqrt{\hat{Z}_{1k}\,\hat{Z}_{1p}}, \tag{1}$$

where:

R, L is longitudinal resistance and inductance of a unit length line

G, C is cross-conductivity and capacity between unit length line conductors.

The input impedance of the homogenous line, whose end wave impedance is, equals wave impedance.

The complex transmission rate $\hat{g}$ of the homogeneous line is also defined by parameters *R, L, G, C;* it can be, however, determined in a similar way, by measuring input impedances $\hat{Z}_k$ and $\hat{Z}_p$ of the homogeneous line of the specific length l :

$$\hat{g} = b + ja = \sqrt{(R + j\omega L)(G + j\omega C)}\,, \tag{2}$$

$$\operatorname{tgh} \hat{g}l = \sqrt{\hat{Z}_{1k} / \hat{Z}_{1p}} \tag{3}$$

Therefore: $\omega = 2\pi f, \qquad \lambda = v\big/ f, \qquad v = 1\big/\sqrt{LC} = c\big/\sqrt{\mu_r \varepsilon_r}\,, \qquad c = 1\big/\sqrt{\mu_0 \varepsilon_0}$

$$\hat{Z}_{1k} = \hat{Z}_0 \operatorname{tgh} \hat{g}l = Z_0 \operatorname{tgh} jal = +jZ_0 \operatorname{tg} al = +jZ_0 \operatorname{tg}(2\pi l/\lambda)$$

$$\hat{Z}_{1p} = \hat{Z}_0 \operatorname{cotgh} \hat{g}l = Z_0 \operatorname{cotgh} jal = -jZ_0 \operatorname{cotg} al = -jZ_0 \operatorname{cotg}(2\pi l/\lambda)\,,$$

where: λ is the transmission line wave length,

v is phase velocity (transmission line wave propagation velocity),

$c = 3.10^8$m/s is light propagation velocity in vacuum, which can be theoretically calculated from two known physical constants μ_0, ε_0 of vacuum.

Constants μ_r, ε_r represent relative permeability and permittivity of the environment.

The following relations hold for input variables $\hat{U}_1, \hat{I}_1, \hat{Z}_1$ of a finite length loss-free line *l*, terminated with load impedance $\hat{Z}_2$, with current flow $\hat{I}_2$ [1], [2]:

$$\hat{U}_1 = \hat{I}_2[\hat{Z}_2 \cos\, al + j\hat{Z}_0 \sin al], \qquad \hat{I}_1 = \hat{I}_2[\cos\, al + j(\hat{Z}_2\big/\hat{Z}_0)\sin al],$$

$$\hat{Z}_1 = \frac{\hat{U}_1}{\hat{I}_1} = \hat{Z}_0 \frac{\hat{Z}_2 \cos\, al + j\hat{Z}_0 \sin al}{\hat{Z}_0 \cos\, al + j\hat{Z}_2 \sin al} = \frac{\hat{Z}_2/\hat{Z}_0 + j \operatorname{tg} al}{1 + j\,\hat{Z}_2/\hat{Z}_0 \operatorname{tg} al} \tag{4}$$

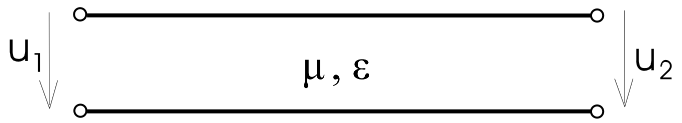

Fig. 1: *Transmission line section of length l*

For a loss-free homogenous line ($R = 0$, $G = 0$), are valid following relations:

$$\hat{Z}_0 = Z_0 = \sqrt{L / C}\,, \tag{5}$$

$$\hat{g} = b + ja = \sqrt{-\omega^2 LC} = j\omega\sqrt{LC}\,, \tag{6}$$

therefore: attenuation constant $b = 0$, and phase factor $a = \omega\sqrt{LC} = 2\pi/\lambda$,
where: $\hat{Z}_0$ is of purely real nature ; $\hat{g}$ is of purely imaginary nature.

If the end of a loss-free section ($R = 0$, $G = 0$) of the transmission line of length *l* is short-circuited ($Z_2 = 0$) or disconnected ($Z_2 \rightarrow \infty$) the following relations hold for the respective input impedance values:

$$\hat{Z}_k = +jZ_0 \operatorname{tg} al \qquad \leftarrow \text{ short-circuit } (Z_2 = 0)$$

$$\hat{Z}_p = -jZ_0 \operatorname{cotg} al \qquad \leftarrow \text{ open-circuit } (Z_2 \rightarrow \infty)$$

Therefore: $\hat{Z}_k \cdot \hat{Z}_p = Z_0^2, \qquad \hat{Z}_k\big/\hat{Z}_p = -\operatorname{tg}^2 al$ (7)

A short-circuit or open-circuit transmission line allows for implementation of active inductance, capacity, and series and parallel resonance circuits. This can be advantageously to utilize in the frequency domain over 300 MHz, because implementation of reactance by elements with concentrated parameters (resistors, coils, capacitors) in this frequency domain may be very difficult, if not impossible [2].

$(\boldsymbol{L})$:	$0 < l < \lambda/4$	(*short-circuit*),	$\lambda/4 < l < \lambda/2$	(*open-circuit*)
$(\boldsymbol{C})$:	$0 < l < \lambda/4$	(*open-circuit*),	$\lambda/4 < l < \lambda/2$	(*short-circuit*)
$(\boldsymbol{LC})_{\mathrm{p}}$:	$l = \lambda/4$	(*short-circuit*),	$l = \lambda/2$	(*open-circuit*)
$(\boldsymbol{LC})_{\mathrm{s}}$:	$l = \lambda/4$	(*open-circuit*),	$l = \lambda/2$	(*short-circuit*)

A transmission line section, whose length is $\lambda/4$ (quarter-wave impedance transformer), can be advantageously used for mutual adaptation of two different impedances.
Thus, insertion of a transmission line section of length $\lambda/4$ of wave impedance $\hat{Z}_0 = \sqrt{\hat{Z}_1\hat{Z}_2}$ between two different impedances $\hat{Z}_1 \neq \hat{Z}_2$ results in a perfect adaptation of these impedances if frequency $f = v/\lambda$. However, frequency changes are reflected in rapid deterioration in impedance adaptation.

A quarter-wave impedance transformer allows for implementation of high-quality inductances and capacities [3]. High-quality inductance L, for example, can be obtained by terminating a loss-free quarter-wave transmission line section of wave impedance Z_0 by a high-quality capacitor of impedance

$\hat{Z}_2 = 1/j\omega\, C_Z$, which gives:

$$\hat{Z}_{\mathrm{IN}} = \hat{Z}_1 = \cdots = Z_0^2/\hat{Z}_2 = (L/C)\, j\omega\, C_Z = j\omega L_{\mathrm{IN}}, \tag{8}$$

where**Chyba! Záložka není definována.**: $L_{\mathrm{IN}} = (L/C)\, C_Z\, C_Z = Z_0^2\, C_Z$
(9)

The actual length l of a quarter-wave impedance transformer depends on the environment:

$$l = \lambda/4 = \frac{c}{4f\sqrt{\mu_r\,\varepsilon_r}} = \frac{\lambda_0}{4\sqrt{\mu_r\,\varepsilon_r}}, \qquad \text{where } \lambda_0 = c/f$$

where λ_0 is the wave length in vacuum and in the normal environment

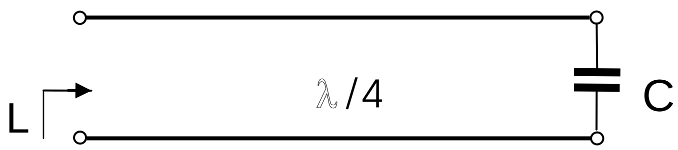

Fig. 2: *The example of high-quality inductance L based on high-quality capacity C_Z by using the quarter-wave impedance transformer.*

3 Conclusions

The development in the field of electric resonance systems with distributed parameters has been intensive in the last decades. For example, hermetically sealed electric waveguide sections of rectangular or circular cross-section, whose internal walls are silver-plated and perfectly polished for the sake of high electric conductivity related to the skin-effect, feature very low resistance to a traveling or a standing electromagnetic wave. This kind of resonance systems is characterized by an extremely high quality factor. Waveguides have been widely applied, mostly in the military radar technology designed for monitoring the air-space, and for air-navigation; in anti-aircraft technology for navigation of various missile systems; in space technology for navigation and control of space-stations and various satellite systems, in particular television and tele-communication satellites. The latest progress in micro-miniaturisation of electronic equipment has engendered numerous application possibilities for the microstrip line technology and microstrip structures manufactured by the electrically conductive thin-film technology. In combination with other microelectronic circuits, they are used for complex micro-miniaturised high-frequency equipment. This technology makes it possible to significantly reduce the size and the weight of the former robust high-frequency devices, which is of great importance to the satellite technology and other electronic space systems operating in the high-frequency domain (of the order of tens GHz).

4 References

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